Recommended Practices for Machinery Installation and Installation Design

API RECOMMENDED PRACTICE 686
PIP REIE 686
FIRST EDITION, APRIL 1996

Process Industry Practices

American Petroleum Institute

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Manufacturing, Distribution and Marketing Department

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CHAPTER 1—INTRODUCTION

Recommended Practices for Machinery Installation and Installation Design

CHAPTER 1—INTRODUCTION

1.1 Scope

1.1.1 PURPOSE

These recommended practices (RP) are intended to provide recommended procedures, practices, and checklists for the installation and precommissioning of new and reapplied machinery for petroleum, chemical, and gas industry services facilities. In general, these recommended practices are intended to supplement vendor instructions and the instructions provided by the original equipment manufacturer (OEM) should be carefully followed with regard to equipment installation and checkout.

Most major topics of these recommended practices are subdivided into sections of "Installation Design" and "Installation" with the intent being that each section can be removed and used as needed by the appropriate design or installation personnel.

1.1.2 EQUIPMENT CLASSIFICATION

These recommended practices are intended to address those installation and construction procedures associated with all machinery. Additional "special purpose" requirements are covered at the end of each section as required.

1.2 Alternative Installation

The installation contractor or design contractor may offer alternative methods of equipment installation as mutually agreed upon by the user and equipment manufacturer.

1.3 Conflicting Requirements

Any conflicts between these recommended practices and/or the manufacturers' recommended procedures shall be referred to the owner's designated machinery representative for resolution before proceeding.

1.4 Definitions

1.4.1 alignment: The process of reducing the misalignment of two adjacent shafts connected by a coupling so that the center of rotation for each shaft is as near collinear as practical during normal operation.

Note: Most misalignment is combination misalignment. It can be resolved into a parallel offset at a given point along the fixed machine centerline and angular misalignment in both the horizontal and vertical planes. The offset is dependent on the location along the fixed machine centerline where it is measured, normally the center of the coupling spacer.

1.4.2 ambient offset: The practice of misaligning two shaft centerlines at ambient conditions to account for the estimated relative changes in shaft centerlines from ambient conditions to operating conditions.

1.4.3 angular misalignment: The angle between the shaft centerline of two adjacent shafts. This angle is normally reported in slope of millimeters of change per decimeter of linear distance (mils per inch) (1 mil = 0.001 inch).

1.4.4 blowdown system: A closed system connected to a machine used to depressure and decontaminate the machine preparatory to maintenance activities; also known as a *maintenance dropout system.*

1.4.5 bolt bound: Where any hold-down bolt is not free in the bolt hole, so that the ability to move the moveable element in a machinery train horizontally or axially is constrained.

1.4.6 breakout spool: A short, flanged length of pipe immediately connected to the machinery piping flanges. Lengths vary with the size of the pipe but range from 15 centimeters (6 inches) to 1 meter (3 feet). The purposes of this spool are to facilitate machinery installation, allow piping modification to reduce pipe strain, isolate the machinery, facilitate commissioning activities such as flushing or blowing lines, and allow removal of temporary inlet strainers; also known as a *dropout spool.*

1.4.7 cementatious grout: A type of grout material that is portland cement based.

1.4.8 combination misalignment: When the centerlines of two adjacent shafts are neither parallel nor intersect. This misalignment is normally described in both angular and offset terms.

1.4.9 condensing service: A gas stream that contains a vapor component that may condense to a liquid during startup, operation, or shutting-down of a compressor or blower. This may include pure vapors such as refrigerants as well as hydrocarbon gas streams. When condensate is present in the gas stream, the term *wet gas* may be used. *Wet gas* may also be used as a synonym to *condensing service.*

1.4.10 dead-leg: A length of piping with no flow.

1.4.11 designated machinery representative: The person or organization designated by the ultimate owner of the equipment to speak on his behalf with regard to machinery installation decisions, inspection requirements, and so forth. This representative may be an employee of the owner, a third party inspection company, or an engineering contractor as delegated by the owner.

1.4.12 drop point: A vertical section of oil mist distribution piping that is usually smaller in diameter than the main oil mist header. This piping rises out of a tee in the main oil mist header, turns horizontally, and extends downward to the machinery being lubricated.

1.4.13 elastomeric coupling: A coupling that obtains its flexibility from the flexing of an elastomeric element.

1.4.14 engineering designer: The person or organization charged with the project responsibility of supplying installation drawings and procedures for installing machinery in a user facility after machinery has been delivered. In general, but not always, the engineering designer specifies machinery in the user facility.

1.4.15 epoxy grout: A type of grout material that consists of a resin base that is mixed with a curing agent (hardener) and usually an aggregate filler.

1.4.16 equipment user: The person or organization charged with operation of the rotating machinery. In general, but not always, the equipment user owns and maintains the rotating machinery after the project is complete.

1.4.17 equipment installer: The person or organization charged with providing engineering services and labor required to install machinery in a user facility after machinery has been delivered. In general, but not always, the installer is the project construction contractor.

1.4.18 equipment train: Two or more rotating equipment machinery elements consisting of at least one driver and one driven element joined together by a coupling.

1.4.19 final alignment: The aligning of two adjacent machinery shafts after the measurement of piping-imposed strains on the machinery are verified as being within the specified tolerances.

1.4.20 flexible-element coupling: A type of rotating machinery coupling that describes both disk and diaphragm couplings. A flexible-element coupling obtains its flexibility from the flexing of thin disks or diaphragm elements.

1.4.21 gear coupling: A type of rotating machinery coupling that obtains its flexibility by relative rocking and sliding motion between mating, profiled gear teeth.

1.4.22 general purpose equipment trains: Those trains that have all general purpose elements in the train. They are usually spared, relatively small in size (power), or in noncritical service. They are intended for applications where process conditions will not exceed 48 bar gauge (700 pounds per square inch gauge) pressure or 205°C (400°F) temperature (excluding steam turbines), or both, and where speed will not exceed 5000 revolutions per minute (RPM).

Note: General purpose equipment trains have all elements that are either manufacturer's standard or are covered by standards such as the following: ANSI/ASME B.73 horizontal pumps, small API Standard 610 pumps, fans, API Standard 611 steam turbines, API Standard 672 air compressors, API Standard 677 general purpose gears, API Standard 674 reciprocating pumps, API Standard 676 rotary positive displacement pumps, API Standard 680 reciprocating air compressors, and NEMA frame motors.

1.4.23 general purpose: Refers to an application that is usually spared or is in noncritical service.

1.4.24 grout: An epoxy or cementatious material used to provide a uniform foundation support and load transfer link for the installation of rotating machinery. This material is typically placed between a piece of equipment's concrete foundation and its mounting plate.

1.4.25 grout pin: A metallic pin or dowel used to tie an epoxy grout pour to its concrete foundation to prevent delamination (or edge lifting) due to differential thermal expansion between the grout and the concrete.

1.4.26 head box: A device used to funnel grout into a baseplate grout fill-hole so as to provide a static head to aid in filling all baseplate cavities with grout.

1.4.27 isolation block valve: A valve used to isolate a process machine preparatory to maintenance. Also known as a *block valve* or *isolation valve*.

1.4.28 mechanical piping analysis: An analysis of the piping connected to a machine to determine the stresses and deflections of the piping resulting from dynamic loadings such as pulsating flow. Determination of the type, location, and orientation of piping supports and piping guides results from this analysis.

1.4.29 minimum flow bypass: (See *recycle line.*)

1.4.30 mounting plate: A device used to attach equipment to concrete foundations; includes both baseplates and soleplates.

1.4.31 nonslam check valve: A mechanically or hydraulically balanced check valve that allows closure of the valve in a controlled fashion. Wafer-style center-guided spring-loaded split-disc check valves or tilting-disc check valves are representative designs.

1.4.32 NPS: Nominal pipe size.

1.4.33 oil mist application fittings: Long path orifices that cause the small oil droplet size in the header ("dry mist") to be converted to larger size oil droplets ("wet mist") to lubricate the bearings. Oil mist application fittings are also known as *reclassifiers*.

1.4.34 oil mist distributor block: A small rectangular block that has four or more holes drilled and tapped in opposite faces. *Drop points* terminate in distributor blocks. An oil mist distributor block may also be described as an *oil mist manifold block*.

1.4.35 oil mist console: A system consisting of the oil mist generator, oil supply system, air filtering system, oil mist header outlet, and necessary controls and instrumentation. Air and oil enter the console to produce oil mist.

1.4.36 oil mist generator: A device located inside the oil mist console that combines oil and air to make oil mist. Typical oil mist generators utilize a venturi to achieve mixing of the oil and the air.

1.4.37 oil mist: A dispersion of oil droplets of 1–3 micron size in an air stream.

1.4.38 oil mist system: A system designed to produce, transport, and deliver oil mist from a central location to a remote bearing housing. This system consists of the oil mist console, distribution piping headers and laterals, application fittings, and the lubricant supply tank and pump.

1.4.39 oil mist header: A network of piping through which the oil mist is transported from the console where it is made to the machinery bearing housing where it is used.

1.4.40 operating temperature (thermal) alignment: A procedure to determine the actual change in relative shaft positions within a machinery train from the ambient (not running) condition and the normal operating temperature (running) condition by taking measurements from startup to normal operating temperature while the machine(s) is (are) operating, or after the shafts have been stopped but the machines are still near operating temperature.

1.4.41 parallel offset misalignment: The distance between two adjacent and parallel shaft centerlines. This offset is normally described in a unit (millimeters or mils) at the flex element location.

1.4.42 peg test: A test performed on optical leveling equipment to ensure that the instrument is properly adjusted and its line of sight is coincident to true earth level.

1.4.43 preliminary alignment: The aligning of two adjacent machinery shafts before the measurement of piping strain on the machinery.

1.4.44 pulsation analysis: An analysis of the piping system connected to a machine to determine the acoustical and mechanical effects of pulsating flow. For small machines a pulsation analysis may consist of comparison to other installations and/or use of proprietary pulsation device design charts, formulas, or graphs. For large, complicated machines a pulsation analysis may consist of a detailed digital or analog modeling of the machine and the piping. Unless otherwise specified, API Standard 618 should be used to provide guidance for the pulsation analysis.

1.4.45 pure mist: The application of oil mist to a machinery bearing housing to lubricate antifriction bearings. The oil mist passes through the bearing elements, and oil droplets coalesce out of the air stream. All oil is drained from the machinery bearing housing, and complete lubrication is provided by the mist alone. Pure mist may also be described as *dry sump* lubrication.

1.4.46 purge mist: The application of oil mist to a machinery bearing housing or reservoir to provide a slight positive pressure. Machinery lubrication is provided by the normal ring oil or submerged bearing lubrication. This prevents contamination that could be caused by infiltration of corrosive agents or condensation of ambient moisture. Purge mist may also be described as *wet sump* mist lubrication.

1.4.47 recycle line: A line from the discharge of a pump, blower, or compressor routed back to the suction system. A recycle line will usually include control elements such as meters or valves. The recycle line may connect directly into the suction line or may connect into suction vessels or liquid knock-out vessels and may include a cooler. Also known as *bypass line*, *minimum flow bypass*, or *kick-back line*.

1.4.48 special purpose equipment trains: Equipment trains with driven equipment that is usually not spared is relatively large in size (power), or is in critical service. This category is not limited by operating conditions or speed.

Note: Special purpose equipment trains will be defined by the user. In general, any equipment train such as an API Standard 612 turbine, API Standard 618 reciprocating compressor, API Standard 613 gear, API Standard 617 centrifugal compressor, or equipment with a gas turbine in the train should be considered to be special purpose.

1.4.49 special purpose application: An application for which the equipment is designed for uninterrupted, continuous operation in critical service and for which there is usually no spare equipment.

1.4.50 static piping analysis: An analysis of the piping system connected to a machine to determine forces and moments on nozzle connections caused by various loading conditions such as pipe weight, liquid loads, and thermal expansion or contraction. These forces and moments are compared to vendor-allowable loads or national standards to ensure that nozzle loadings meet guidelines. This analysis includes specification of pipe anchors, guides, supports, and sometimes spring supports and expansion joints to control strain. Where large vertical piping displacements occur, machinery may sometimes be mounted on spring-supported baseplates to reduce nozzle loading.

1.4.51 suction knockout vessel or liquid dropout vessel: A vessel located in the suction line to a compressor or blower used to separate any entrained liquid from the gas stream. It may contain a demister mat and/or centrifugal separators to aid in this separation. Usually the compressor or blower takes suction from the top of the knockout vessel.

1.4.52 table top foundation: An elevated three-dimensional reinforced concrete structure that consists of large beams or a thick slab connecting the tops of the supporting columns. The mechanical equipment is supported by the large beams or the slab located at the top of the structure.

1.4.53 total indicated runout (tir): The runout of a diameter or face determined by measurement with a dial indicator (also known as *total indicator reading*). The indicator reading implies an out-of-squareness equal to the reading or an eccentricity equal to half the reading.

1.4.54 vendor: The agency that manufactures, sells, and provides service support for the equipment.

1.4.55 warmup line: A line used to purge warm or hot fluid through a process machine. The intention is to heat up or maintain the temperature of a machine to a temperature greater than the surrounding ambient temperature.

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Chapter 2—Rigging and Lifting

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CHAPTER 2—RIGGING AND LIFTING

1.1 Scope

1.1.1 This chapter provides general guidelines for rigging and lifting of machinery from shipping trucks, railcars, and so forth, onto the foundation or platform.

Note: This chapter is intended to be used for all machinery. Even small pumps can be damaged by improper lifts. The extent of the rigging and lifting plan can be reduced when specified by the user. The lifting plan for small machinery could be in the form of a site meeting at the start of construction, if agreed to by the user. However, if not specified otherwise, this section shall be used for all machinery.

1.1.2 This chapter is intended to supplement the rules and regulations that the rigging and lifting subcontractor must abide by, such as state or local government inspections and permits, OSHA 1926, Subparts H and N, and ASME/ANSI B30.

1.2 Preplanning the Lift

1.2.1 The installer shall be responsible for obtaining the following as a minimum:

a. Shipping and net weights of each separate component of the machinery or machinery package.

b. Manufacturer drawings indicating the location of lifting lugs/points, the expected load at each point, and the center of gravity.

Note: Lifting lugs are often provided on machinery to lift individual components and are not intended to be used to lift the entire machine (that is, lifting lugs on WP-II motor air housings cannot be used to lift the entire motor).

c. Manufacturer's recommendations for the lift including the use of spreader bars, slings, and so forth.

1.2.2 The installer shall prepare a rigging and lifting plan of action that includes the following:

a. A rigging plan showing the lifting points and including the load capacities of spreader bars, slings, cables, shackles, hooks, rings, and so forth. Load capacities shall be based upon a minimum safety factor of 1.5. Plans shall also be made for lifting crated equipment.

Note: When the safety factor of 1.5 results in the selection of a more expensive crane, the selection may be reduced upon an appropriate engineering review and agreement by both the installer and the user designated representative.

b. The selected lifting equipment and confirmation that the load and lift radius are within the capacity and range ratings of the manufacturer of the lifting equipment.

c. Layout sketches showing the setup location for the lifting equipment in relationship to the initial pick point of the load and its final installation point. The sketch should also show the proximity to important structures, pipe racks, and overhead electrical services. OSHA 1926.550 gives clearance requirements for electrical services.

d. Setup time for the lifting equipment and overall duration of the lift.

Note: Coordinate with the plant traffic control personnel for any roadway blockages.

e. Check route to be taken when bringing machinery to final location. Check for overhead clearance, turn radius, road bed, and so forth.

1.2.3 The installer shall check site plans for underground piping, sewers, electrical cables, or other utilities in the area of lift. Outrigger cribbing pads shall be used to eliminate any damage to roads and also to reduce the possibility of outriggers breaking through soft ground, reducing the capabilities of the crane.

Note: Many lifts are made from unpaved areas. Point loads from crane tires and outriggers can damage underground utilities. Review potential problem areas with a civil engineer to determine if the ground cover is adequate.

1.2.4 The installer shall confirm that floor slabs on which the crane may sit have cured adequately. Confirm that machinery foundations have cured and grout preparations have been completed.

1.2.5 If the machinery will be set in a partially completed structure, or if structural members must be removed to lower the machinery into the structure, the lifting plan must be reviewed and approved by the structural engineer responsible for the design of the structure. Temporary shoring, bracing, or supports shall be reviewed and approved by the structural engineer.

1.2.6 The installer shall confirm that all equipment is up to date with respect to permits and inspections. Request that the rigging spreader bars, slings, cables, and so forth, are field inspected just prior to the lift being started. Refer to OSHA 1926, Subparts H and N, for inspection requirements.

1.2.7 The installer shall hold a prelift meeting with the user and manufacturer (if required) to ensure that the plan of action is agreed to and understood.

1.3 Lifting the Machinery

1.3.1 The installer shall verify that the cables and slings are bearing only on the intended lift points and are not transmitting any loads onto auxiliary piping, instruments, chain guards, and so forth.

1.3.2 Lift points for individual machinery pieces shall not be used for lifting machinery skids or packages. This can apply to lifting lugs that may be found on motors, gear boxes, casings, inspection covers, and so forth. When in doubt, consult the manufacturer. Do not use equipment shafts for lift points.

1.3.3 For baseplate- or skid-mounted machinery, only use lift points on the baseplate or skid. Do not use the machinery as a lift point unless approved by the manufacturer.

Note: Care must be exercised in lifting skid-mounted equipment where part of the machinery or its auxiliaries have been removed for shipment, thus changing the center of gravity.

1.3.4 The installer shall keep other subcontractor and plant personnel from working under the lift and keep them a safe distance away until the machinery is secured in place on its foundation or structure.

1.3.5 For sleeve bearing machinery without thrust bearings, the rotor shall be blocked to restrict axial travel prior to lift.

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Chapter 3—Jobsite Receiving and Protection

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CHAPTER 3—JOBSITE RECEIVING AND PROTECTION

1.1 Scope

1.1.1 This recommended practice (RP) defines the minimum requirements for protecting project machinery and related components from deterioration while in field storage, after installation, and during the period prior to commissioning.

1.1.2 In all cases where the manufacturer's requirements or recommendations differ from the instructions provided in this document, the user's designated representative shall be consulted to determine which takes precedence.

1.1.3 An inspection and protective maintenance program shall be initiated and maintained by the user's designated representative for stored and installed equipment until it is turned over to the care, custody, and control of the user.

1.2 Responsibility

Overall responsibility for protecting project machinery from deterioration in the field, per this recommended practice, rests with the construction manager and his designated representative until the machinery is turned over to the user.

1.3 Preplanning

1.3.1 Verify that all procurement schedules, shipping lists, manufacturer's storage recommendations, installation manuals, and drawings have been forwarded to the designated machinery representative.

1.3.2 Review weights, configuration, and method of shipping before arrival at the jobsite. Determine type of equipment required to unload the shipment, (that is, forklift, boom truck, crane, and so forth) and schedule accordingly.

Note: See API RP 686/PIP REIE 686, Chapter 2—Rigging and Lifting, for further details. Care must be taken to ensure that safe and appropriate rigging procedures are followed.

1.3.3 When specified, schedule the manufacturer's representative for receiving inspection. Schedule user's inspectors, where required, such as rotating equipment, instrument, and electrical engineers.

1.4 Jobsite Receiving and Inspection

Upon arrival of the machinery or portions thereof at the jobsite:

a. Visually inspect components for physical damage or contamination by opening packages and crates. Hermetically sealed containers should not be opened, but visually inspected for damage and the hermetic seal maintained.
b. Verify that shipping protection has been applied and is still in effect.
c. Verify that shop inspection has been completed and that the vendor has supplied the purchase order documentation and packing lists.
d. Verify that loose components and separate packages match the packing lists.
e. Verify that special handling instructions are provided and carried out.
f. Verify proper identification of the components.
g. Perform visual inspection of components for compliance with project requirements.
h. Inspect carbon steel or other ferrous flange faces for damage and coat with type A, B, or D preservative, unless prohibited by process application (see note 1). Reinstall protective covers. Where car seals on inspection covers or flanges have been specified, inspect the car seals for integrity (see note 2).

Note 1: Preservative types are described in Appendix A. Final selection of the preservative depends on the type of storage (indoor, outdoor, sheltered), weather conditions, and atmospheric corrosion potential. Equipment data sheets and manufacturer's instructions shall be reviewed to determine if there are specific preservative requirements. Refer to the notes in Appendix A for additional details.

Note 2: Use caution with soft-gasketed flanges. Soft gaskets may absorb water and corrode carbon steel flanges.

i. Verify that plugs and caps are in place, desiccants are unsaturated, and equipment is lubricated, as required. Nonmetallic (such as plastic) plugs and caps shall not be used.
j. Verify that inert-gas-purged equipment still has the required pressure applied. Report failures to the manufacturer and request corrective action. This equipment shall remain sealed unless otherwise instructed by the designated machinery representative.
k. Inspect grout surfaces for proper factory blasting and coating.
l. Tapped openings in the stuffing boxes and gland plates shall be closed and sealed with pipe plugs. Plug material shall be of the same or better than seal gland plate metallurgy. As a minimum, the plugs shall be stainless steel.
m. When specified, impact-measuring devices shall be inspected to determine if the equipment has been exposed to any excessive shock loads. Where required, the manufacturing representative shall be present.
n. Record all inspections (refer to Appendixes B and C).

o. Report any damage to the shipping company and vendor immediately. Ensure that any claim forms required by the shipper or vendor are completed.

1.5 General Instructions—Jobsite Protection

1.5.1 Manufacturer's or vendor's recommendations for storage and protective care shall be reviewed by a user designated representative and shall be strictly followed when transmitted to the field. If the manufacturer's recommendations are not available, the information included in this recommended practice shall be used as a minimum acceptable guide.

1.5.1.1 Review the procurement documents to determine if the equipment had been prepared for a predetermined storage period. For example, if the equipment was procured per 4.4.1 of API *Standard Paragraphs*, preparation for shipment would be "suitable for six months of outdoor storage from time of shipment, with no disassembly required before operation, except for inspection of bearings and seals. In such cases, redundant preparation procedures would be postponed until the initial time period runs out."

Note: It is recommended that where machines are to be partially or completely disassembled for storage preservation or inspection by the contractor or user, the vendor's service representative should be on site to ensure the accuracy of the work and the preservation of the warranty.

1.5.1.2 Protective storage requirements for specific items of equipment such as pumps, blowers, fans, compressors, and gear boxes are found in subsequent sections of this procedure.

1.5.2 Records documenting the following information are to be kept by field material control personnel using the forms referenced:

a. Conditions of equipment and materials upon arrival at the jobsite before and after unloading. Use the checklist in Appendix B.

b. Maintenance and storage procedures followed, and dates maintenance was performed. See forms provided in Appendixes B and C of this chapter.

1.5.3 All equipment and material shall be stored free from direct ground contact and away from areas subject to ponding water. As a minimum, laydown areas shall be graveled areas.

1.5.4 For outdoor storage, even cross-cut timber with at least a 10 centimeter × 10 centimeter (4 inch × 4 inch nominal) cross section, laid flat and level, shall be used for laydown. Equipment weight shall be considered when selecting timber size. Warped timber or telephone poles are not acceptable. Timbers shall be placed perpendicular to major support structures and shall be full width of the skid or baseplate.

1.5.5 Indoor storage should be used whenever possible.

Note: Third party storage facilities may prove to be the most economical method for equipment requiring clean, dry, and climate-controlled conditions. On an existing site, the user may be able to provide some storage facilities.

1.5.6 Temporary protective coverings shall allow free air circulation to prevent humidity condensation and collection of water.

1.5.7 The installer shall attempt to preserve and maintain the integrity of the delivery packaging whenever appropriate. Replace packaging material after inspection. Review the integrity of control boxes and panels with respect to weather protection. Store indoors if required.

1.5.8 All carbon and low alloy steel shall be protected from any contact with corrosive atmospheres or wet atmospheres so as to prevent rust formation.

1.5.9 Painted surfaces shall not require additional protection but shall be examined periodically for signs of rusting. Touch up, using the manufacturer's recommended methods and materials, shall be performed within a practical and reasonable period of time.

1.5.10 All items with machined surfaces shall be stored so that the machined surfaces can be examined periodically (monthly) for signs of rust.

1.5.11 Any special parts and tools for construction purposes that accompany vendor shipments shall be tagged, protected, and stored per the vendor's and/or user's recommendations. All tags must be stainless steel and wired to the special part or tool. Paper tags are not permitted.

1.5.12 Keep the storage area and equipment clean by providing physical protection and covering when work operations such as concrete chipping, sanding, painting, and rigging are performed in the area. Stainless steel shall be protected from weld splatter and grinding dust of low alloy steel.

1.5.13 Periodic rotation of equipment will be discussed in subsequent sections. In all cases, determine that all shipping blocks on rotating components have been removed and that there is adequate lubrication before rotation. Determine that any desiccant bags or protective plastics are clear of moving parts. To rotate the shaft, use a tool such as a strap wrench that will not mar machined surfaces.

1.5.14 Preservatives and/or storage lubricants can adversely affect the safety and operating life of equipment if they react with the process fluid or operating lubricant. Specific examples are (a) grease- or oil-based products in contact with components to be installed in oxygen or chlorine service, (b) preservatives contaminating interiors of fluorochlorohydrocarbon refrigeration compressors, and (c) hydrocarbon flush oil contaminating synthetic oil passages.

The installer shall ensure that all preservative and storage lubricants are suitable for the specific application.

1.5.15 Unless otherwise specified, special purpose equipment shall be stored with a positive pressure, 2–3 millimeters Hg (1–2 inches W.C.), dry nitrogen purge (see note 1). The equipment shall have a temporary gauge to determine purge pressure. Remove the temporary gauge before startup. The equipment shall be inspected weekly to ensure that purge integrity is maintained. If a positive pressure cannot be maintained, purge at a rate of 2–3 SLPM (4–6 SCFH).

Note 1: Review all nitrogen purge installations with the user's safety personnel with respect to confined space procedures, warning signs, and asphyxiation hazards before putting the purge into service.

Note 2: External (temporary) soft packing, held by adjustable stainless steel bands (geared clamps), can be placed against, or touching the labyrinths (or equivalent seals) to significantly reduce the amount of dry nitrogen purge.

1.5.16 All equipment cavities, cooling passages, mechanical seals, positive displacement pump plunger cavities, and so forth, shall be drained of all water to prevent damage due to freezing temperature.

1.5.17 Dirt, ice, salt, and other foreign matter shall be removed as soon as possible after arrival on site.

1.5.18 Unless stated differently in subsequent sections on specific equipment, the following shall apply:

a. Oil-lubricated bearing housings, seal housings, stuffing boxes, hydraulic equipment, and gear cases shall be fogged and approximately one-fourth filled with a manufacturer-approved oil. All openings shall then be closed and sealed tightly.

b. When specified by the user, every other month the condition of the preservative oil shall be checked by measuring the total acid number (TAN) of the oil. If the TAN is less than 0.2, the oil shall be replaced with fresh oil. The date when checked and the TAN shall be recorded in the inspection records. Check with the oil supplier to determine if it needs to be heated for replacement.

c. All externally exposed, bare carbon steel or cast iron surfaces including shafts and couplings (except elastomeric components) shall be coated with type A, B, or D preservative. All machined surfaces shall be coated with type A, B, or D preservative. All exposed machined surfaces shall also be wrapped with waxed cloth (see note).

Note: Moisture can be held under waxed cloth if not tightly sealed. Periodic inspections under the cloth may be warranted.

d. Verify that grease-lubricated bearings have been greased by the manufacturer with the specified grease. Some greases are not compatible when mixed.

1.5.19 When an oil mist preservation system is specified by the user (see note), it shall be as follows:

Note: Oil mist systems are typically specified on large projects where more than ten pieces of equipment will be stored longer than six months.

a. Oil mist shall be used to protect the bearings, bearing housings, seal areas and process ends of the equipment.

1. Oil mist lubrication connections on equipment purchased for permanent oil mist lubrication shall be used.
2. Equipment purchaser shall have specified to equipment vendor that oil mist preservation will be utilized on the equipment.
3. Cavities not normally mist lubricated during permanent operation will need to be fitted with supply and vent connections (typically NPS 1/4).

b. The oil mist system shall be designed and sized for preservation service.

1. As a minimum the mist generator shall be equipped with the following instrumentation: air pressure regulator, pressure relief valve, level gauge, and mist pressure gauge.
2. The mist header system shall be NPS 2 minimum galvanized schedule 40 pipe properly supported and sloped.
3. Mist flow to each application point can be less than that required for lubrication during normal operation.
4. Plastic tubing (temporary use only) can be used to connect from the mist header to the application point.

c. The oil used in the mist system shall be a good quality, paraffin-free turbine oil. A temperature sensitive, vapor emitting oil should not be used. Equipment preservative oils shall be compatible with the oil used in the oil mist system to eliminate the need to disassemble and remove the preservative oil.

d. All machinery shall be connected to the system immediately upon arrival on site.

e. Equipment is maintained in the storage yard by rotating shafts and periodically draining condensed oil from the housing.

Note: Oil shall not be drained to ground.

f. For equipment that will be permanently oil mist lubricated, the movement of equipment from the storage yard to permanent locations shall be coordinated so that the maximum outage of mist preservation is minimized.

1.6 Lubricants and Preservatives

1.6.1 The table and notes in Appendix A describe some of the physical characteristics, application methods, and life expectancies of preservative types A, B, C, and D that are referred to in this practice. Final selection types shall be approved by the equipment manufacturer and User.

1.6.2 Care shall be taken to ensure the compatibility of the preservative with elastomeric parts, seals, gaskets, and so forth.

1.6.3 All lubricant and preservative Material Safety Data Sheets (MSDSs) shall be available, and associated hazards reviewed with all personnel handling and using these materials.

1.6.4 The term desiccant shall mean silica gel or any other approved water absorbing material. All desiccants shall have prior approval from the manufacturer or the user designated representative. Check desiccant monthly. Replacements shall be approved by the user.

1.6.5 Preservatives shall not be used on surfaces where prohibited by process application.

1.6.6 In succeeding sections, references are made to removing preservatives before the machinery is placed in service. This is always true for type D preservative. However, with the proper selection of types A, B, and C, removal can be eliminated. The preservative would need to be compatible with the permanent lubricating fluid, the process fluid, and materials of construction, that is, elastomers. The preservative shall also be inspected to be sure that it has not absorbed any abrasive dust.

1.7 Bolts

1.7.1 All loose assembly bolts, nuts, and fasteners shall be packaged, identified, and stored in a sheltered area.

1.7.2 Type B or type C preservative shall be applied to the threaded portion of all anchor bolts, washers, and nuts that are not galvanized or plated.

1.8 Spare Parts, Special Tools, and Miscellaneous Loose Items

1.8.1 Items purchased as spare parts shall be tagged and handed over to the user's designated machinery representative upon receipt and completion of jobsite receiving inspection per 1.4.

1.8.2 Storage and protective maintenance of miscellaneous loose items shall be as directed by the manufacturer.

1.8.3 Extra drawings and manuals shipped with the equipment shall be saved and handed over to the user.

Note: Formal distribution of these types of documents should have occurred before shipment per 1.3.1.

1.8.4 Special tools shall be kept by the installer until work has been completed, then turned over to the user's designated machinery representative.

1.9 Auxiliary Piping for Rotating Equipment

The following applies to auxiliary piping that is shipped loose for field assembly.

1.9.1 PIPE COMPONENTS

Carbon steel pipe components that will require long-term storage outdoors during the construction period (or stainless steel in a saltwater atmosphere) shall be coated externally and internally with thinned type B or a type C preservative, unless prohibited by process application.

1.9.2 FLANGES

1.9.2.1 Flanges received bolted face-to-face need not be separated for inspection; however, the face-to-face crevice shall be coated with type A, B, or D preservative prior to outdoor storage.

1.9.2.2 After inspection of loose flanges, flange gasket surfaces shall be coated with type A, B, or D preservative prior to outdoor storage. Flanges for prefabricated piping and lube oil systems shall be gasketed and covered with 5-millimeter ($^3/_{16}$-inch) metal covers.

Note: Temporary gaskets can usually be made from service sheet gasket material.

1.9.2.3 Care shall be taken to protect gasket surfaces of loose flanges from damage during handling and storage.

1.9.2.4 Flanges to be stored outdoors for periods exceeding six months or in corrosive atmospheres (saltwater air, industrial, and so forth) shall be coated externally and internally with thinned type B preservative.

1.9.2.5 Preservatives shall be removed from all surfaces with a suitable solvent prior to installation of the components.

1.9.3 VALVES

1.9.3.1 Whenever possible, valves shall be stored indoors or under cover.

1.9.3.2 All machined surfaces such as valve stems (including threads), packing glands, and bonnet bolts shall receive a heavy coat of appropriate grease or equivalent for atmospheric corrosion protection.

1.9.3.3 Valve flange gasket surfaces shall be coated with type A, B, or D preservative prior to reinstalling protective covers after internal inspection.

1.9.3.4 Protective covers shall be made of a weatherproof material and of such construction to provide a weathertight seal. Plastic plugs and flange covers are not permitted.

1.9.3.5 All ball valve internals shall be coated prior to reinstalling protective covers after internal inspection.

1.9.3.6 All ball valves shall be protected and stored in the open position.

1.9.3.7 Multiple turn, metal-seated valves shall be stored in the closed position to minimize the length of stem exposed. Multiple turn, soft-seated valves shall be stored one turn from the closed position. Valves shall be stored with valve openings horizontal to prevent water accumulation.

1.9.3.8 All valves shall be stored above grade on a well-drained, hard surface.

1.9.3.9 Periodic (at least once per month) checks shall be made to ensure that protective procedures are effective. If deterioration is observed, the user shall be notified so that appropriate corrective action can be initiated.

1.9.3.10 Packing inhibitors are usually effective for only six months. Valves with packing that are stored for longer periods shall be checked and protected against stem corrosion if necessary.

1.9.3.11 Preservatives shall be removed with solvent from all surfaces prior to installation of valves.

1.9.3.12 All ring joint flanges shall be examined when received and the condition recorded. Spot checks for corrosion shall be made monthly while in storage.

1.10 Compressors—General

1.10.1 Clean and coat all flange gasket surfaces with type A, B, or D preservative.

1.10.2 Install weatherproof protective covers of such construction to provide a watertight seal on all openings. Plastic plugs and flange covers are not permitted.

1.10.3 Consult the manufacturer to determine if additional intermediate rotor shaft supports are required. Provide the supports as necessary.

1.10.4 Spare rotating elements shall be stored per manufacturer's specific instructions.

Note: Rotating elements should be stored in a controlled environment such as vertically in a controlled room or nitrogen purged containers.

1.10.5 Preservatives for oxygen and refrigeration compressors must be approved by the equipment manufacturer.

1.11 Reciprocating Compressors

Note: Also see 1.10, Compressors—General.

1.11.1 Coat exposed rods, eccentrics, plungers, and machined surfaces with type A, B, or D preservative. If the valves have been shipped loose, tag and store per manufacturer's recommendations.

1.11.2 Nonlubricated compressors with TFE or carbon piston or piston ring shall not be contaminated with oil. Such machines, if not already shop protected, shall be sealed, purged of air, and kept pressurized with anhydrous nitrogen at 2–3 millimeters Hg (1–2 inches w.c.).

Install a temporary pressure indicator to indicate nitrogen pressure. Remove the temporary gauge before compressor initial run-in.

1.11.3 Cylinders and crankcase shall be inspected when the compressor is received on site by removal of the inspection covers. If water or dirt has entered the equipment through damaged covers, the equipment shall be cleaned out and rust preventive treatment restored.

1.11.4 If the compressor requires field assembly, remove the protective coatings from cylinder walls, valves, rods, and so forth, and clean all parts (including crankcase) with solvent. Assemble using the manufacturer's recommended preservative freely on cylinder walls, valves, rods, bearings, and rubbing parts and fill crankcase as recommended by the manufacturer.

Do not install carbon rings or rod packing until the compressor is serviced for initial operation. Fill crankcase and lubricators as recommended by the manufacturer, with type C preservative.

Note: Where compressors require field assembly, consideration should be given to bringing in the factory representative to confirm inspection, preservation, and assembly procedures.

1.11.5 Where applicable, open the drip feed lubricator and operate the force feed lubricators weekly. If the compressor has a manual priming main oil pump, operate it for at least one minute. Turn the crank shaft 2¹/4 revolutions. Shaft rotation must be accomplished with a strap wrench or other nonmarring device. Check for rust spots. Close the drip feed lubricators and refill the lubricators as necessary. Record protective activity in the inspection records.

Note: If lubricated compressor cylinders are attached to the frame and the piston and rods are installed, only rotate the crankshaft if the compressor cylinder bore and piston rod packing lubricator can be operated prior to rotation. On nonlubricated (NL) compressors, if the compressor cylinders are attached to the frame and the pistons and rods are installed, only rotate the crankshaft if it has been confirmed that all desiccants have been removed and that a positive pressure dry nitrogen purge is being maintained on the cylinders.

1.11.6 Large compressor frames [in excess of approximately 4 meters (12 feet) in length] that are not skid mounted and that are to be stored more than a few days prior to installation should be aligned following the manufacturer's recommendations to prevent permanent distortion of the compressor frame.

1.12 Centrifugal Compressors

Note: Also see 1.10, Compressors—General.

1.12.1 Open bearing housing and verify that vendor has applied protective coating to shaft journals and thrust bearing disc and that noncontacting vibration probe target areas are not disturbed. If deficient, reapply shaft lubricant and coat inside of housing with manufacturer's approved preservative.

1.12.2 Check all lubricant fill points, sight glass connections, and piping to seals to ensure that lubricants or protective fluids do not leak from any joints.

1.12.3 Mark shaft and rotate 2¹/4 revolutions weekly. Record protective activity in the inspection records. Shaft rotation must be accomplished with a strap wrench or other nonmarring device.

1.12.4 Open and inspect bearing housing every two months.

1.12.5 Types A, B, and D preservative shall be removed with solvent from all surfaces prior to final installation of compressor.

1.12.6 All large compressors, if expected to be in the field in excess of 3 months, shall be purged with nitrogen. When nitrogen is not available, case openings shall be sealed. Vapor phase inhibitor and desiccant shall be used to protect internals from rusting. The equipment shall be tagged indicating the number and location of all vapor phase inhibitor and desiccant bags.

1.13 Fans and Blowers

The following procedure shall be used for receiving and protecting fans and blowers.

1.13.1 Coat exposed machined surfaces and shaft extension with type A, B, or D preservative.

1.13.2 Fill bearing housing to bottom of shaft with the manufacturer's recommended oil.

1.13.3 Mark shaft and rotate $2^1/4$ revolutions weekly. Record protective activity in the inspection records. Shaft rotation must be accomplished with a strap wrench or other nonmarring device.

1.13.4 Preservatives shall be removed with solvent from all surfaces prior to installation of fans and blowers.

1.13.5 Install weatherproof protective covers of such construction to provide a watertight seal on all openings. Plastic plugs and flange covers are not permitted.

1.14 Gearboxes

The following procedure shall be used for receiving and protecting gearboxes at the jobsite.

1.14.1 Determine if gearbox oil level is correct. Add the manufacturer's recommended oil if gear case contains less than the required amount. Check bearing housing oil level; fill as necessary.

1.14.2 Coat exposed machined surfaces and shaft extension with type A, B, or D preservative. Type D preservative shall be removed with solvent from all surfaces prior to installation.

1.14.3 Mark low-speed shaft and rotate $2^1/4$ revolutions weekly. Shaft rotation must be accomplished with a strap wrench or other nonmarring device.

1.14.4 Purge gear case with nitrogen if required by the manufacturer's instructions or if deemed prudent by the user for the climatic conditions at the site. Purge per 1.5.15.

1.14.5 Record protective activity in the inspection records.

1.15 Pumps—General

The following procedure shall be used for receiving and protecting pumps during the storage and installation period at the jobsite.

1.15.1 Coat coupling parts, except elastomeric parts and flexible stainless steel discs, with type A, B, or D preservative.

1.15.2 Shipping covers shall be removed, flange gasket surfaces inspected, and internals checked for cleanliness. Coat flange surfaces with type A, B, or D preservative.

1.15.3 Tag all loosely shipped items (such as couplings, oilers, and seal system components, if loose) with the pump identification number and store in a covered area.

1.16 Centrifugal Pumps

1.16.1 Install weatherproof protective covers of such construction to provide a watertight seal on all openings. Plastic plugs and flange covers are not permitted.

1.16.2 Fill bearing housings to the bottom of shaft with the manufacturer's recommended oil.

1.16.3 For cast iron, carbon steel, and low alloy pumps, fill the pump casing with type C preservative and rotate to coat the internals.

1.16.4 Mark shaft and rotate $2^1/4$ revolutions weekly. Record protective activity in the inspection records. Shaft rotation must be accomplished with a strap wrench or other nonmarring device.

1.16.5 Type D preservative shall be removed with solvent from all surfaces with solvent prior to installation of pump.

1.16.6 Fill the piping loop for the barrier fluid of a dual seal pump with a process compatible fluid if it contains any carbon steel components.

1.17 Vertically Suspended Pumps

1.17.1 Apply type C preservative to shaft journals at sleeve bearings and to thrust bearing disc.

1.17.2 Fill bearing housings to the bottom of shaft with vendor recommended oil.

1.17.3 Coat the bowl assembly with type A, B, or D preservative and close both ends.

1.17.4 Coat barrel flange, discharge head flanges, stuffing box, and all other machined surfaces with type A, B, or D preservative.

1.17.5 Install weatherproof protective covers of such construction to provide a watertight seal on all openings. Plastic plugs and flange covers are not permitted.

1.17.6 Type D preservative shall be removed with solvent from all surfaces prior to installation of pump.

1.18 Reciprocating Pumps

1.18.1 Remove pistons and rods, if recommended by the manufacturer; coat with type A, B, or D preservative; tag each part with the equipment number; and store in covered area.

1.18.2 Remove rod packing, if recommended by the vendor; tag; and store in covered area.

1.18.3 Remove suction and discharge valves; dip in type A, B, or D preservative; wrap in waxed cloth; tag; and store in covered area.

1.18.4 Fill crankcase with type C preservative to the recommended level.

1.18.5 Coat cylinder wall and distance piece wall with type C preservative.

1.18.6 Type D preservative shall be removed with solvent from all surfaces prior to installation of pump.

1.19 Steam Turbines

The following procedure shall be used for receiving and protecting turbines during the installation and storage period at the jobsite.

1.19.1 Coat stuffing box and shaft in packing area with type B or C preservative and replace on turbine.

1.19.2 Clean and coat all flange gasket surfaces with type A, B, or D preservative.

1.19.3 Install weatherproof protective covers of such construction to provide a watertight seal on all openings.

1.19.4 Shipping covers shall be removed, flange gasket surfaces inspected, and internals checked for cleanliness.

1.19.5 Identify and tag all loosely shipped items and store in a covered area.

1.19.6 GENERAL PURPOSE TURBINES

1.19.6.1 If carbon shaft packing rings were not removed at the factory, remove and store indoors. Tag the turbine from which the rings have been removed. The carbon rings shall be reinstalled just prior to startup. Removal and reinstallation shall be performed by qualified personnel.

1.19.6.2 Open bearing housings and coat shaft journals with type C preservative.

1.19.6.3 Fill bearing housings to bottom of shaft with vendor recommended oil.

1.19.6.4 Fill hydraulic governor per manufacturer's recommendation.

1.19.6.5 Rotate shaft 2¼ revolutions weekly. Record protective activity in the inspection records. Shaft rotation must be accomplished with a strap wrench or other nonmarring device.

1.19.6.6 Type D preservative shall be removed with solvent from all surfaces prior to installation of turbine.

1.19.7 SPECIAL PURPOSE TURBINES

1.19.7.1 Inspect and coat surfaces of valve rack, cam, and cam followers with type A, B, or D preservative.

1.19.7.2 Open bearing housings and coat shaft journals, thrust bearing disc, and bearing housing internally with type C preservative.

1.19.7.3 Coat shaft extension with type A, B, or D preservative.

1.19.7.4 Special purpose turbine casings/internals shall be protected with nitrogen purging. Purge per 1.5.15. Where this is not possible and approved by the user, spray turbine internals through openings with type C preservative.

1.19.7.5 Mark shaft and rotate 2¼ revolutions weekly. Record protective activity in the inspection records. Shaft rotation must be accomplished with a strap wrench or other nonmarring device.

1.19.7.6 Type D preservative shall be removed with solvent from all surfaces prior to installation of turbine.

1.20 Motors

The following procedure shall be used for receiving and protecting electrical motors during the installation period at the jobsite. Specific storage instructions are normally provided by all motor manufacturers. Failure to follow these instructions may void the warranty. The procedures that follow must be adhered to, provided they do not invalidate the manufacturer's warranty.

1.20.1 RECEIVING INSPECTION OF MOTORS

After receipt at site but prior to any motor being stored or installed, the following shall be performed:

a. An insulation resistance-to-ground test shall be made and recorded. This log will show the dates of the test and the insulation resistance value.
b. Oil levels shall be inspected. An inspection shall be made for any evidence of oil leakage.
c. Shafts shall be rotated and checked for freedom of movement.

1.20.2 STORAGE

1.20.2.1 Fill bearing housing with recommended oil if not factory lubricated or the level is low.

1.20.2.2 Rotate the shaft manually until the lubricant is evenly distributed to wearing surfaces. Rotate $2^1/4$ revolutions weekly thereafter. Shaft rotation must be accomplished with a strap wrench or other nonmarring device.

1.20.2.3 Coat shaft with type A, B, or D preservative.

1.20.2.4 Wrap shaft seal areas with waxed cloth.

1.20.2.5 Apply type A, B, or D preservative to baseplate and motor case feet.

1.20.2.6 Store motors indoors when possible. A motor is suitable for outdoor storage if the enclosure type is TEFC, TENV, or explosion proof. Motors without space heaters shall not be stored outdoors without user's approval unless provisions are made by the installer to supply an adequate source of heat to the motor to protect it from moisture. If unable to store indoors, motors shall be stored in their operating position on a well-drained hard surface.

1.20.2.7 When a space heater is provided by the manufacturer, it shall be connected, energized, and operated continuously until the motor becomes operational.

Note: Proper warning signs must be installed to prevent injury or electrical shock to personnel.

1.20.2.8 Preservatives shall be removed with solvent from all surfaces prior to installation of motor, using caution to not have solvent contact the windings.

1.20.3 TESTING

Insulation resistance of all motors shall be tested upon receipt, just prior to installation, and just prior to startup and shall be recorded in the inspection records. The test voltage levels and the insulation resistance shall be per the manufacturer's instructions. If the megger readings do not meet the manufacturer's requirements, winding dryout may be required. Dry out the stator per the motor manufacturer's instructions. Other methods may be harmful to the windings.

1.21 Instrumentation on Packaged Machinery

1.21.1 All instruments shall be inspected by qualified personnel for compliance to purchase specifications, proper tagging, and shipping damage.

1.21.2 After inspection, instruments are to be replaced in their original factory boxes, properly tagged, and stored on shelves in a dry enclosed area.

1.21.3 For instruments or control panels that have been premounted on the machinery package that cannot be stored in a dry, enclosed area, the user and manufacturer shall be consulted.

Note: Removal and indoor storage of premounted instruments and control panels may be required if such devices cannot be protected from rain, humidity, temperature, or dusty conditions. Explosion-proof enclosures are not necessarily weatherproof enclosures. Open conduit connections can allow entrance of moisture. This subject should have been addressed during the procurement or shop inspection stage, but is sometimes overlooked.

1.21.4 ELECTRONIC INSTRUMENTS

1.21.4.1 Electronic instruments shall be stored in a dust-free room between 8°C and 45°C (45°F and 110°F).

1.21.4.2 If humidity is excessive, seal and store the instruments in plastic wrap, place in a box with desiccant outside the plastic wrapping, and store indoors. Take care that the desiccant does not contact any wiring, terminals, or electronic parts.

1.21.4.3 The manufacturer's recommendations shall be reviewed to determine if climate-controlled storage facilities are required.

1.21.5 PNEUMATIC INSTRUMENTS

Storage in a dry enclosed area is sufficient for pneumatic instruments.

1.21.6 INSTRUMENT CASES

1.21.6.1 Instrument cases with electronic parts, relays, and so forth, shall always be opened and checked by qualified personnel, unless shop inspections have been made and documented.

1.21.6.2 If the instrument case is in a weatherproof housing, reseal and store the instrument in a room between 8°C and 45°C (45°F and 110°F).

1.21.6.3 If in an explosion-proof housing, store in boxes with desiccant.

1.21.6.4 If covers need to remain left open and unsealed, place the boxes in an indoor storage environment.

1.21.7 LOCAL CONTROL PANELS

1.21.7.1 Open packaging enough to identify the control panel, reseal, and place in a dry enclosed area between 8°C and 45°C (45°F and 110°F).

1.21.7.2 When in a high-humidity area, put desiccant inside packaging before resealing.

1.21.8 DIAL THERMOMETERS, PRESSURE GAUGES, GAUGE GLASSES

Protect against physical damage from construction activities, or remove, tag, and store in a dry enclosed area. Process connections shall be capped or plugged with metal caps/plugs until the instruments are reinstalled.

APPENDIX A—CHARACTERISTICS OF CONVENTIONAL STORAGE PRESERVATIVES

Table A-1—Storage Preservation

Storage condition and/or severity	Outdoor storage, general exposure to elements	Indoor Storage Under Severe Conditions, or Outdoor storage (partial shelter) under moderate conditions, or outdoor storage with exposure to elements for short term only	Indoor Storage under moderate conditions	Outdoor storage with exposure to elements under the most severe conditions
	A	B	C	D
Product and typical characteristics	Firm coating, resistant to abrasion	Soft coating (self-healing)	Thin oily film	Asphaltic film, needs removal before part is used
Density				
kg/m³ at 15.6°C	868.5	923.7	876.9	922.5
lb/gal at 60°F	7.25	7.71	7.32	7.70
Viscosity				
cSt at 40°C	—	—	14	149
cSt at 100°C	24.8	33 1	3.3	—
SSU at 100°F	—	—	79	800
SSU at 210°F	123	162	37.4	—
Flash Point				
°C	279	260	166	38
°F	535	500	330	100
Melting or pour point				
°C	73	66	–4	—
°F	164	151	+25	—
Unworked penetration				
At 25°C (77°F)	75	245	—	—
Film thickness, mil	1.6	1.6	0.9	3.0
Approximate coverage				
m²/liter	26	26	44	11
sq ft/gal	1000	1000	1800	450
Nonvolatiles, %	99	99	—	55
Methods of application/ temperature, °C	dip/85 brush swab/60–71	dip/77 swab/18–27	roller coat, brush, mist	spray, dip, or brush/ ambient
Maximum time until inspection and possible reapplication under condition				
Mild	Extended	Extended	6–12 Months	Extended
Moderate	1–3 Years	1–3 Years	1–6 Months	1–3 Years
Severe	6–12 Months	6–12 Months	Not recommended	6–12 Months

Note: Extracted from proceedings of the Fourteenth Turbomachinery Symposium, Texas A&M University, Table 1, Page 36, "Storage Preservation of Machinery" by Heinz P. Bloch.

Notes

1. This tabulation represents an overview of interacting factors that allows the specifying engineer to select the most appropriate preservative for a given situation. Indoor and outdoor storage protection is addressed, but lubricants or preservatives used for oil mist systems are not covered.
2. The severity of indoor storage is a function of such factors as dampness, poor air circulation, widely fluctuating temperatures, or presence of corrosive fumes. If conditions are moderately severe, product "C" will provide an adequate oily film and some abrasion resistance. It does not contain water-displacing or fingerprint-suppressing agents.
3. Product "B" has a greaselike consistency and leaves a thick film that will provide protection in the most severe indoor environments. If stored parts are sheltered from direct exposure to sun, rain, and snow, effective outdoor rust protection can be achieved with this product. Application of product "B" is preferably made by dipping at a temperature of 71–77°C (160–170°F). For parts too large to dip, application can be made by brush. This product forms a soft, thick, waxy coating on application, with the surface coating gradually drying to form a protective film or crust while the underlying material remains soft and plastic. This is an important characteristic because it affords a self-healing effect. When a minor break occurs, the softer material will slowly flow together and reseal the damaged film.
4. The degree of protection obtained in exposed outdoor environments will depend to some extent on the thickness and durability of the barrier film provided by the rust preventive material. For relatively short-term storage, product "B" will give effective protection. For longer periods, product "A" is recommended. It provides the toughest coating for a product of this type, and is more resistant to film rupture than product "B." For dip application, product "A" should be heated to 85°C (185°F).
5. Product "D" is a solvent-cutback asphaltic material. This product provides the best protection for long-term outdoor storage, but must be removed before the part is put into service. The preferred application method is by spray, although dipping and brush applications are also suitable. Product "D" dries to a thick, hard, durable, black film but may be removed with a good quality mineral spirits solvent.
6. Although products "A" through "C" do not require removal before the part is placed in service, care should be taken to be sure that the coating has not absorbed abrasive dust.
7. Many of the desirable attributes of premium preservatives are listed below:
   - Dry to a mildly tacky film that should not collect appreciable amounts of airborne particulates.
   - Provide freedom from oxidation in indoor and outdoor storage for extended periods of time.
   - Due to their polar nature, remove water from the pores of the metal, replacing the water with the rust preventive coating.
   - In the form of films, have extremely low moisture transmission characteristics, even in contact with water.
   - Have the ability to neutralize acid, making a suitable rust preventive for acidic atmospheres and where fingerprints may create a corrosive action on metal surface.
   - Are self-healing, if in film form. If the film is accidentally ruptured, it should heal over the ruptured area.
   - Even as film, should be readily removed with solvent or a solvent-emulsion cleaner when desired.
   - Are safe to apply over partially painted or conventional elastomeric parts.

APPENDIX B—MACHINERY RECEIVING AND PROTECTION CHECKLIST

Project No.:	Equip. Tag No.:	Report No.:
Prepared By:	Storage Location:	Date:
Equipment Description:		

Initials Date

1.4 Jobsite Receiving and Inspection

1.4.a Visual inspection for physical damage or contamination.

Comments (before unloading): ____________________

____

____

Comments (after unloading): ____________________

____

____

1.4.b Shipping protection intact? ______ ______

1.4.c Have offsite (shop) inspections been made? ______ ______

1.4.d Loose components/packages match packing lists? ______ ______

1.4.e Are special handling instructions required (and carried out)? ______ ______

1.4.f Components properly identified? ______ ______

1.4.g Do components comply with project requirements? ______ ______

1.4.h Flange faces undamaged and properly coated? ______ ______

1.4.i Plugs/caps in place, desiccants unsaturated, and equipment lubricated? ______ ______

1.4.j For inert gas purged equipment, is the required pressure still applied? ______ ______

1.4.k Grout surfaces clean and coated? ______ ______

1.4.l Tapped openings in stuffing boxes and gland plates sealed? ______ ______

1.4.m Impact measuring devices inspected? ______ ______

1.4.o Damage reports completed and issued to shipper/vendor?

1.5 General Instructions—Jobsite Protection

1.5.1 Are manufacturer's recommendations for storage and protection available?
Note: If so, the manufacturer's recommendations take precedence, but continue to follow this checklist for items not covered by the manufacturer. ______ ______

1.5.3 Equipment/material free of ground contact? Laydown area graveled as a minimum! ______ ______

1.5.4 For outdoor storage, is equipment on timber? ______ ______

1.5.6 Protective coverings allow free air circulation and prevent collection of water?
Note: Reuse delivery packaging, if possible. ______ ______

EQUIPMENT NO.: _______

		Initials	Date
1.5.8	Carbon and low alloy steel protected from corrosive or wet atmospheres?	_______	_______
1.5.11	Special parts and tools tagged and handed over to User?	_______	_______
1.5.12	Equipment protected from construction operations such as chipping, sanding, painting, rigging, welding, and so forth.	_______	_______
1.5.13	For periodic rotation of equipment, are shipping blocks, desiccant bags, and protective plastic clear of moving parts? Is equipment properly lubricated for rotation?	_______	_______
1.5.14	Have proper preservatives been selected?	_______	_______
1.5.15	Nitrogen purge in place for special purpose equipment or where specified? Use Appendix C for logging of purge inspections.	_______	_______
1.5.16	All cavities, cooling passages, and so forth, drained of water to prevent freezing?	_______	_______
1.5.17	Dirt, ice, and salt removed?	_______	_______
1.5.18	Unless stated differently in subsequent sections on specific equipment, the following applies:	_______	_______
1.5.18.a	Oil lubed bearing housings, seal housings, stuffing boxes, hydraulic equipment, and gear cases fogged and 1/4 filled with approved oil?	_______	_______
1.5.18.b	When specified, measure and record TAN number.	_______	_______
1.5.18.c	Exposed carbon steel coated with type A, B, or D preservative? Machined surfaces coated with type A, B, or D and wrapped with waxed cloth?	_______	_______
1.5.18.d	Grease lubed bearings greased by the manufacturer?	_______	_______
1.5.19	Oil mist system required?		

1.6 Lubricants and Preservatives

		Initials	Date
1.6.2	Are selected preservatives compatible with elastomeric parts, seals, gaskets, and so forth?	_______	_______
1.6.3	MSDSs on file and hazards reviewed?	_______	_______

1.7 Bolts

		Initials	Date
1.7.1	Loose bolts, nuts, and fasteners identified and stored in sheltered area?	_______	_______
1.7.2	Preservative applied to nongalvanized or plated items?	_______	_______

1.8 Spare Parts

		Initials	Date
1.8.1	Spare parts inventoried and issued to User upon receipt?	_______	_______

1.9 Auxiliary Piping For Rotating Equipment

		Initials	Date
1.9.1	Pipe components coated internally and externally for long-term storage?	_______	_______
1.9.2	Flanges inspected and coated?		
1.9.3	Valves inspected and coated? Ball valves in open position? Gate and globe valves in closed position and stored horizontal?	_______	_______

EQUIPMENT NO.: _______

		Initials	Date
1.10	**Compressors—General**		
1.10.2	Watertight covers on all openings?	_______	_______
1.10.3	Are intermediate rotor shaft supports required?		
1.10.4	Is vertical storage of rotating elements required by the manufacturer?	_______	_______
1.10.5	Preservatives and procedures for refrigeration, oxygen, and chlorine service approved by manufacturer?	_______	_______
1.11	**Reciprocating Compressors**		
1.11.1	Exposed rods, eccentrics, plungers, and machined surfaces coated?	_______	_______
1.11.2	Nonlubed compressors nitrogen purged, not contaminated with preservatives?	_______	_______
1.11.3	Covers on openings in cylinders and crankcase undamaged? If damaged, check for water or dirt inside.	_______	_______
1.11.4	For field assembled compressors, have loose components been properly cleaned and preserved? Have carbon rings and rod packing been left out until just prior to initial operation?	_______	_______
1.11.5	Lubrication through force feed lubricators or drip feed lubricators, and/or through manually priming main oil pump once per week?	_______	_______
1.12	**Centrifugal Compressors**		
1.12.1	Is bearing housing properly lubricated and preserved?	_______	_______
1.12.2	Have the lubricant fill points, site glass, and piping been checked for leaks?	_______	_______
1.12.6	Has a nitrogen purge, or vapor phase inhibitors and desiccant been applied per 1.12.6?	_______	_______
1.13	**Fans and Blowers**		
1.13.1	Have all exposed low alloy surfaces and shafts been coated with preservative?	_______	_______
1.13.2	Bearing housing oil level correct?	_______	_______
1.13.5	Weatherproof covers installed?	_______	_______
1.14	**Gearboxes**		
1.14.1	Is gear box full of manufacturer's recommended oil?	_______	_______
1.14.2	Have machined surfaces and shafts been coated?	_______	_______
1.14.3	Has a nitrogen purge been applied, when specified?	_______	_______
1.15	**Pumps—General**		
1.15.1	Coupling parts, except elastomers, coated?	_______	_______
1.15.2	Have flange surfaces been inspected and coated?	_______	_______
1.15.3	Have loose components been tagged?		

EQUIPMENT NO.: _______

		Initials	Date
1.16	**Centrifugal Pumps**		
1.16.1	Have all openings been covered?	_______	_______
1.16.2	Have bearing brackets been filled with oil?	_______	_______
1.16.3	Have low alloy pump casings been coated?	_______	_______
1.16.4	Barrier fluid piping filled?	_______	_______
1.17	**Vertical Suspended Pumps**		
1.17.1	Has preservative been applied to shaft journals at sleeve bearing and thrust disc?	_______	_______
1.17.2	Bearing brackets completely filled?	_______	_______
1.17.3	Bowl assembly, barrel flange, discharge head flanges, stuffing box, and machined surfaces coated?	_______	_______
1.17.5	Weatherproof covers installed on all openings?	_______	_______
1.18	**Reciprocating Pumps**		
1.18.1	When recommended by manufacturer, have pistons and rods been removed, coated, tagged, and stored in covered area?	_______	_______
1.18.2	Has rod packing been removed and tagged, when required?	_______	_______
1.18.3	Have suction and discharge valves been removed, coated, and tagged?	_______	_______
1.18.4	Has crankcase been filled with preservative?	_______	_______
1.18.5	Have cylinder and distance piece walls been coated?	_______	_______
1.18.6	Exposed shafts coated?	_______	_______
1.19	**Steam Turbines**		
1.19.1	Have stuffing box, shaft in packing area, and flange gasket surfaces been coated?	_______	_______
1.19.3	Are weatherproof covers on all openings?	_______	_______
1.19.4	Have internals been inspected for cleanliness?	_______	_______
1.19.5	Have loosely shipped components been tagged?	_______	_______
1.19.6	General Purpose Turbines	_______	_______
1.19.6.1	Have carbon rings been removed, tagged, and stored indoors?	_______	_______
1.19.6.2	Have shaft journals been lubricated?	_______	_______
1.19.6.3	Have bearing housings been filled?	_______	_______
1.19.6.4	Have exposed shafts been coated?	_______	_______
1.19.6.5	Has governor been filled with manufacturer's approved fluid?	_______	_______
1.19.7	Special Purpose Turbines	_______	_______
1.19.7.1	Have valve racks, cam, and cam followers been inspected and coated?	_______	_______
1.19.7.2	Have bearing housings, shaft journals, and thrust bearing discs been coated?	_______	_______

EQUIPMENT NO.: _______

1.19.7.3 Have exposed shafts been coated? _______ _______

1.19.7.4 Has the nitrogen purge been applied? _______ _______

1.20 Motors

1.20.1 Have motors been inspected and tagged? _______ _______

1.20.1.a Has an insulation test been made and logged? Have oil levels been checked? _______ _______

1.20.2.3 Has shaft been coated? _______ _______

1.20.2.4 Have seal areas been covered with waxed cloth? _______ _______

1.20.2.5 Have motor baseplate or feet been coated? _______ _______

1.20.2.6 Have nonweatherproof motors been stored indoors? _______ _______

1.20.2.7 Have space heaters been energized? Have warning signs been posted? _______ _______

1.21 Instrumentation

1.21.1 Do instruments comply with specifications, and are they properly tagged? _______ _______

1.21.2 Are loose instruments stored in a dry enclosed area, in original factory packaging? _______ _______

1.21.3 Can premounted instruments be stored outdoors? _______ _______

1.21.4 Are electronic instruments stored in a dry heated room? _______ _______

1.21.5 Are pneumatic instruments stored in a dry area? _______ _______

1.21.6 Are instrument cases and local control panels stored in a dry heated room? _______

1.21.8 Are thermometers, pressure gauges, and gauge glasses protected from physical damage? _______ _______

APPENDIX B—MACHINERY RECEIVING AND INSPECTION CHECKLIST EQUIPMENT NO.: ______

PERIODIC SERVICES BETWEEN TIME RECEIVED AND START-UP (See Note 1)							
ITEM	INTERVAL	DATES/INITIALS					
Visual inspection that coverings and coatings are intact	Monthly						
Inspection of painted surfaces	Monthly						
Inspection of machined surfaces	Monthly						
Inspect desiccant	Monthly						
Motor insulation resistance test	Monthly						
Inspect bearing housing; replace/refill as necessary	2 Months						
Check TAN of preservative oil, if specified	2 Months						
Oil check	2 Weeks						
Rotation of shafts No. of turns _____ (See Note 2)	Weekly						
Compressors—force feed/drip feed lubrication (paragraph 1.11.6)	Weekly						

Note 1: For nitrogen blanketing log, see Appendix C.

Note 2: Number of turns to be filled in at start of project.

APPENDIX C—INERT GAS PURGE MAINTENANCE LOG

Inert Gas Purge Maintenance Log						
Project No.:		Equip. Tag No.:		Report No.:		
Prepared By:		Location:		Date:		
Purge Medium Required:		Purge Pressure Required:		Interval[a]		
Equipment Description:						
DATE	CHECKED BY	CONNECTIONS OK YES/NO	GAUGE PRESSURE	FLOW RATE[b]	INITIAL	REMARKS

(a) Interval D=Daily W=Weekly M=Monthly.
(b) Record flow rate in SLPM (SCFM) when a continuous flow purge is used in lieu of a constant pressure blanket.

Recommended Practices for Machinery Installation and Installation Design

Chapter 4—Foundations

Manufacturing, Distribution and Marketing Department

API RECOMMENDED PRACTICE 686
PIP REIE 686
FIRST EDITION, APRIL 1996

Process Industry Practices

American Petroleum Institute

CONTENTS

Recommended Practices for Machinery Installation and Installation Design

CHAPTER 4—FOUNDATIONS

Section 1—Definitions

1.1 designated machinery representative: The person or organization designated by the ultimate owner of the equipment to speak on the owner's behalf with regard to machinery installation decisions, inspection requirements, and so forth. This representative may be an employee of the owner, a third party inspection company, or an engineering contractor, delegated by the owner.

1.2 engineering designer: The person or organization charged with the project responsibility of supplying installation drawings and procedures for installing machinery in a user facility after machinery has been delivered. In general, but not always, the engineering designer specifies machinery in the user facility.

1.3 equipment user: The organization charged with operation of the rotating equipment. In general, but not always, the equipment user owns and maintains the rotating equipment after the project is complete.

1.4 equipment installer: The person or organization charged with providing engineering services and labor required to install machinery in a user facility after machinery has been delivered. In general, but not always, the installer is the project construction contractor.

1.5 general purpose equipment trains: Those trains that have all general purpose elements in the train. They are usually spared, relatively small in size (power), or are in noncritical service. They are intended for applications where process conditions will not exceed 48 bar gauge (700 pounds per square inch gauge) pressure or 205°C (400°F) temperature (excluding steam turbines), or both, and where speed will not exceed 5000 revolutions per minute (RPM).

Note: General purpose equipment trains have all elements that are either manufacturer's standard or are covered by standards such as the following: ANSI/ASME B.73 horizontal pumps, small API Standard 610 pumps, fans, API Standard 611 steam turbines, API Standard 672 air compressors, API Standard 677 general purpose gears, API Standard 674 reciprocating pumps, API Standard 676 rotary positive displacement pumps, API Standard 680 reciprocating air compressors, and NEMA frame motors.

1.6 special purpose equipment trains: Equipment trains with driven equipment that is usually not spared, is relatively large in size (power), or is in critical service. This category is not limited by operating conditions or speed.

Note: Special purpose equipment trains will be defined by the user. In general, any equipment train such as an API Standard 612 turbine, API Standard 618 reciprocating compressor, API Standard 613 gear, API Standard 617 centrifugal compressor, or equipment with a gas turbine in the train should be considered to be special purpose.

1.7 table top foundation: An elevated three-dimensional reinforced concrete structure that consists of large beams or a thick slab connecting the tops of the supporting columns. The mechanical equipment is supported by the large beams or the slab located at the top of the structure.

Section 2—Machinery Foundation Installation Design

2.1 Scope

2.1.1 Unless otherwise indicated, this practice addresses the general considerations for the installation design of soil-supported reinforced concrete foundations supporting general- and special-purpose machinery.

2.1.2 Any conflicts between this practice, the engineering drawings, the equipment manufacturer's specifications, other specifications referenced in this practice, and the contract documents shall be brought to the attention of the user for resolution.

2.1.3 The following abbreviations are used in this document:

ACI	American Concrete Institute
ANSI	American National Standards Institute
ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials

2.2 General Requirements

2.2.1 This section provides guidelines for the preinstallation design of soil-supported reinforced concrete foundations supporting machinery. The final detail design of the foundation shall be performed under the direction of a qualified engineer considering all possible forces, deflection limitations, vibration responses, geotechnical conditions, and mechanical and environmental requirements.

2.2.2 Unless otherwise specified, all machinery, including vertical in-line pumps, should be supported by a reinforced concrete foundation. Machinery that requires an elevated installation may be supported on structural steel of adequate stiffness and strength.

Note: Elevated machinery may be directly supported by structural steel provided adequate stiffness and strength is provided. The intent of 2.2.2 is to discourage the use of concrete foundations without reinforcing steel and stilt-supported equipment.

2.2.3 The recommended minimum foundation dimensions, the sizes and locations of the anchor bolt holes, and the forces applied by the machinery must be obtained from the equipment vendors to aid in the design of the foundation.

2.2.4 The development of the foundation dimensions shall consider the layout of the equipment, the piping arrangement, concrete cover required for anchor bolts, and the minimum outline dimensions recommended by the equipment vendor.

2.2.5 The elevation of the top of the foundation should be set to allow a minimum thickness of grout of 25 millimeters (1 inch).

Note: The grout manufacturer should be consulted to determine the maximum and minimum thickness of grout for a particular installation. Factors such as flowability and heat generation should be taken into account when the grout thickness is determined.

2.2.6 The bottom of the foundation shall be placed at a sufficient depth below the ground to prevent damage to the machinery or piping by the effects of frost penetration.

2.2.7 The design engineer should also consider incorporating the individual foundations of several machines in the same vicinity into one common foundation mat.

Note: Consideration should be given to incorporating the foundations of several individual machines in the same vicinity into one foundation. A large combined mat foundation may provide a more economical foundation than several closely spaced individual foundations. When multiple machines are placed on a single mat foundation, the designer should consider all possible loading arrangements and combinations of the machines to produce the most unfavorable effects on the supporting foundation, including partial foundation loading due to removal of individual units for maintenance.

2.2.8 The structural design of all reinforced concrete shall be in accordance with ACI 318, *Building Code Requirements for Reinforced Concrete*.

2.2.9 The foundation design shall be capable of resisting all applied dynamic and static loads specified by the machinery manufacturer, loads from thermal movement, dead and live loads as applicable or as specified in the local building codes, wind or seismic forces, and any loads that may be associated with installation or maintenance of the equipment.

2.2.10 For design, the loads specified in 2.2.9 shall be combined to produce the most unfavorable effect on the supporting foundation, but the effects of both wind and seismic activity need not be considered to act simultaneously.

Note: ASCE 7, *Minimum Design Loads for Buildings and Other Structures*, may be used as a guide for determining design loads unless otherwise specified by an applicable local building code, user design criteria, or the manufacturer's specifications. Design load combinations may be as specified in ACI 318.

2.2.11 The foundation shall have adequate strength and rigidity to meet the deflection limitations specified by the machinery manufacturer when subjected to all design load combinations specified in 2.2.10. The foundation shall be free of resonant frequencies within a minimum of 20 percent of the operating speed range of the equipment.

2.2.12 Machinery loads shall be supported directly by the foundation and not by access platforms.

Note: Machinery mounted on the top of the columns and/or major cross beams of a properly designed elevated frame foundation is considered to be in accordance with this provision.

2.2.13 The driven machinery and the driver shall be supported from a common foundation.

Note: The common foundation is to reduce the possibility of differential settlement between the two components.

2.2.14 Foundations for reciprocating compressors greater than 150 kilowatts (200 brake horsepower) and all table-top special purpose equipment shall be dynamically analyzed. If the analysis predicts a resonance, then the mass of the foundation should be increased (if possible) to overtune it.

2.2.15 Compressor trains in the same vicinity should be arranged with the crankshafts parallel to each other and not in line.

2.2.16 Supports for the crankcase distance pieces, cylinder, and pulsation dampers shall be an integral part of the block (supported by a common foundation) foundation.

2.3 Geotechnical

2.3.1 Machinery foundations shall be proportioned for all loading conditions with respect to soil conditions. The foundation shall be designed to support the applied service loading without exceeding the allowable bearing capacity of the soil (refer to 2.3.3) or the allowable limits for settlement to prevent damage to piping system connections, internal machinery alignment, or other connecting auxiliary equipment.

2.3.2 In the absence of known soil parameters, a qualified geotechnical consultant (soil specialist) should establish the soil properties necessary for foundation design.

Note: In the absence of known soil design values, a geotechnical engineer may be employed to provide the field exploration and laboratory testing required to evaluate the soil properties supporting the foundation. The structural engineer should exercise good judgment as to when a geotechnical engineer is needed. Generally, a geotechnical engineer should always be used for soil foundation design for machine foundations over 150 kilowatts (200 horsepower).

2.3.3 The maximum soil pressure due to static and dynamic load combinations should not exceed 75 percent of the allowable soil bearing capacity. When wind or earthquake loading is included in the load conditions, the allowable capacity can be increased by one-third. Uplift of the foundation shall be avoided.

2.3.4 The foundation shall be of adequate size to provide uniform bearing pressure and minimal differential settlement.

Note: To reduce the potential for differential static settlement, the center of the mass of a machine foundation should coincide with the centroid of the soil foundation or pile resistance. The horizontal eccentricity should be limited to 5 percent of the corresponding foundation dimension.

2.4 Rectangular Block Foundations

2.4.1 This section provides guidelines for machinery block foundation design. The final detail dimensions and reinforcing steel requirements are dependent on a structural (static and/or dynamic) analysis or other means to judge that the foundation will perform adequately.

Note: In addition to a static structural analysis, a complete block foundation design may require a dynamic structural analysis including consideration of the soil interaction, unbalanced dynamic forces, limiting displacements, and all possible modes of vibration.

2.4.2 A machinery block foundation supported on soil should have a minimum mass ratio of three times the mass of the machinery for centrifugal machines and five times the mass for reciprocating machines, unless analysis demonstrates that a lesser value will perform adequately. A block foundation subject to vibrations may require a dynamic analysis to ensure that the provisions of 2.2.11 are met.

Note: The minimum mass ratios 3:1 and 5:1 are traditional empirical values for foundation mass to equipment mass that should be used unless a lesser amount can be demonstrated to perform adequately. Although the 3-to-5 mass ratio has been a good rule of thumb, in certain installations a dynamic analysis of the rectangular concrete foundation may be necessary to adequately predict its behavior.

2.4.3 The foundation must be of sufficient width to prevent rocking and adequate depth to permit properly embedded anchor bolts.

Note: The width of the foundation should be at least 1.5 times the vertical distance from the base to the machine centerline, unless analysis demonstrates that a lesser value will perform adequately.

2.4.4 The foundation must be of sufficient width to accommodate the grout between the edge of the mounting plate and the edge of the foundation.

2.4.5 The foundation should provide a minimum factor of safety of 1.5 against overturning and sliding due to all applied forces and couples.

Note: A larger factor of safety may be required depending on the type of soil. The use of passive soil resistance around the perimeter of the foundation to aid in achieving stability must be used with caution. The designer may decide to neglect the contribution of passive resistance to stability if the possibility exists of soil loss due to excavation or erosion around the foundation after it is constructed. The removal of soil around the foundation will result in loss of the passive soil pressure component.

2.4.6 The top of the finished foundation should be elevated a minimum of 100 millimeters (4 inches) above the finished elevation of the floor slab or grade to prevent damage to the machinery from runoff or wash-down water.

2.4.7 Unless permitted by the equipment user, the minimum reinforcing steel in a general purpose block foundation shall be the greater of that required by ACI 318 to resist all forces or for shrinkage and temperature. Reinforcing should be continuous from face to face with proper lap splices.

Note: The required reinforcing steel necessary to resist the internal forces and moments is relatively small in the majority of block foundations because of their massive size. Therefore, the minimum quantity of steel will likely be controlled by the amount of steel necessary to meet temperature and shrinkage requirements. Although ACI 318 does not specifically address the required steel in a block foundation, the requirement of 0.18 percent of the cross-sectional area of the concrete may be used as guidance for the amount of temperature reinforcing steel in a foundation using grade 60 reinforcing. In the event that a foundation size greater than 1.20 meters (48 inches) thick is required for stability, rigidity, or damping, the minimum reinforcing steel may be as suggested in ACI 207.2R, *Effect of Restraint, Volume Change, and Reinforcement on Cracking of Massive Concrete*, with a suggested minimum reinforcement of 22.2-millimeter (#7) bars at 30 centimeters (12 inches) on center.

2.4.8 The maximum reinforcing bar spacing for perimeter reinforcing should not exceed 300 millimeters (12 inches) on center, and the minimum bar size shall not be less than 12.7 millimeters (#4).

2.4.9 Block foundations for reciprocating machines (compressors, and so forth) should have a minimum of 50 percent of the block thickness embedded in the soil, unless otherwise specified by the equipment user.

Note: It is desirable to have at least 50 percent of the total depth of the foundation embedded in the soil to increase the lateral restraint and the damping ratios for all modes of vibration.

Note: A typical rectangular block foundation detail is shown in Appendix A.

2.5 Vertically Suspended Can Pump Foundations

2.5.1 The foundation shall be designed so that the pump can is directly attached to a mounting plate and is removable without damaging the grout.

Note: This requires that the pump be provided with a machined mounting plate that is grouted to the foundation.

2.5.2 The foundation must be designed with inner foundation liners to prevent water from contacting the pump can. The foundation must be watertight. Drain holes or openings in the foundation are not acceptable.

2.5.3 A minimum radial clearance of 50 millimeters (2 inches) between the outside of the pump can and the inner liner surface of the foundation cavity should be maintained.

Note: Pumps in low-temperature service that require insulation will need greater clearance to accommodate finished insulation dimensions and piping that may be external to the pump can.

2.5.4 The foundation shall be designed to allow sufficient axial clearance to the pump can to prevent distortion due to thermal growth. The bottom surface of the cavity should be at least 300 millimeters (1 foot) beneath the bottom of the pump can. (Refer to the typical suspended can pump detail in Appendix B.)

2.6 Elevated Frame Foundations

2.6.1 A dynamic analysis of an elevated frame foundation (table-top foundation) shall be required to demonstrate that the natural frequencies of the foundation do not coincide with and are separated from the operating speed range of the equipment by at least 20 percent. The foundation design for variable-speed equipment will require that the foundation be checked for resonant frequencies through the entire range of operating speeds.

Note: A "table-top foundation" is an elevated three-dimensional reinforced concrete structure that consists of large beams or a thick slab connecting the tops of the supporting columns. The mechanical equipment is supported by the large beams or the slab located at the top of the structure.

2.6.2 Condensers and turbines shall be supported on a common foundation.

2.6.3 The height of an elevated frame foundation should be kept to a minimum. The height should be determined by the minimum number of straight runs of process piping, the required slope of the lube oil drain piping, or other mechanical and maintenance requirements.

2.7 Effects of Equipment on Surrounding Area

2.7.1 The effects of vibrating equipment on the surrounding area should be investigated. Consider the location and degree of isolation required for the foundation with respect to adjacent sensitive equipment, disturbance to people, and the effects to the supporting and/or adjoining structures.

Note: The effects of vibration generated by the equipment on the operation of adjacent equipment or people should be factored into the location of the equipment. In addition to taking measures to isolate the foundation from an adjacent slab or structure in the early stages of the project, it may be possible to locate the equipment to reduce the transmission of vibrations to the surroundings. The actual method of isolating the foundation from adjacent structures is left to the designer. The intent of this provision is to call attention to the need for foundation isolation due to vibration generated by the machinery.

2.7.2 The effects foundation construction may have on adjacent equipment, people, egress requirements, existing foundations supporting adjacent structures, and manufacturing production should be considered in the design stages. All necessary precautions should be taken in the design to protect the safety of personnel directly exposed to the construction or working in the vicinity of construction.

Note: One of the best times to address the effects that construction may have on the existing facility and personnel in the area is during the initial design stages. Proper location of the foundation may reduce the construction difficulties associated with protecting personnel and maintaining existing production.

2.8 Concrete

2.8.1 Foundation materials shall be selected to prevent premature deterioration due to chemical attack or exposure to oil. In an aggressive environment, consider the use of protective coatings, polymer concrete, or additional concrete cover to protect the reinforcing steel.

2.8.2 All concrete shall have a minimum compressive strength of 28 newtons per square millimeter (4000 pounds per square inch) at 28 days, unless otherwise specified by the user.

2.8.3 High early strength concrete shall be used only with the approval of the equipment user.

2.8.4 When foundation thicknesses are greater than 120 centimeters (48 inches) thick, the engineer should consult ACI 207.2R and other ACI mass concrete requirements for concrete mixes and installation.

2.9 Reinforcing Steel

Unless otherwise specified by the equipment user, all reinforcing steel shall conform to the requirements of ASTM A615, *Standard Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement,* grade 60 with a minimum yield strength of 414 newtons per square millimeter (60 kips per square inch).

2.10 Anchor Bolts and Sleeves

2.10.1 Unless otherwise specified by the equipment user, equipment shall be installed on mounting plate(s), and the direct attachment of equipment feet to the foundation using the anchor bolts shall not be permitted. Mounting plates shall be of sufficient strength and rigidity to transfer the applied forces to the foundation.

2.10.2 Mounting plates shall be attached to the foundation with anchor bolts.

2.10.3 Anchor bolts alone or in combination with shear attachments on the equipment mounting plate shall be capable of transmitting the loading applied by the machinery and the design loads specified in 2.2.9 combined to produce the most unfavorable effects. The transfer of forces by means of grout chemical adhesion of the baseplate to the foundation shall not be considered in the design.

Note: The intent of 2.10.2 and 2.10.3 is to neglect the contribution of the grout bond strength for transferring forces from the mounting plate to the foundation. Although this adhesion may exist, a positive means of attachment by anchor bolts and/or shear keys is recommended.

2.10.4 The required embedment of anchor bolts in the foundation shall be determined by accepted engineering practices for cast-in-place anchors or certified vendor information for mechanical or adhesive type anchors. The anchor bolt embedment shall be adequate to resist the torque values specified in the grouting section of this practice or the forces applied by the equipment or required by applicable codes.

Note: The design of anchor bolt embedment may be as suggested in ACI 349, *Code Requirements for Nuclear Safety Related Concrete Structures—Steel Embedments*, Appendix B.

2.10.5 Unless otherwise specified by the equipment user, anchor bolts material should be ASTM A36 or ASTM A575-M1020. In areas exposed to corrosive chemical vapors or liquids, the anchor bolt should be fabricated from a material resistant to chemical attack or provided with a proper chemical-resistant coating such as galvanizing.

Note: The anchor bolt material selected for use, whether it is the material specified in 2.10.5 or another material, should be clearly marked on the structural drawings. This information is not only required for fabrication but may be helpful in future modifications to the foundation. It may be necessary to fabricate the anchor bolts from a material that will be capable of resisting the attack of an aggressive environment. Not only is this necessary to prevent the reduction of the anchor bolt net section, but it will also facilitate the future removal of the equipment for maintenance.

2.10.6 Anchor bolts should be installed using sleeves, unless otherwise specified by the equipment user. The inner diameter of the sleeve should be at least twice the diameter of the anchor bolts. The length of the sleeve shall be the greater of 150 millimeters (6 inches) or sufficient length to permit adequate elongation of the anchor bolt during tightening. The minimum distance from the edge of the anchor bolt sleeve to the edge of the foundation shall be the greater of 150 millimeters (6 inches), four anchor bolt diameters, or the edge distance necessary to transfer the forces in the anchor bolts to the concrete foundation.

Note: Anchor bolt sleeves are required to permit a section of the bolt to be protected from concrete or grout adherence. This section of the bolt is kept free from the concrete and grout to permit the proper elongation of the anchor bolt during the tightening procedure. The use of anchor bolt sleeves is not primarily intended to permit easy bending of the bolt to aid in equipment alignment, but to allow the elongation to take place. (Refer to the anchor bolt details in Appendixes C and D.)

2.10.7 Anchor bolts for machinery should be cast-in-place or adhesive stud bolt with nut(s) and washer, unless otherwise specified by the equipment user. The washer should conform to ANSI B18.22.1 and nut(s) should be full size, heavy hex conforming to ANSI B18.2.2.

2.10.8 Anchor bolts should project a minimum of 2 threads above the fully engaged nut(s).

2.11 Drawing Information

2.11.1 In addition to the structural information necessary to construct the foundation, the drawings must clearly indicate the elevation of the top of the finished (poured) foundation and the bottom of the soleplate, the locations of the anchor bolts and sleeves, the anchor bolt diameter, the depth of embedment into the foundation of the anchor bolts, the length of the anchor bolts threads, and the length of the anchor bolt projections.

Note: The above information should be clearly marked on the drawing in order for it to be readily identified during the final checks before concrete placement. Refer to the typical foundation detail in Appendix A to clarify the location of the finished foundation level.

2.11.2 The required 28-day minimum compressive strength of the concrete foundation and the yield strength of the reinforcing steel shall be clearly specified on the structural drawings.

Note: Not only is this information necessary for construction of the foundation, it may be necessary in the future to identify the material properties for possible modifications or investigations of the foundation. Placing this information on the drawings will permit its permanent retention with the foundation structural details.

2.11.3 The anchor bolt material shall be specified on the structural drawing.

2.11.4 The required soil bearing capacity shall be specified on the structural drawings.

Section 3—Machinery Foundation Installation

3.1 Scope

3.1.1 Unless otherwise indicated, this practice addresses the general considerations for the installation of soil-supported reinforced concrete foundations supporting general- and special-purpose machinery.

3.1.2 Any conflicts between this practice, the engineering drawings, the equipment manufacturer's specifications, other specifications referenced in this practice, and the contract documents shall be brought to the attention of the equipment user for resolution.

3.1.3 The following abbreviations are used in this section:

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
OSHA	Occupational Safety and Health Administration
PIP	Process Industry Practices

3.2 General Requirements

3.2.1 This section provides guidelines for the construction of reinforced concrete foundations. Proper concrete preplacement and placement procedures are essential to the successful installation of machinery foundations.

3.2.2 Construction of the foundation shall be performed in a safe manner and shall be subject to all OSHA safety requirements.

3.2.3 Excavations for the foundation shall be made safe to prevent any danger to personnel or existing structures.

3.2.4 The owner shall be advised if construction of the foundation will block an existing means of emergency egress for personnel and/or safety equipment.

3.3 Soil Conditions

3.3.1 Foundations designed to be directly supported on soil shall be constructed on undisturbed soil or fill material properly compacted in accordance with sound engineering practices and the project specifications.

Note: The statement "sound engineering practices" requires that the fill be constructed from suitable fill material that has been properly installed and compacted under the guidance of a qualified soil engineer.

3.3.2 Unless otherwise specified, the contractor shall require a qualified soil specialist to inspect the soil supporting the foundation and determine its adequacy to provide the required bearing capacity. The contractor shall provide the equipment user with written documentation by the qualified soil specialist certifying the soil supporting the foundation has the minimum specified bearing capacity.

Note: This will require the soil beneath the foundation to be examined by a qualified soil specialist or geotechnical engineer suitable to the equipment user before proceeding with the construction of formwork or placement of concrete. It may also require that a test be performed to verify the safe bearing capacity of the soil.

3.3.3 Unless otherwise specified, prior to the start of construction, the contractor shall submit to the equipment user for acceptance and review the qualifications of the person responsible for performing the soil inspection specified in 3.3.2.

3.4 Formwork

3.4.1 All formwork and form accessories shall be in accordance with ACI 301 and PIP STS03001.

Note: ACI 301, *Specifications for Structural Concrete for Buildings*, and PIP STS03001, *Plain and Reinforced Concrete*.

3.4.2 Unless otherwise indicated on the contract drawings, provide minimum 19-millimeter (3/4-inch) chamfer strips at all corners on permanently exposed surfaces or on edges of formed joints.

3.4.3 Unless otherwise specified by the equipment user, removal of formwork shall be in accordance with ACI 301 and PIP STS03001.

3.5 Reinforcing Steel

3.5.1 Reinforcing steel materials, fabrication, and placement shall be in accordance with ACI 301 and PIP STS03001.

3.5.2 Unless otherwise noted on the structural drawing, all reinforcing steel shall conform to the requirements of ASTM A615, *Standard Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement*, grade 60, with a minimum yield strength of 414 newtons per square millimeter (60 kips per square inch).

3.6 Anchor Bolts and Sleeves

Anchor bolts and sleeves shall be located to the specified tolerances in all three planes and securely supported to prevent misalignment during the concrete placement operation. The anchor bolts shall not be reduced in diameter nor offset to facilitate alignment with the mounting plate. Modification of the mounting plate to facilitate alignment is not permitted unless authorized by the designated machinery representative.

Note: The use of a template to aid in the placement of anchor bolts is recommended. The template will assist in accurately placing the anchor bolts.

3.7 Field Verification Prior to Concrete Placement

3.7.1 Immediately prior to concrete placement, the anchor bolt locations, projections, and diameters shall be field verified to match the anchor bolt hole location in the mounting plate. In the event that the baseplate is not at the site, the anchor bolts' location shall be verified against the structural foundation drawings and the manufacturer's drawings. The anchor bolts shall also be examined to verify that they have been installed plumb, have the correct length and projection, are adequately secured to prevent displacement during the concrete placement, and the threads are not stripped or damaged. All necessary procedures shall be taken to correct any discrepancies or deficiencies before concrete operations shall be permitted to begin.

3.7.2 All anchor bolt sleeves shall be covered or filled with a nonbonding moldable material to prevent entry of concrete.

3.7.3 Prior to concrete placement, the proposed elevation of the top of the foundation concrete shall be verified with the elevation specified on the foundation drawing, and the necessary procedures shall be taken to correct any discrepancies.

3.8 Concrete Mixing and Placement Procedures

3.8.1 Concrete materials, formwork, handling, mixing, and placement shall conform to ACI 301 and PIP STS03001.

3.8.2 Materials, mixing, handling, and placement of mass concrete shall be in accordance with ACI 301 and PIP STS03001. Adequate control of the concrete temperature shall be maintained at the pour point.

3.8.3 Unless otherwise specified on the drawings, at the point of delivery, concrete shall have maximum slump of

100 millimeters (4 inches) when achieved by water alone. If a slump greater than 100 millimeters (4 inches) is required for proper placement of concrete, it may be increased up to 200 millimeters (8 inches) using a high-range water-reducing agent.

3.8.4 The field addition of water to increase the slump shall not be permitted without approval of the equipment user.

3.8.5 Foundations shall be made in one continuous pour unless otherwise approved by the equipment user or shown on the drawings.

3.8.6 Immediately after placement, concrete shall be protected from cold or hot weather extremes, mechanical injury, and premature drying and shall be cured as specified in ACI 301 and PIP STS03001.

Note: ACI 301, *Specifications for Structural Concrete for Buildings*, requires that normal concrete be cured (preservation of moisture) for 7 days after placement.

3.8.7 Unless otherwise approved by the equipment user, the foundation preparation procedures for grouting specified in the grouting section of this specification or the setting of any equipment on the foundation shall not be permitted to begin until concrete curing in accordance with ACI 301 and PIP STS03001 has been completed, and the concrete has attained the specified 28-day compressive design strength as defined in ACI 301.

Note: The ability of concrete to reach the specified strength is a function of temperature and moisture retention. Normal concrete, when properly cured, will attain the specified design strength approximately 28 days after placement. The concrete shall be presumed to have reached the specified compressive design strength when the requirements of ACI 301 for removal of formwork have been met. If approved by the equipment user, the use of high early strength concrete may be used to reduce the duration time required to reach the desired strength in situations where cure time is on the critical path. Refer to ACI 301 and ACI 308 for additional information on curing concrete.

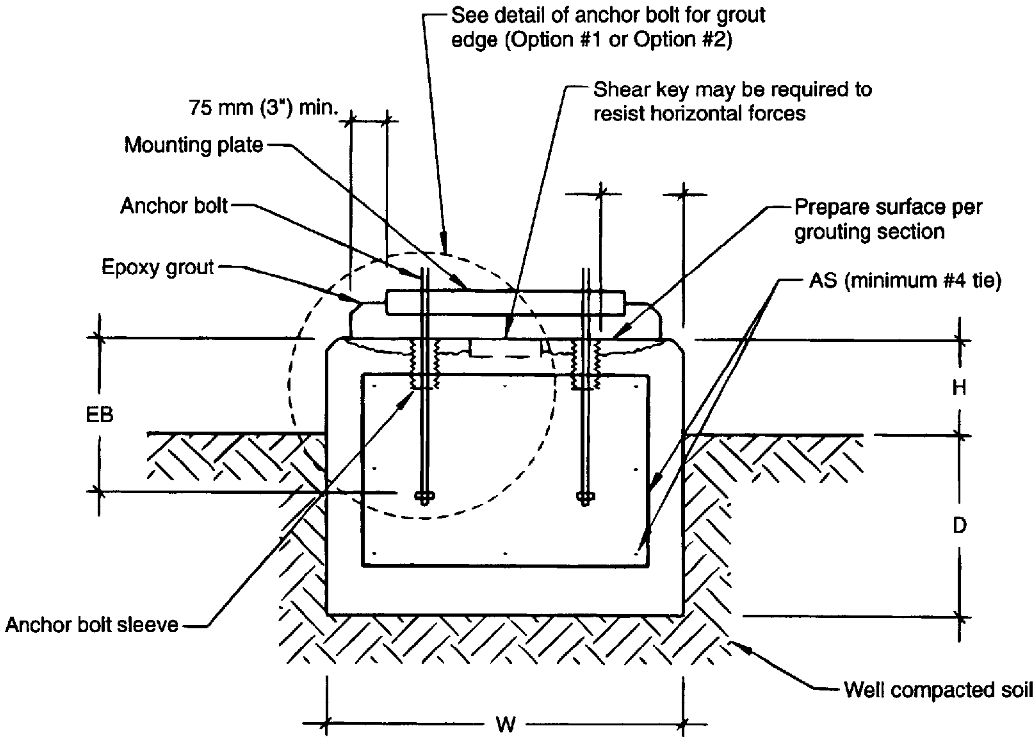
3.8.8 All concrete shall have a minimum compressive strength of 28 newtons per square millimeter (4000 pounds per square inch) at 28 days, unless otherwise specified on the drawings.

3.8.9 High early strength concrete shall be used only with the approval of the equipment user.

3.9 Concrete Quality Control

The equipment user or the designated machinery representative reserves the right to subject the concrete foundation construction to inspection by an ACI-certified inspector or any owner-designated testing agency. Tests of concrete compressive strength, air content, and slump shall be as designated by the equipment user, designated machinery representative, or in accordance with PIP STS03001 and ACI 301.

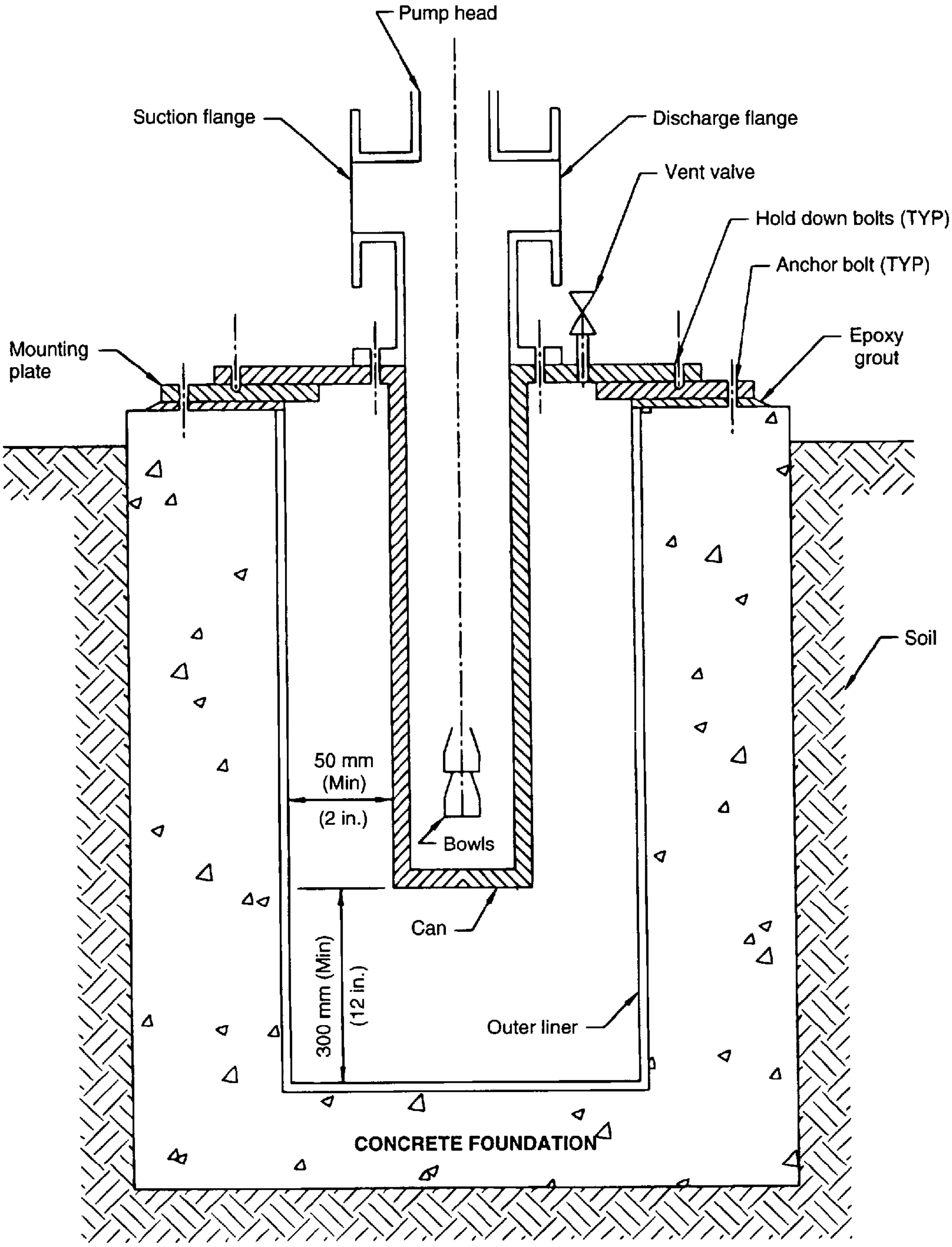
APPENDIX A—TYPICAL FOUNDATION AND ANCHOR BOLT DETAILS



Section Through Foundation

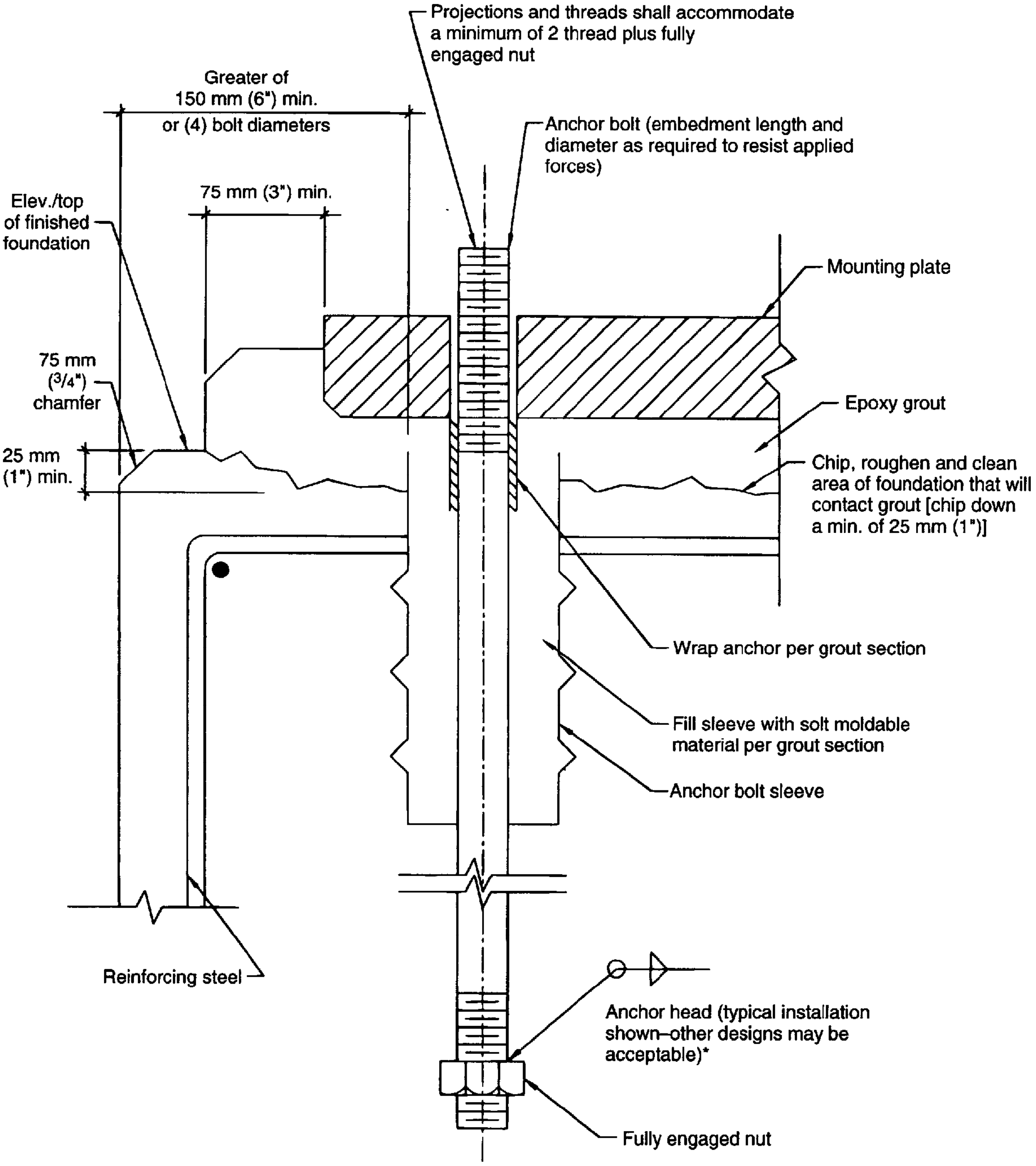
W	Width	Refer to foundation design section of specification
EB	Anchor Embedment	Shall be as required to resist anchor bolt forces
D	Depth Below Grade	Shall be adequate to prevent frost heave
H	Depth Above Grade	Shall be adequate to prevent damage to equipment from water due to runoff (100 mm (4") minimum)
AS	Area of Reinforcing	Refer to the minimum area of steel requirements of the reinforcing section of foundation design
ED	Anchor Bolt Sleeve Edge Distance	Shall be adequate to develop required force on anchor bolt, a minimum of 150 mm (6") or (4) bolt diameters (whichever is greater), or as recommended by anchor bolt manufacturer.

Figure A-1—Typical Rectangular Block Foundation Detail



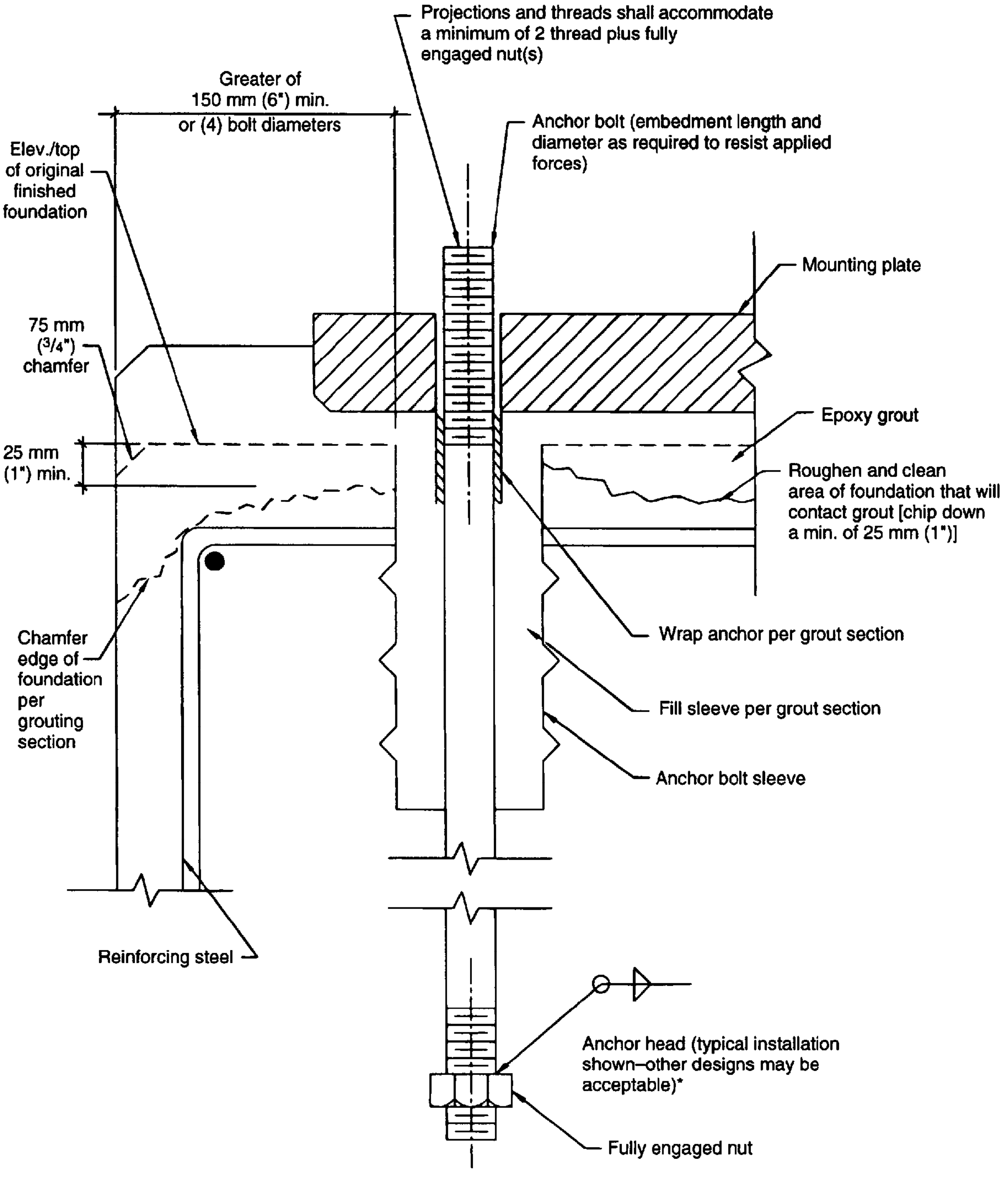
Note: Can = Pressure Retaining Casing

Figure A-2—Typical Vertically Suspended Can Pump Foundation



Note: ACI 349 may be a possible design reference for anchor head.

Figure A-3—Typical Anchor Bolt Detail—
Option 1, Grout Pour Not to Edge of Foundation



Note: ACI 349 may be a possible design reference for anchor head.

Figure A-4—Typical Anchor Bolt Detail—
Option 2, Grout Pour to Edge of Foundation

Recommended Practices for Machinery Installation and Installation Design

Chapter 5—Mounting Plate Grouting

Manufacturing, Distribution and Marketing Department

API RECOMMENDED PRACTICE 686
PIP REIE 686
FIRST EDITION, APRIL 1996

Process Industry Practices

American Petroleum Institute

CONTENTS

Recommended Practices for Machinery Installation and Installation Design

CHAPTER 5—MOUNTING PLATE GROUTING

Section 1—Definitions

1.1 cementatious: A type of grout material that is portland cement based.

1.2 designated machinery representative: The person or organization designated by the ultimate owner of the equipment to speak on the owner's behalf with regard to machinery installation decisions, inspection requirements, and so forth. This representative may be an employee of the owner, a third party inspection company, or an engineering contractor delegated by the owner.

1.3 engineering designer: The person or organization charged with the project responsibility of supplying installation drawings and procedures for installing machinery in a user facility after machinery has been delivered. In general, but not always, the engineering designer specifies machinery in the user facility.

1.4 epoxy: A type of grout material that consists of a resin base that is mixed with a curing agent (hardener) and usually an aggregate filler.

1.5 equipment installer: The person or organization charged with providing engineering services and labor required to install machinery in a user facility after machinery has been delivered. In general, but not always, the installer is the project construction contractor.

1.6 equipment user: The organization charged with operating the rotating equipment. In general, but not always, the equipment user owns and maintains the rotating equipment after the project is complete.

1.7 general-purpose equipment trains: Those trains that have all general-purpose elements in the train. They are usually spared, relatively small in size (power), or are in noncritical service. They are intended for applications where process conditions will not exceed 48 bar gauge (700 pounds per square inch gauge) pressure or 205°C (400°F) temperature (excluding steam turbines), or both, and where speed will not exceed 5000 revolutions per minute (RPM).

Note: General purpose equipment trains have all elements that are either manufacturer's standard or are covered by standards such as the following: ANSI/ASME B.73 horizontal pumps, small API Standard 610 pumps, fans, API Standard 611 steam turbines, API Standard 672 air compressors, API Standard 677 general purpose gears, API Standard 674 reciprocating pumps, API Standard 676 rotary positive displacement pumps, API Standard 680 reciprocating air compressors, and NEMA frame motors.

1.8 grout: An epoxy or cementatious material used to provide a uniform foundation support and load transfer link for the installation of rotating machinery. This material is typically placed between a piece of the equipment's concrete foundation and its mounting plate.

1.9 grout pin: A metallic pin or dowel used to tie an epoxy grout pour to its concrete foundation to prevent delamination (or edge lifting) due to differential thermal expansion between the grout and the concrete.

1.10 head box: A device used to funnel grout into a baseplate grout fill-hole so as to provide a static head to aid in filling all baseplate cavities with grout.

1.11 mounting plate: A device used to attach equipment to concrete foundations; includes both baseplates and soleplates.

1.12 peg test: A test performed on an optical leveling instrument to ensure that it is properly adjusted and its line of sight is coincident to true earth level.

1.13 special-purpose equipment trains: Equipment trains with driven equipment that is usually not spared, is relatively large in size (power), or is in critical service. This category is not limited by operating conditions or speed.

Note: Special purpose equipment trains will be defined by the user. In general, any equipment train such as an API Standard 612 turbine, API Standard 618 reciprocating compressor, API Standard 613 gear, API Standard 617 centrifugal compressor, or equipment with a gas turbine in the train should be considered to be special purpose.

Section 2—Machinery Grouting Installation Design

2.1 Scope

Grout is a material used to fill the void between a piece of equipment's baseplate or soleplate and the mating foundation. This filler material provides uniform support and a load-transfer link between the equipment and its foundation. Thus the equipment, the foundation, and eventually the earth effectively become one system.

System is the key word. A poorly designed foundation or baseplate, or improper installation techniques, can result in chronic rotating equipment problems. These problems include high vibration, rotating assembly "rubs," poor seal life, and mechanical failures. Therefore, a machinery installation must be thought of as a system, not as a conglomeration of pieces designed independently within their own guidelines.

This section defines the minimum recommended procedures, practices, and design requirements of grouted equipment mounting plates (soleplates and baseplates). In general, the instructions supplied by the grout manufacturer should be carefully followed. Any questions regarding mounting plate grouting design are to be referred to the owner's designated representative before proceeding.

2.2 General/Special Purpose Equipment

This section is intended to address those grouting design requirements associated with all machinery. Additional special-purpose machinery requirements are covered in the appendixes at the end of this chapter.

2.3 Drawing and Data Requirements

The designer shall produce detailed design drawings of the grout layout for special-purpose machinery. Grout layout drawings shall be completed during engineering design and shall be submitted to the purchaser for review. These drawings shall be included in the design package for the machinery foundation.

Grouting design drawings (or typical data sheets) shall provide all necessary information for the installation of equipment on mounting plates. This information shall include, but not be limited to, the following:

a. Expansion joint location.
b. Elevation to top of mounting plate.
c. Elevation to top of grout.
d. Grout materials and estimated quantities.
e. Grout pocket location (if any).
f. Grout forming details (that deviate from Appendix F) and head-box elevation.
g. Baseplate grouting and vent holes.
h. Anchor bolt location and projection.
i. Grout pin locations and quantity (if used).
j. Shimming and leveling screw requirements.

2.4 Selection of Grout

Unless otherwise specified, all machinery shall be grouted using epoxy grouts.

Note 1: Epoxies typically have over three times the compressive strength of cementatious grouts and tend to have a longer useful service life. Epoxy grouts are also available that are resistant to chemical attack.

Note 2: Cementatious grouts are suitable as "filler" materials in less demanding applications where vibration, dynamic loading, and temperature extremes are not a concern. This type of grout is typically used as a "filler" inside structural steel baseplates to increase damping and reduce vibration transmission or for use on "static" equipment where vibration is not a concern. Cementatious grouts are also typically not resistant to acid and chemical attack.

2.4.1 The use of rapid-flow grouts shall be limited to applications where the depth of the grout pour is less than 19 millimeters (3/4 inch). The reduction of aggregate quantity in grout mixtures to improve flow properties is not permitted. Rapid-flow epoxy grouts shall not be used unless specifically approved by the user.

Note: Typically, rapid-flow grouts are only used for grout pours of less than 40 millimeters (1 1/2 inches).

2.4.2 A layered combination of nonshrink cement and epoxy grout may be used for machinery with large baseplates that have structural webs deeper than 9 inches as follows:

a. The first layer for this type of installation shall be general purpose epoxy grout poured to a level that is 25 millimeters (1 inch) above the bottom of the internal baseplate stiffeners.
b. The second layer shall be a nonshrink cementatious grout poured to a level that is approximately 50 millimeters (2 inches) from the top of the baseplate decking.
c. The top layer shall be a general purpose epoxy grout and shall be poured to the top of the baseplate.

Note that the next layer for this type of installation shall not be poured until the previous layer is properly cured.

2.5 Expansion Joints

2.5.1 Expansion joints shall be incorporated into large epoxy grout pours to reduce the possibility of cracking, especially when machinery-to-grout temperature differentials of 30°C (50°F) are encountered. Expansion joints should be placed at approximately 1.4- to 2.8-meter (4- to 6-foot) intervals in the grout foundation.

2.5.2 Expansion joints should be made from 12- to 25-millimeter (1/2- to 1-inch) thick closed-cell neoprene foam rubber. Polystyrene may also be used. Ensure that the expansion joint material is compatible with the grout.

2.5.3 Expansion joints require sealing after the grout has cured with elastic epoxy seam sealant (liquid rubber) or silicone rubber (room temperature vulcanizable).

2.6 Mounting Plate Design

Note: The purpose of this section is to provide the foundation designer with mounting plate design criteria necessary for proper installation.

2.6.1 Unless otherwise specified, all equipment shall be installed on mounting plates.

2.6.2 All soleplate outside corners shall have a minimum 50-millimeter (2-inch) radius (in the plan view) to prevent cracking of the foundation grout due to stress concentration at the corners. All baseplates shall have radiused corners appropriate to the baseplate design.

2.6.3 All mounting plate anchor bolt holes should have a minimum 3-millimeter (1/8-inch) annular clearance with the anchor bolt to allow for field alignment of mounting plates.

2.6.4 Mounting plates should extend at least 25 millimeters (1 inch) beyond the outer three sides of equipment feet.

2.6.5 Mounting plates should be provided with vertical leveling screws, as opposed to shims or wedges. Shims and wedges should not be used.

Note: Shims and wedges, if left in place after grouting, may cause "hard" spots that interfere with the grout's ability to provide uniform base support. They may also allow moisture penetration and the resultant corrosion and grout spalling.

2.6.6 Elevation adjustment nuts are not permitted under the mounting plate that will be grouted in and become a permanent part of the foundation. This allows the mounting plate to be supported by the grout, not by the leveling devices.

2.6.7 Mounting plate leveling jackscrews should be provided with leveling pads as shown in Appendix G.

2.6.8 Typical mounting plate jackbolt arrangements for leveling are shown in Appendixes E and F.

2.6.9 The bottom of baseplates between structural members should be open. When the baseplate is to be grouted, it should be provided with at least one grout hole having a clear area of at least 0.01 square meters (20 square inches) and no dimension less than 10 centimeters (4 inches) in each bulkhead section. These holes should be located to permit grouting under all load-carrying structural members. Where practical, the holes should be accessible for grouting with the equipment installed and should have 12-millimeter (1/2-inch) raised-lip edges. Vent holes of at least 12 millimeters (1/2 inch) in size should be provided at the highest point of and in each bulkhead section of the baseplate. These measures allow for controlled grout placement and verification that each section is filled with grout.

Note: In general, vent holes of approximately 12 millimeters (1/2 inch) in diameter on 46-centimeter (18-inch) centers should be provided.

2.6.10 When specified, grouting pins of #6 reinforcing bar shall be provided around the perimeter of the mounting plate on 3-centimeter (6-inch) centers to prevent delamination between the concrete foundation and the epoxy grout. Grouting pins should be set in epoxy with a 10-centimeter (4-inch) minimum imbedment depth before installation of grout on foundation.

2.7 Grout Design for Auxiliary Equipment

When specified, consoles and other auxiliary equipment skids shall be installed with composite grout pours as specified in 2.4.2.

Section 3—Machinery Grouting Installation

3.1 Scope

Pouring epoxy or cementatious grout under machinery is only a small part of a grout job. Much preparation is required before the grout is actually poured. These pregrout preparations can make the difference between a grout job lasting for the life of the machinery, or only a few months or years.

This section defines the minimum recommended procedures, practices, and inspections for the installation of grouted equipment mounting plates (soleplates and baseplates). The purpose of these instructions is to provide guidelines for the installation of grouted mounting plates. In general, the instructions supplied by the grout manufacturer should be carefully followed. Any questions regarding mounting plate installation and grouting are to be referred to the owner's designated representative before proceeding.

3.2 General/Special Purpose Equipment

This section is intended to address those grouting construction procedures associated with all machinery. Additional special-purpose machinery requirements are covered in the appendixes at the end of this chapter.

3.3 Grouting Precautions

During the mixing, handling, and installation of grout materials, the following minimum practices must be employed:

a. All grout Material Safety Data Sheets (MSDSs) shall be available and associated hazards reviewed with all grouting personnel.
b. Goggles or face shields and aprons should be worn by those personnel mixing and pouring the grout.
c. Protective gloves should be worn by all personnel involved in the grouting operation.
d. Dust masks or respirators (in accordance with MSDS requirements) should be worn by those personnel exposed to the aggregate prior to mixing.
e. Soap and water should be available for periodic hand cleaning, should the need arise.
f. Some epoxy grouts exhibit a very strong exothermic reaction and the possibility of thermal burns exists. Caution must be exercised in this regard.

3.4 Foundation Curing

Check foundation curing time before proceeding with preparation for grouting. The foundation shall be cured for at least seven days per ACI 301 prior to grout preparation. Epoxy grout shall never be poured on "green" or uncured concrete. Concrete must also be exposed to a drying-out period to ensure that the capillaries are free of moisture and will provide proper grout bonding.

3.5 Anchor Bolt Preparation

3.5.1 Ensure that templates, if purchased, have been used for anchor bolt locations.

3.5.2 Verify that anchor bolt sleeves are clean and dry and have been filled with a nonbonding moldable material. This material will prevent water accumulation in the anchor bolt sleeves and is pliable enough to allow for small anchor bolt movement, if needed.

Note: Anchor bolt sleeves are not intended to provide sufficient movement to allow for gross misalignment of anchor bolts to their mounting plate holes. Lateral movement for alignment purposes should not exceed 6.5 millimeter (1/4 inch).

3.5.3 The anchor bolt threads should be covered with duct tape or other suitable means to keep them clean and to prevent any damage that might occur during the chipping and grouting operation.

3.5.4 All anchor bolt locations, projections, and diameters shall be field verified to match the anchor bolt hole pattern in the mounting plate prior to grouting.

3.6 Foundation Preparation

3.6.1 A weather-protective cover may be necessary during inclement weather conditions. Wind, sun, rain, and ambient temperatures have a definite effect on the quality of a grouting installation. During hot weather, the foundation and equipment should be covered with a shelter to keep the uncured grout from being exposed to direct sunlight as well as dew, mist, or rain. In cold weather, a suitable covering to allow the foundation to be completely enclosed shall be constructed. A convective heating source should be provided so as to raise the entire foundation and equipment temperature to above 18°C (65°F) for at least 48 hours prior to and after grouting.

3.6.2 In the areas that will be covered by grout, the foundation shall be prepared by chipping away all laitance (poor quality concrete) and oil-soaked or damaged concrete down to exposed fractured coarse aggregate. A minimum of 25 millimeters (1 inch) of concrete must be removed in this chipping process down to a depth to permit 25 to 50 millimeters (1 to 2 inches) (minimum) of clearance between the concrete and the bottom of the soleplate. Scarifying the surface with a needle gun or bushing tool or sandblasting to remove laitance from the foundation is unacceptable. Concrete chipping and removal must not be performed with heavy tools, such as jackhammers, as they could damage the structural integrity of the foundation. A chipping hammer with a chisel bit is the preferred tool for this purpose.

3.6.3 Where practical, epoxy grout vertical thickness at the edge of the foundation should be equal to or greater than the distance from the foundation edge to the baseplate periphery. For machinery foundations where the grout extends to the edge of the concrete, the corners of the concrete shall be chipped to form a 50-millimeter (2-inch) minimum 45-degree chamfer. Grout forms shall be placed so as to allow proper filling of the chamfer area.

Note: The purpose of the concrete foundation chamfer is to provide a shear plane at the grout-to-concrete interface to prevent delamination.

3.6.4 The foundation must be kept free of contamination by oil, dirt, water, and so forth, after it has been prepared for grouting. Protective sheeting (such as sheets of clean polyethylene) shall be used to cover the prepared surfaces when work is not in progress.

3.6.5 When the surface chipping is complete, the foundation shall be thoroughly broomed and air-blown free of all dust with clean, dry, oil-free air.

3.7 Grout Forms

3.7.1 All grout forms shall be built of materials of adequate strength and securely anchored and sealed to withstand the liquid head and forces developed by the grout during placement.

3.7.2 Grout forms shall be attached to the foundation or pavement with drilled anchors. Power nailing is not permitted.

3.7.3 The inside surfaces of all grout forms shall have three coats of paste wax applied to prevent grout adherence. Oil or liquid wax is not permitted.

3.7.4 Grout forms shall be properly sealed to prevent grout leakage. Grout leaks will *not* self-seal. Bitumastic or room temperature vulcanizable (RTV) silicone rubber can be used for this purpose.

3.7.5 Grout forms shall have 25-millimeter (1-inch), 45-degree chamfer strips at all vertical corners and at the horizontal surface of the grout.

Note: All chamfer edges required in the grout should be incorporated into the forms because epoxy grout cannot be easily cut or trimmed after hardening.

3.8 Mounting Plate Design Verification

3.8.1 Unless direct grouting has been specified, check to ensure that all equipment is to be installed on mounting plates and that no part of the equipment is to be direct grouted.

3.8.2 Check to ensure that all mounting plate outside corners have a minimum 50-millimeter (2-inch) radius to prevent cracking of the foundation grout due to stress concentration at the corners. All sharp edges are to be broken.

3.8.3 Check to ensure that all mounting plate anchor bolt holes have a minimum 3-millimeter (1/8-inch) annular clearance to allow for field alignment of mounting plates.

3.8.4 Check to ensure that all pump and other small base plates have been provided with vertical leveling screws, as opposed to shims or wedges. Shims and wedges are not to be used.

Note: Shims and wedges, if left in place after grouting, may cause "hard" spots that interfere with the grout's ability to provide uniform base support. They may also allow moisture penetration and the resultant corrosion and grout spalling.

3.8.5 Check to ensure that baseplates have been provided with one 10-centimeter (4-inch) (minimum) grout filling hole in the center of each bulkhead section with one 12-millimeter (1/2-inch) vent hole near each corner of the section. This allows for controlled grout placement and verification that each section is filled with grout.

3.8.6 Check to ensure that mounting plates have sufficient grout holes and air vents in each compartment to allow for proper grouting.

Note: In general, vent holes of approximately 12 millimeters (1/2 inch) in diameter on 45-centimeter (18-inch) centers should be provided.

3.8.7 Check to ensure that elevation adjustment nuts under the baseplate that will be grouted in and become a permanent part of the foundation have not been supplied. This allows the baseplate to be supported by the grout, not by the leveling devices.

3.8.8 Check to ensure that baseplate leveling jackscrews have been provided with stainless steel leveling pads.

3.8.9 Check to ensure that all baseplate welds are continuous and free of cracks.

3.8.10 Check to ensure that all grout pour and vent holes are accessible.

3.9 Preparation of Mounting Plates

3.9.1 MOUNTING PLATE PREPARATION

3.9.1.1 Oil, grease, and dirt shall be cleaned from all grout surfaces of mounting plates. These can be removed with a solvent wipe-down. The mounting plate grout surfaces should have been prepared and ready for installation by the machinery manufacturer; if not, then they must be prepared as follows: Mounting plates shall be blasted to "near white metal" to remove any rust or scale. Care must be taken to avoid any damage to mounting plate machined top surfaces. Final cleaning should be done with an owner-approved solvent. Mineral spirits cannot be used for this purpose due to the oily residue. All "mounting plate" grout surfaces are then to be immediately coated with a "grout compatible" coating in preparation for grout placement.

Note 1: Epoxy primers have a limited life after application. The grout manufacturer should be consulted to ensure proper field preparation of the mounting plates for satisfactory bonding of the grout.

Note 2: For baseplates with interlocking structural members, sandblasting of the bottom of the base is usually not required. Such baseplates rely on the interlock of structural shapes into the grout, as opposed to the bond between the grout and the coating.

3.9.1.2 Mounting plate jackscrews shall be liberally coated with paste wax or grease to prevent grout adherence. Liquid waxes and oil are not permitted. Care must be taken to prevent wax from contacting the concrete foundation or metal surfaces that will be in contact with the grout.

3.9.1.3 All miscellaneous mounting plate holes (such as coupling guard holes) are to be plugged to prevent the entrance of grout. All plugs are to be coated with paste wax to prevent grout adherence.

3.9.1.4 Ensure that all equipment is isolated and in a strain-free condition with all piping, conduit, and so forth, disconnected.

3.9.2 EXPANSION JOINTS

3.9.2.1 Expansion joints shall be made from 25-millimeter (1-inch) thick closed-cell neoprene foam rubber (polystyrene may also be used) and shall be placed on 1.4- to 2.8-meter (4- to 6-foot) intervals in line with the anchor bolts and perpendicular with the centerline of the baseplate.

3.9.2.2 Expansion joints shall be "glued" into position prior to the grout pour with silicone rubber (RTV) or elastic epoxy seam sealant (liquid rubber).

3.9.3 SOLEPLATE INSTALLATION AND LEVELING

3.9.3.1 All soleplate elevations are to be set in accordance with the construction drawings. On multiple soleplate installations, one of the soleplates is chosen as the "reference" soleplate with regard to elevation. This "reference" soleplate is usually the one under the equipment requiring "process" connections.

3.9.3.2 As a minimum, soleplate level shall be set with a master level or a precision machinist's level. Levels should always be checked before beginning the plate leveling process by checking level repeatability when reversing 180 degrees.

3.9.3.3 All other soleplates are then installed and leveled with respect to the reference plate. Individual soleplate elevations are to be set to a tolerance of ±0.06 millimeters (±0.0025 inches) with respect to the reference plate.

3.9.3.4 Soleplate level is to be set longitudinally and transversely to within 40 micrometers per meter (0.0005 inches per foot) with no more than 13 micrometers (0.005 inches) elevation difference between any two points taken on an individual soleplate. In addition, each pair of soleplates (where more than one soleplate is used under an individual piece of equipment) shall be at the same elevation to within 13 micrometers (0.005 inches).

3.9.3.5 Soleplate level can be achieved by adjusting the jacking screws, shimming subsoleplates, or dual wedges with adjusting screws and then snugging the anchor bolt nut to hold the soleplate in place. Elevation adjustment nuts are not permitted under the baseplate that will be grouted in and become a permanent part of the foundation. This allows the baseplate to be supported by the grout, not by the leveling devices.

3.9.3.6 Final elevation and level of all soleplates should be set with a precision tilting level and precision scale. To balance the length of sighting distance, the tilting level is to be set near the foundation within a 6-meter (20-foot) radius of all soleplates. A peg test of the instrument prior to the start of the leveling is essential.

3.9.3.7 All shims used in subsoleplates shall be AISI Standard type 300 stainless steel.

3.9.3.8 For equipment installations where the equipment is bolted to the soleplates prior to grouting, an initial alignment check in accordance with the alignment section of this document shall be performed to verify that coupling spacing and final alignment can be achieved without modifying the hold-down bolts or the machine feet.

3.9.3.9 All level readings are to be measured and recorded on data sheets. Typical data sheets for this purpose are shown in Appendixes B-1 through B-3.

3.9.4 BASEPLATE INSTALLATION AND LEVELING (API 610 AND ASME PUMPS, AND GENERAL-PURPOSE EQUIPMENT)

3.9.4.1 All baseplate elevations shall be set in accordance with the construction drawings.

3.9.4.2 Prior to grouting, an initial alignment check in accordance with the alignment section of this document shall be performed to verify that coupling spacing and final alignment can be achieved without modifying the hold-down bolts or the machine feet.

3.9.4.3 As a minimum, baseplate level shall be set with a master level or a precision machinist's level. Levels should always be checked before beginning the plate leveling process by checking level repeatability when reversing 180 degrees. All baseplate level measurements shall be taken on the equipment mounting surfaces.

3.9.4.4 The equipment baseplate mounting surfaces are to be leveled longitudinally and transversely to within 200 micrometers per meter (0.002 inches per foot) for API 610 pumps and to within 400 micrometers per meter (0.005 inches per foot) for general purpose equipment and ASME pumps.

3.9.4.5 Baseplate level is achieved by adjusting the jacking screws and then snugging the anchor bolt nut to hold the baseplate in place.

3.9.4.6 All level readings are to be measured and recorded on Data Sheets. Typical Data Sheets for this purpose are shown in Appendix B at the end of this section.

3.10 Reciprocating Compressors

3.10.1 For direct-grouted reciprocating compressors and for those installations where the soleplate is bolted to the bottom of the crankcase prior to grouting, alignment must be verified and recorded before pouring any grout. Of particular importance are the following alignment readings:

a. Frame level.
b. Crankshaft web deflection (ideally this should be zero). As a general rule of thumb, the web deflection should not exceed 100 micrometers per meter (0.0001 inches per inch) of piston stroke.
c. Crankshaft-to-main bearing side clearance (this provides an indication of crankshaft-to-main bearing alignment in the horizontal plane).
d. Rotor-to-stator air-gap clearance on single bearing motors (this should be equal all around the motor).
e. Coupling alignment on two-bearing motors.

3.10.2 The compressor frame hold-down bolts must be snugged down (not full torque) to hold the frame in position during grouting.

3.10.3 After the frame is leveled and aligned, it must be allowed to set for 24 hours prior to beginning the grouting. Level and frame alignment readings must be rechecked before grouting.

3.11 Pregrout Meeting

3.11.1 A pregrout meeting should be held at least one day prior to the grout pour to understand and agree on procedures, to ensure all necessary materials are on hand, and to clarify grouting responsibilities. The parties present at this meeting should include, as a minimum, the grout manufacturing technical representative, the designated machinery representative, the foreman in charge of the grouting activity, the foremen in charge of supporting the grouting activities (such as scaffolding and laborers), the grouting materials coordinator, and a site safety representative.

Note: Typically this meeting is done for special-purpose equipment or prior to pouring the grout foundations for a group of similar equipment.

3.11.2 During the pregrout meeting, contingency plans should be developed, such as how the job will be handled (or postponed) in the event of inclement weather.

3.11.3 During the meeting it must be made clear that once the grout pour begins, it will continue without interruption until completion.

3.11.4 A representative from the grout manufacturer is recommended if the installation personnel are not familiar with the grouting materials, forming, installation, and so forth, or if a special-purpose equipment train is being installed.

3.12 Pregrout Setup

3.12.1 Remove any dust or dirt accumulation from the grout-prepared surface with clean, dry, oil-free air.

3.12.2 Check to ensure that mounting plates are rigidly installed and that anchor bolt nuts are snug prior to grout application to ensure that they will not float out of position.

3.12.3 Prior to pouring grout, the area between the top of the anchor bolt sleeves and the bottom of the mounting plates shall be packed with a soft moldable material (such as foam pipe insulation) to exclude grout as shown in Appendixes E and F. This is to ensure that the anchor bolt sleeves do not fill with grout and that the anchor bolts are free to move (for minor alignment correction and bolt-stretch) within the limits of their sleeves. Anchor bolt threads must also be protected with duct tape or other suitable means.

3.12.4 Check the grout form elevation to ensure that the top surface of the grout will match the elevation shown on the construction drawings. Typically, the elevation to the top of the grout extends half the thickness of the soleplate.

3.12.5 Unless otherwise specified, on pump baseplates, the pump and the driver shall be removed from the base in order to provide access to the grout holes and facilitate leveling.

Note: Advantages of removing pump and driver are as follows:

- Baseplates are easily leveled, using the machined mounting pads to check for levelness, without distortion of the baseplates.
- Access to grout holes for grouting is improved.
- With baseplates that are sloped, leakage from the lowest vent hole is more easily controlled.
- Grout cleanup of pump and driver is not required.
- Cleanup of baseplates is easier.

3.12.6 Unless otherwise specified by the user, on general-purpose equipment, the machinery and its driver shall be removed from the baseplate prior to grouting when level surface access does not allow level measurement and/or when necessary to provide adequate access to baseplate grout hole openings.

3.12.7 Recheck all mounting plates for elevation and level immediately before grouting.

3.12.8 Ensure that grouting material is in clean, dry, unopened containers and has been stored at a temperature of approximately 21°C (75°F) for 48 hours prior to grouting.

3.12.9 Ensure that all foundation and metal surfaces are within the temperature range of 18–32°C (65–90°F).

3.12.10 Ensure that a sufficient quantity of grouting materials is on hand at the jobsite to complete the job (15–25 percent extra).

3.12.11 Ensure that clean tools, mixing equipment, and safety supplies are on hand at the jobsite.

3.12.12 Ensure that Material Safety Data Sheets and personnel protection requirements have been reviewed with all grouting personnel.

3.13 Grout Mixing

3.13.1 No partial units of epoxy, resins, hardener, or aggregate are to be used.

3.13.2 The resin and hardener are to be mixed at 200–250 rpm per the grout manufacturer's specified time period prior to introducing the aggregate. There should be no entrained air in the resin/hardener mixture.

3.13.3 Full bags of aggregate are to be slowly added to the blended resin/hardener liquid and sufficiently mixed to completely wet-out the aggregate.

3.13.4 Grout should be mixed in a clean, slow-speed (15–20 rpm) portable mortar mixer (not a concrete mixer). For small pours, grout can be mixed in a clean wheelbarrow with a mortar hoe.

3.14 Mounting Plate Grouting

3.14.1 Grout the mounting plates in accordance with the grout manufacturer's instructions.

3.14.2 To apply the grout, start at one end of the forms and fill the cavity completely while advancing toward the other end. This will prevent air entrapment. Do not vibrate the grout as a means of helping it flow as this tends to separate the aggregate from the resin binder. Limited use of push tools may be employed to help distribute the grout, using long strokes rather than short jabs. Violent ramming of the grout is not permitted.

3.14.3 The grout volume used should be checked against the estimated cavity volume. This is a good way to check for air pockets and insufficient filling.

3.14.4 Check frequently for grout leaks. Leaks will not self-seal, and if not stopped, will cause voids.

3.14.5 For special-purpose equipment, a grout sample shall be obtained for each batch mixture (polystyrene cupful) for compressive strength testing. All samples are to be labeled and their batch placement location noted.

3.14.6 A final check of soleplate elevation and level shall be made before the grout sets.

3.14.7 Air bubbles rising to the surface of epoxy grout may be removed by lightly spraying the bubble surface with the grout manufacturer's cleaning solvent.

3.14.8 If required, the exposed surface of the grout can be troweled or broomed when it is in a tacky state to provide a nonskid surface. Troweling and brooming may be facilitated by the use of grout solvent. Troweling and brooming shall be carried out in a manner that precludes excessive blending of the grout solvent into the surface of the grout.

3.14.9 Remove any grout head boxes after the grout has set sufficiently. Do not plug any baseplate fill and vent holes until the grout has set (this can cause base distortion due to grout expansion).

3.15 Post-Grouting Instructions

3.15.1 Typically, three days after the grout has been poured, the grout should be of sufficient hardness to remove jackscrews and grout forms. This will ensure that the grout has obtained most of its strength and hardness.

Note: The grout is of sufficient hardness if a sixpenny finishing nail cannot be driven into the grout surface.

3.15.2 Mounting plates that settle unevenly and/or beyond the specified level tolerance shall be corrected. Correction of level may include removal and regrouting or field machining of the equipment mounting surfaces.

3.15.3 Mounting plate jackscrew holes shall be filled with a flexible sealant material (not grout) such as room temperature vulcanizable (RTV) silicone rubber or with short cap screws that do not extend below the threaded holes in the mounting plate.

3.15.4 Check grout for softness. This can be done by placing a magnetic-based dial indicator on the soleplate (referenced to the concrete foundation) and checking for any movement as each anchor bolt is loosened and retightened. Soleplate movement should not exceed 20 micrometers (0.001 inch).

3.15.5 After the grout has cured, expansion joints shall be sealed with elastic epoxy seam sealant (liquid rubber) or silicone rubber (RTV).

3.15.6 The entire top of the machinery foundation shall then be painted with a grout-compatible nonskid protective coating to protect the foundation cap from oil and weathering. This coating shall extend down from the top of the foundation at least 45 centimeters (18 inches).

3.15.7 Lubricate all anchor bolt threads liberally and torque anchor bolts in accordance with the manufacturer's recommendations. The Table A-1 in Appendix A may be used as a guide if manufacturer information is not available.

3.15.8 All anchor bolts shall have full penetration of the anchor bolt nut and 2$^1/_2$ threads protruding above the anchor bolt nut.

3.16 Filling Grout Voids

3.16.1 After the grout has cured, check for voids by tapping along the top deck of the mounting plate. Mark the void areas to allow for proper identification when filling. A solid thud indicates a good grout area while a drumlike hollow sound indicates a void requiring filling.

3.16.2 Void areas are to be filled by drilling NPT $^1/_8$ holes in opposite corners of each void area. One hole in each void is to be tapped for installation of a NPT $^1/_8$ grease fitting; the other holes serve as vents. Grout is then pumped into each void with a grout gun until the grout emerges from the vent holes.

3.16.3 Care must be exercised in filling voids as high pressures created from the grout gun can lift or distort the baseplate. It is therefore extremely important that the grout and vent holes are in communication with each other. An air squeeze bottle may be used to test for communication by blowing air into the grout hole and noting its exit at the vent hole (do not use high-pressure air). A dial indicator shall also be used to monitor baseplate movement during void filling. Remove all grease fittings when finished.

3.16.4 Clean up any spilled grout with the grout manufacturer's approved solvent.

3.16.5 After the void grout has cured, recheck the baseplate to ensure that all voids are filled with grout. If void areas still exist, repeat the drilling and pumping procedures as necessary.

Section 4—Grouting Checklists

4.1 Machinery Installation Pregrout Setup Checklist

INITIALS/DATE		Anchor Bolt Preparation
______ ______	3.5.2	Anchor bolt sleeves are clean and dry and filled with a non-bonding moldable material.
______ ______	3.5.2	Anchor bolts are not tilted or bolt-bound and are perpendicular with respect to the bottom of the baseplate/soleplate.
______ ______	3.5.3	Foundation anchor bolt threads are undamaged.
______ ______	3.5.3	Foundation anchor bolt threads have been wrapped with duct tape for protection.
______ ______	3.5.4	All anchor bolt locations and projections have been verified.
		Foundation Preparation
______ ______	3.6.1	An adequate weather-protective cover has been constructed over the areas to be grouted.
______ ______	3.6.2	Concrete foundation is roughened up and all laitance removed for a good grout bond.
______ ______	3.6.2	The minimum grout thickness under any portion of the baseplate/soleplate will be 25–50 millimeters (1–2 inches).
______ ______	3.6.2	Foundation is free of structural cracks.
______ ______	3.6.3	All grout forms have been provided with 25-millimeter (1-inch) 45-degree chamfer strips at vertical corners and horizontal edges.
______ ______	3.6.4	Concrete grout areas are clean and free of oil, dust, and moisture.

INITIALS/DATE		Grout Forms
______ ______	3.7.1	Grout forms are of adequate strength to support the grout.
______ ______	3.7.3	Inside surfaces of grout have three coats of paste wax applied.
______ ______	3.7.4	Grout forms have been sealed to the foundation to prevent leaks.
______ ______	3.7.5	Grout forms have 25-millimeter (1-inch), 45-degree chamfer strips at all vertical corners and at the horizontal surface of the grout.
		Mounting Plate Design Verification
______ ______	3.8.2	Baseplate/soleplate has 50-millimeter (2-inch) minimum radiused corners.
______ ______	3.8.3	Anchor bolts have 3-millimeter (1/8-inch) annular clearance in baseplate or soleplate holes.
______ ______	3.8.4	All pump and other small baseplates have been provided with vertical leveling screws.
______ ______	3.8.5	Baseplates have been provided with one 10-centimeter (4-inch) minimum grout filling hole in the center of each bulkhead section and one 12-millimeter (1/2-inch) vent hole.
______ ______	3.8.6	Baseplates have sufficient grout and air vent holes in each compartment to allow for proper grouting.
______ ______	3.8.7	Elevation adjustment nuts will not be permanently grouted.
______ ______	3.8.8	Baseplate leveling jackscrews have been provided with stainless steel leveling pads.

INITIALS/DATE	Mounting Plate Design Verification (continued)
______ ______	**3.8.9** Baseplate welds are continuous and free of cracks.
______ ______	**3.8.10** All grout pour and vent holes are accessible.

Mounting Plate Preparation

______ ______	**3.9.1.1** Baseplate/soleplate has been blasted and all grouting surfaces prepared in accordance with the grout manufacturer's recommendations.
______ ______	**3.9.1.2** Three coats of paste wax have been applied to all surfaces where grout bond is not desired. These surfaces include jackscrews, grout forms, and coupling guard bolts.
______ ______	**3.9.1.3** All miscellaneous mounting plate holes are plugged to prevent the entrance of grout.
______ ______	**3.9.1.4** Equipment to be grouted is isolated and in a strain-free condition with all piping, conduit, and so forth, disconnected.

Expansion Joints

______ ______	**3.9.2.1** Expansion joints placed on 1.4- to 2.8-meter (4- to 6-foot) intervals.
______ ______	**3.9.2.2** Expansion joints fixed into position such that they will not move when grout is poured.

Soleplate Installation and Leveling

______ ______	**3.9.3.1** The elevation to the top of equipment baseplate or soleplate referenced to the civil benchmark is in agreement with the construction grout drawing.
______ ______	**3.9.3.7** All shims used in subsoleplates are AISI Standard type 300 stainless steel.

INITIALS/DATE	Soleplate Installation and Leveling (continued)
______ ______	**3.9.3.9** All machined baseplate or soleplate surfaces are level in accordance with the specification, and signed-off Data Sheets for level record have been completed.

Baseplate and Installation Leveling API 610 and ASME Pumps, and General Purpose Equipment

______ ______	**3.9.4.1** All baseplate elevations set in accordance with the construction drawings.
______ ______	**3.9.4.2** A preliminary equipment alignment check has been made.
______ ______	**1.9.4.5** All baseplate surfaces are level in accordance with the specification, and signed-off Data Sheets for level record have been completed.

Pregrout Setup

______ ______	**3.12.1** All surfaces in contact with grout are clean, dry, and oil free.
______ ______	**3.12.2** Anchor bolt nuts have been "snugged" into position to prevent baseplate/soleplate floating.
______ ______	**3.12.3** Anchor bolt sleeves have been filled with flexible mastic material.
______ ______	**3.12.3** Top of anchor bolt sleeve has been packed with a soft moldable material.
______ ______	**3.12.4** Grout form elevation agrees with the construction drawings.
______ ______	**3.12.8** Grouting material is in clean, dry, unopened containers and has been stored at a temperature of approximately 21°C (75°F) for 48 hours prior to grouting.

INITIALS/DATE **Pregrout Setup (continued)**

______ ______ **3.12.9** All foundation and metal surfaces are within the temperature range of 18–32°C (65–90°F).

______ ______ **3.12.10** Sufficient quantity of grouting materials are on hand at the jobsite to complete the job (15–25 percent extra).

______ ______ **3.12.11** Clean tools, mixing equipment, and safety supplies are on hand at the jobsite.

______ ______ **3.12.12** Material Safety Data Sheets and personnel protection requirements have been reviewed with all grouting personnel.

EQUIPMENT IDENTIFICATION NUMBER ______________________________

GROUTING INSPECTOR ______________________________ DATE ______________

4.2 Machinery Installation Grout Placement Checklist

INITIALS/DATE

______ ______ Ambient temperature at beginning of grout pour ______°C (°F).

______ ______ Pre-grout meeting has been completed and all personnel understand the grout plan and individual responsibilities.

Grout Mixing

______ ______ **3.13.2** Resin and hardener are mixed at 200–250 rpm for the specified time and no air entrainment is indicated.

______ ______ **3.13.3** Full bags of aggregate are slowly added to blended resin/hardener liquid and mixed to completely wet-out the aggregate.

______ ______ **3.13.3** No partial units of epoxy, resins, hardener, or aggregate used.

______ ______ **3.13.4** Grout mixed in a clean, slow-speed (15–20 rpm) portable mortar mixer (or in a wheel-barrow for small pours).

INITIALS/DATE **Mounting Plate Grouting**

______ ______ Grout is placed within its pot life.

Time at beginning of pour:

__________(AM) (PM).

Time at end of pour:

__________(AM) (PM).

______ ______ **3.14.2** No vibrator is used to facilitate grout placement.

______ ______ **3.14.2** Grout pour rate is slow enough to permit air to escape.

______ ______ **3.14.3** The grout volume used agrees with the estimated cavity volume.

______ ______ **3.14.4** No grout leaks are observed.

______ ______ **3.14.5** For special purpose equipment, a grout sample is obtained for each batch mixture (polystyrene cup full) for compressive strength testing. All samples are to be labeled and their batch placement location noted.

______ ______ **3.14.7** All grout surface air bubbles are removed.

______ ______ **3.14.9** Grout holes and vent holes filled with grout.

______ ______ Ambient temperature at end of grout pour ______°C (°F).

EQUIPMENT IDENTIFICATION NUMBER ______________________________

GROUTING INSPECTOR ______________________________ DATE ______________

4.3 Machinery Installation Post-Grouting Checklist

INITIALS/DATE		**Post-Grouting Instructions**
______ ______	**3.15.1**	Grout is of sufficient hardness to remove forms.
______ ______	**3.15.1**	Grout forms remained in place after grouting for 48–36 hours.
______ ______	**3.15.3**	Mounting plate jackscrew holes are filled with a flexible material such as RTV silicone rubber.
______ ______	**3.15.4**	Grout is checked for "softness" with a dial indicator. Baseplate/soleplate checked for soft foot at each anchor bolt location with a magnetic base dial indicator as anchor bolts are torqued. Base movement does not exceed 0.02 millimeter (0.001 inch).
______ ______	**3.15.5**	Expansion joints sealed with elastic epoxy seam sealant.
______ ______	**3.15.6**	Top of machinery foundation painted with a grout-compatible nonskid protective coating.
______ ______	**3.15.7**	Lubricate all anchor bolt threads liberally and torque anchor bolts in accordance with the manufacturer's recommendations. Anchor bolt size: ______________ Torque specification: ____________ Installed torque: ________________
______ ______	**3.15.8**	Ensure that all anchor bolts have full penetration of the anchor bolt nut and a minimum of 2½ threads protrude above the anchor bolt nut.

INITIALS/DATE		**Filling Grout Voids**
______ ______	**3.16.1**	Baseplate "sounded" for voids and all voids repaired. Indicate number of voids found, their size, and their location: __________.
______ ______	**3.16.2**	Void areas have NPT 1/8 holes installed in opposite corners of void with grease fitting installed in one of the holes.
______ ______	**3.16.3**	Grout void fill and vent holes are in "communication."
______ ______	**3.16.3**	Dial indicator used on mounting plate to monitor plate movement while filling grout void.
______ ______	**3.16.4**	All spilled grout is cleaned up with manufacturer's approved solvent.
______ ______	**3.16.5**	Recheck baseplate to ensure that all voids are filled with grout.

EQUIPMENT IDENTIFICATION NUMBER ______________________________

GROUTING INSPECTOR ______________________________ DATE ____________

APPENDIX A—ANCHOR BOLT TORQUE TABLES

Table A-1—30,000 PSI Internal Bolt Stress

Nominal Bolt Diameter (inches)	Number of Threads (per inch)	Torque (foot-pounds)	Compression (pounds)
1/2	13	30	3,780
5/8	11	60	6,060
3/4	10	100	9,060
7/8	9	160	12,570
1	8	245	16,530
1 1/8	8	355	21,840
1 1/4	8	500	27,870
1 1/2	8	800	42,150
1 3/4	8	1,500	59,400
2	8	2,200	79,560
2 1/4	8	3,180	102,690
2 1/2	8	4,400	128,760
2 3/4	8	5,920	157,770
3	8	7,720	189,720

Note 1: All torque values are based on anchor bolts with threads well-lubricated with oil.
Note 2: In all cases the elongation of the bolt will indicate the load on the bolt.

Table A-2—2110 kg/cm^2 Internal Bolt Stress

Nominal Bolt Diameter (mm)	Torque (newton-meters)	Compression (kilograms)
M12	31	1,778
M16	110	3,311
M24	363	7,447
M30	1,157	18,247
M52	3,815	37,136

Note 1: All torque values are based on anchor bolts with threads well-lubricated with oil.
Note 2: In all cases the elongation of the bolt will indicate the load on the bolt.

APPENDIX B—LEVELING DATA SHEET AND DRAWINGS

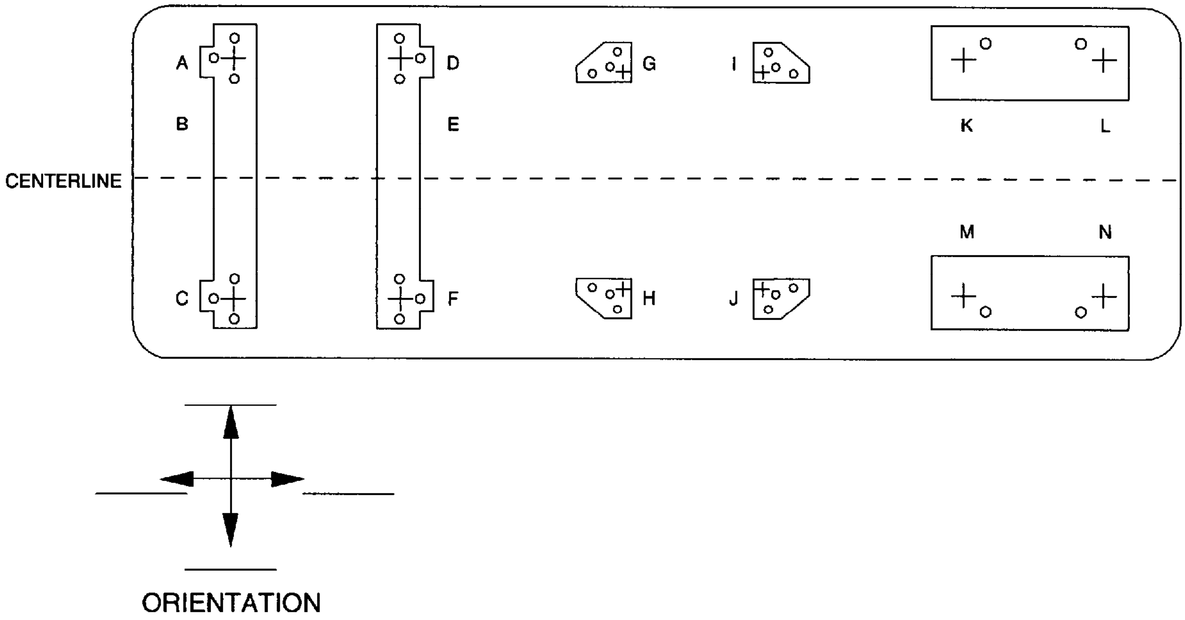


Figure B-1—Typical Mounting Plate Layout for Elevation and Level Measurement

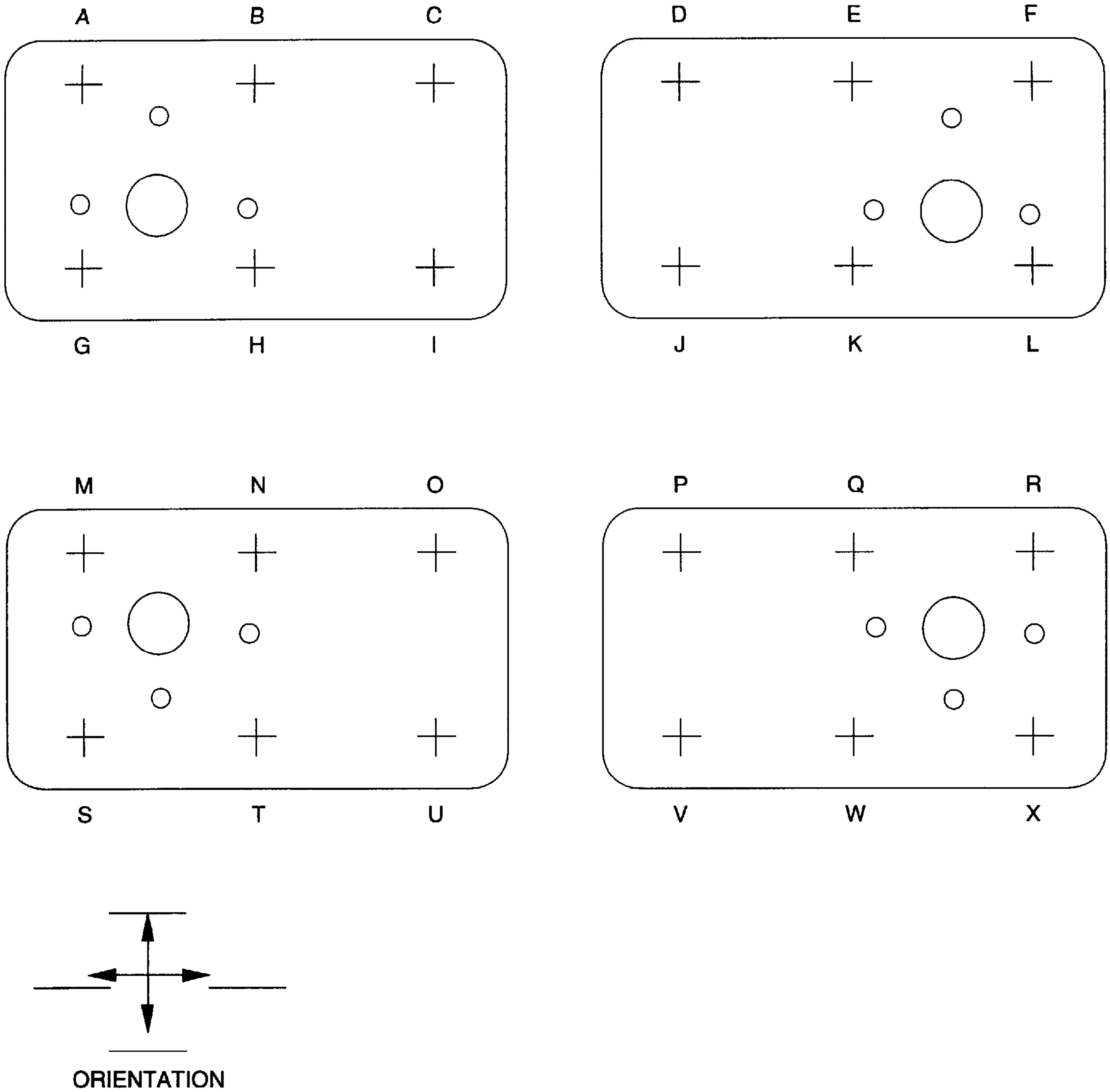


Figure B-2—Typical Soleplate Layout for Elevation and Level Measurement

Typical Mounting Plate Level Data Sheet
(Sheet 1 of 1)

Elevation specified on Civil Drawing ____________________

Elevation of Soleplate at Location "A" ____________________

Civil Drawing Reference No. ____________________

Location	Elevation Referenced to Location "A"	Comments
B	____________________	
C	____________________	
D	____________________	
E	____________________	
F	____________________	
G	____________________	
H	____________________	
I	____________________	
J	____________________	
K	____________________	
L	____________________	
M	____________________	
N	____________________	

CHECK BY ____________________CONTRACTOR DATE____________________

APPROVED BY ____________________(USER) DATE____________________

APPENDIX C—TYPICAL MOUNTING PLATE ARRANGEMENT FOR BASEPLATE MOUNTED SPECIAL-PURPOSE EQUIPMENT

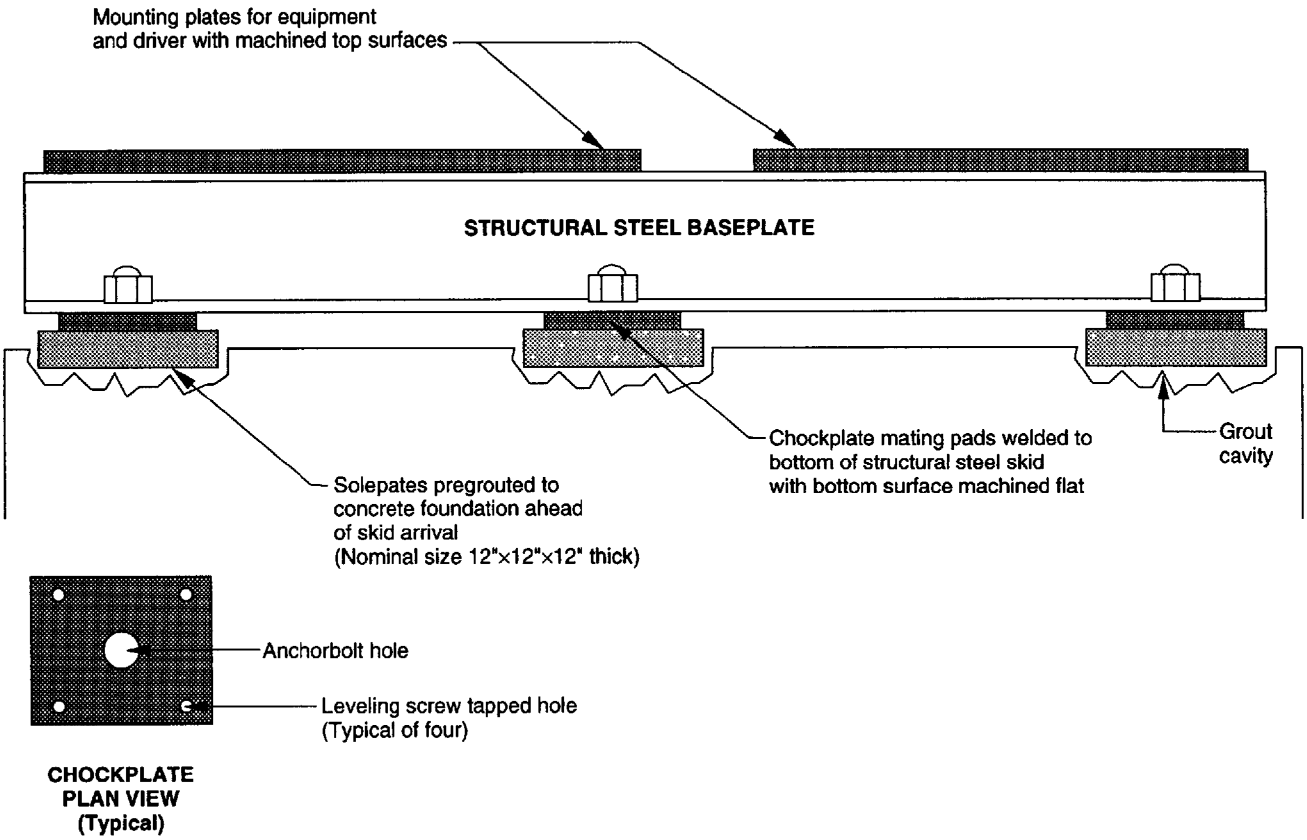


Figure C-1—Typical Mounting Plate Arrangement
for Baseplate Mounted Special-Purpose Equipment

APPENDIX D—BASEPLATE LEVELING FOR HORIZONTAL CENTRIFUGAL PUMPS (FOR USE WHEN A PUMP AND/OR ITS DRIVER ARE NOT REMOVED FROM THE BASEPLATE FOR GROUTING)

BASEPLATE LEVELING

Procedure

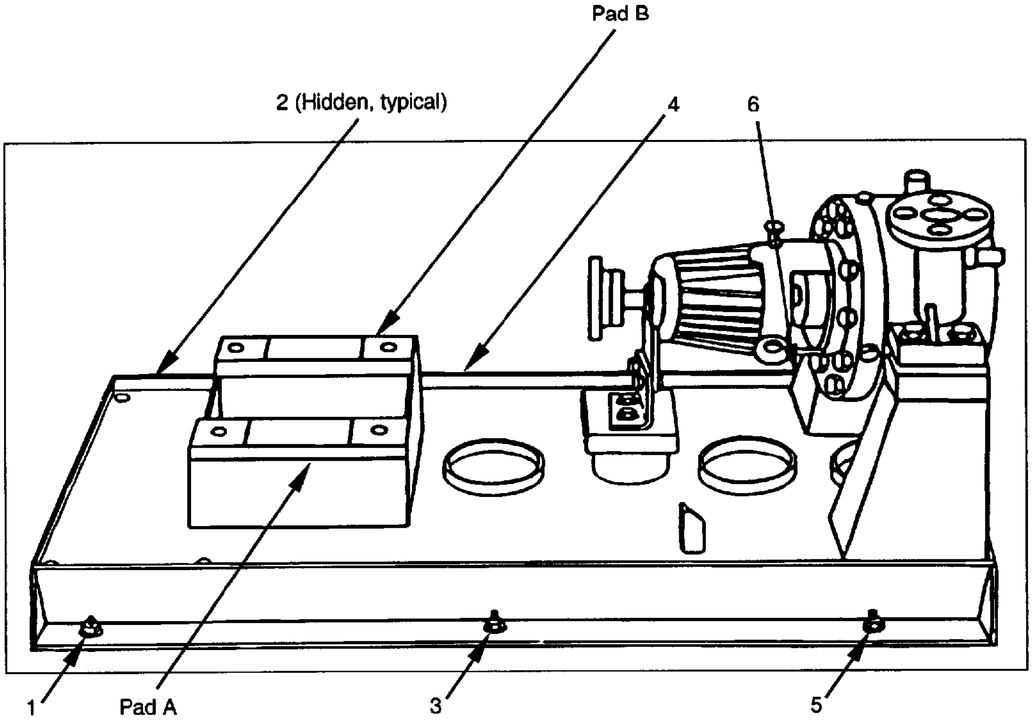
1. Determine high end of baseplate. Then start leveling across pads on high end by adjusting leveling bolts adjacent to the pad that you are leveling. For example, when leveling driver pads A and B in crosswise direction, level at anchor points 1 and 2 (see Figure D-1) with level positioned as shown by Figure D-3. Continue leveling until baseplate is level in crosswise direction at places illustrated by Figures D-2 and D-3 — pads A and B must be level across middles and across ends, particularly those ends nearest pump.

   Note: Use only base pads for determining level. *Never* use nozzles or baseplate rails.

2. Level both sides of baseplate in lengthwise direction by adjusting leveling bolts adjacent to pad that you are leveling. For example, when leveling pad A, level at anchor points 1, 3, and 5, Figure D-1, with level positioned as shown by Figure D-4. Continue leveling until both sides of baseplate (that is, pads A, B, and each side of pump) are level in lengthwise direction at places illustrated by D-4 and D-5.

3. Tighten foundation anchor bolts and pump feet hold-down bolts. As you tighten bolts, position level as illustrated in the four leveling figures and check leveling in both crosswise and lengthwise directions. If tightening bolts disturbs leveling, adjust leveling bolts until baseplate is level in both directions at place where leveling was disturbed. Again tighten bolts and verify leveling in both directions. Continue this procedure until all bolts lengthwise and crosswise directions are tight.

   Figures D-1–D-5—Single Stage Overhung Pump
   Figures D-6–D-10—Between Bearing Single or Multistage Pump



Note: Points 2, 4, and 6 are directly across from Points 1, 3, and 5, respectively.

Figure D-1—Baseplate Top View

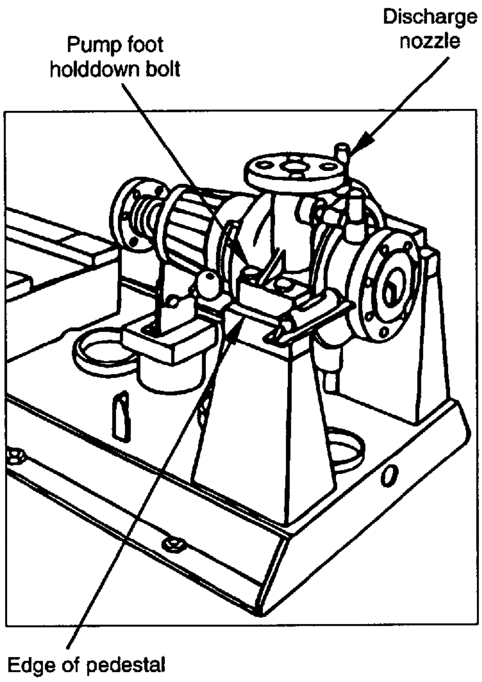


Figure D-2—Leveling Pump End Crosswise

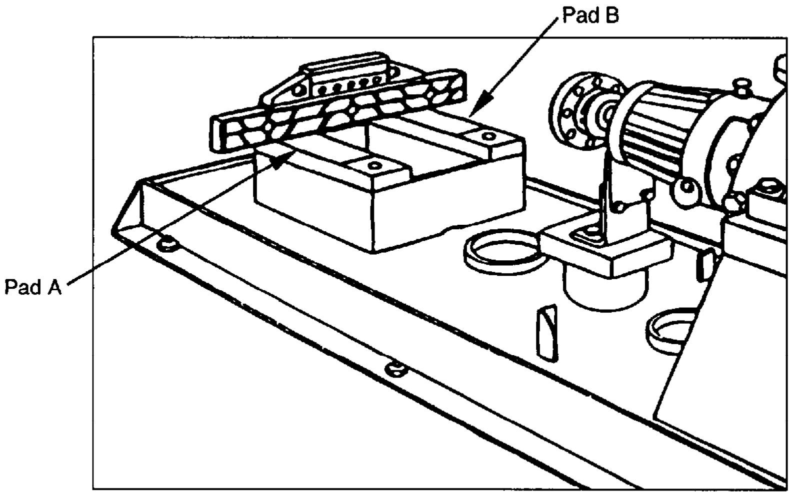


Figure D-3—Leveling Driver End Crosswise

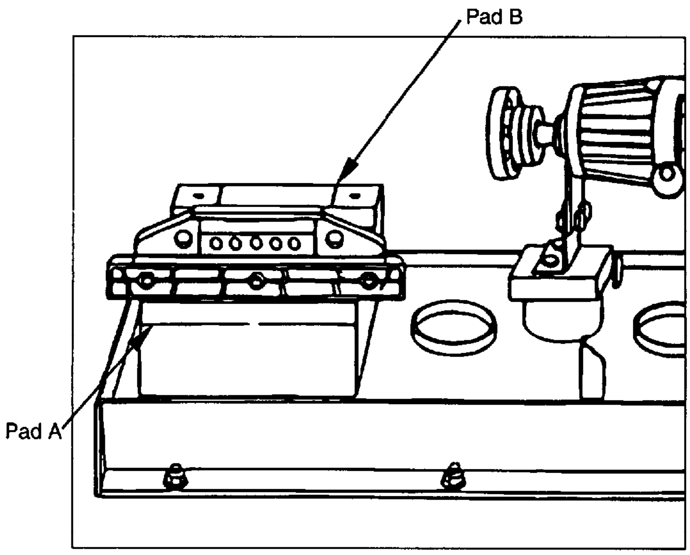


Figure D-4—Leveling Driver End Lengthwise

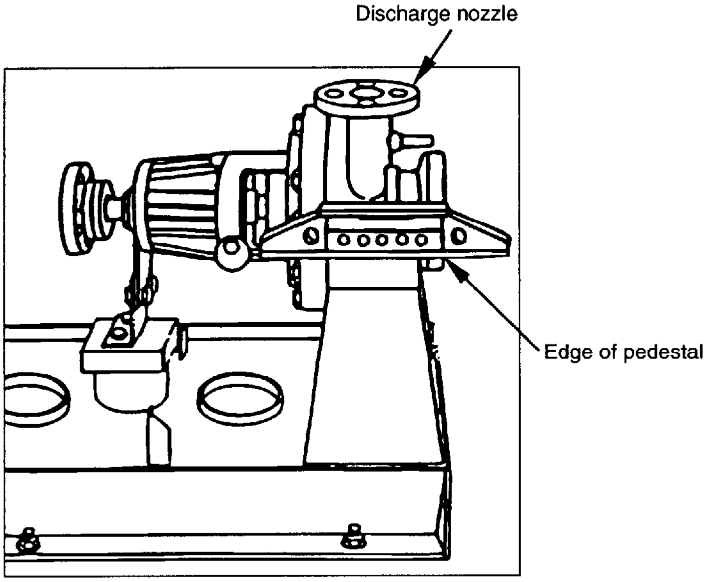


Figure D-5—Leveling Pump End Lengthwise

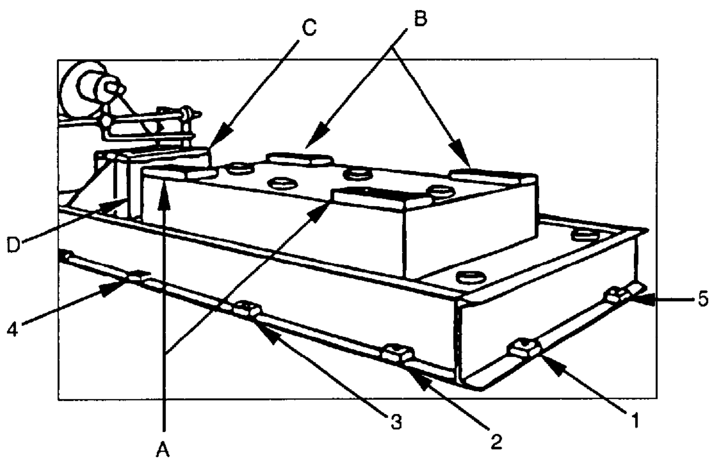


Figure D-6—Baseplate Top View (Typical)

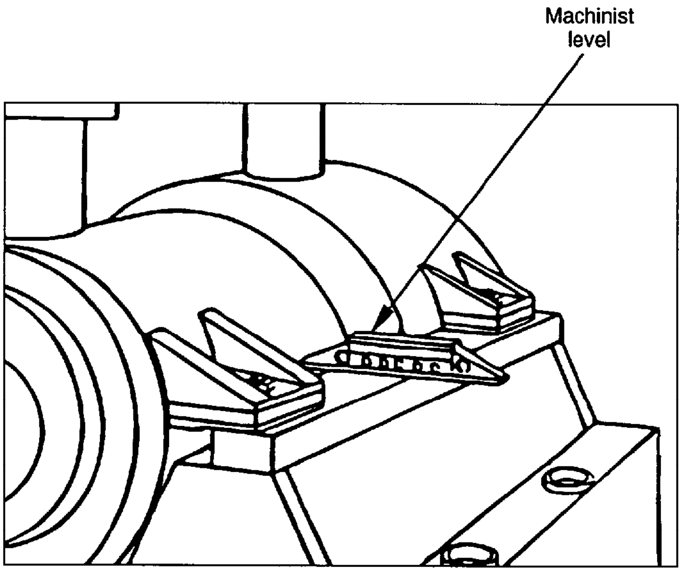


Figure D-7—Leveling Pump End Crosswise

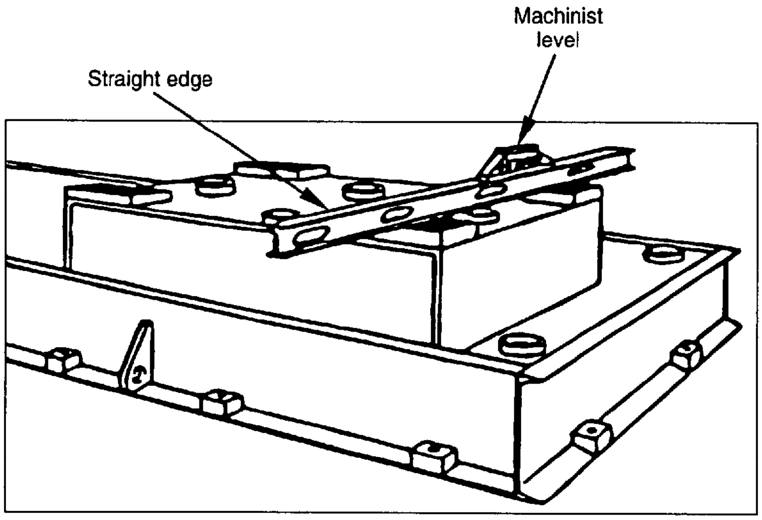


Figure D-8—Leveling Driver End Crosswise (Typical)

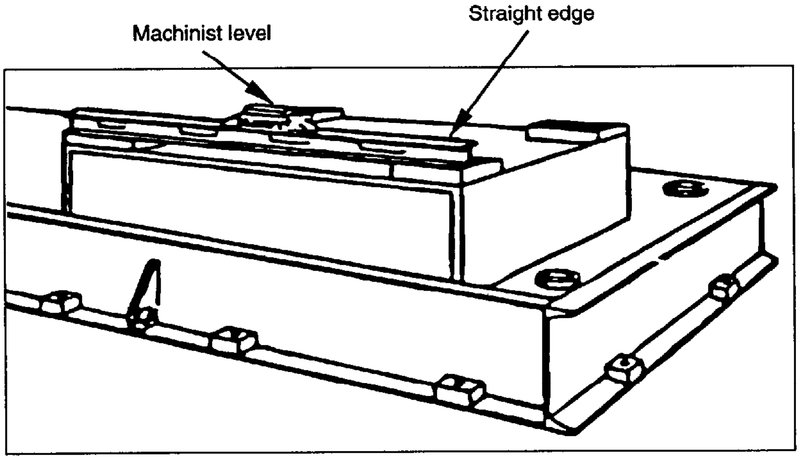


Figure D-9—Leveling Driver End Lengthwise (Typical)

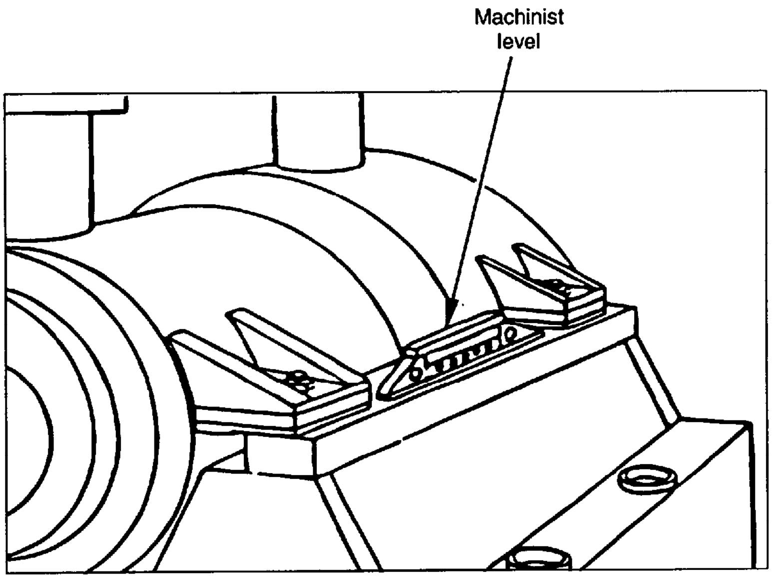


Figure D-10—Leveling Pump End Lengthwise

APPENDIX E—TYPICAL GROUTING INSTALLATION OF SOLEPLATES

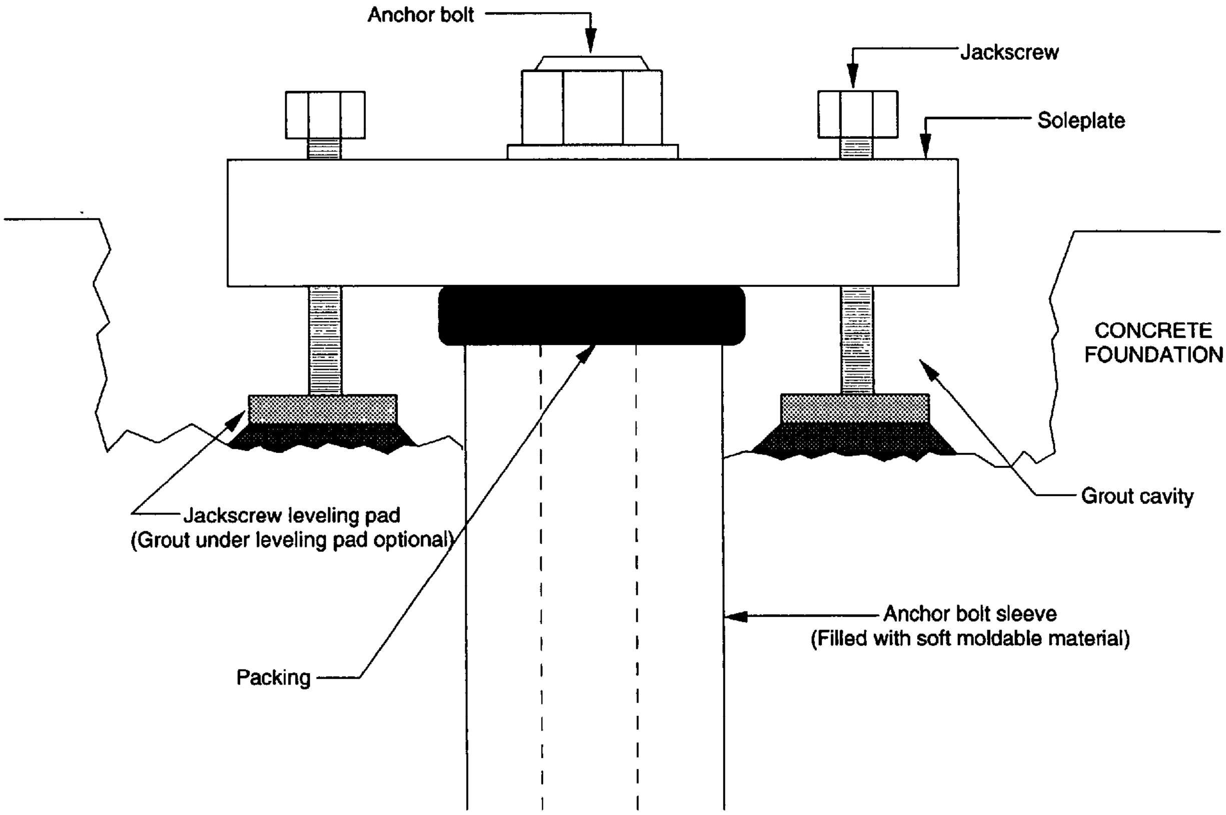


Figure E-1—Typical Grouting Installation of Soleplates

APPENDIX F—TYPICAL GROUTING INSTALLATION OF BASEPLATES FOR PUMPS AND GENERAL PURPOSE EQUIPMENT

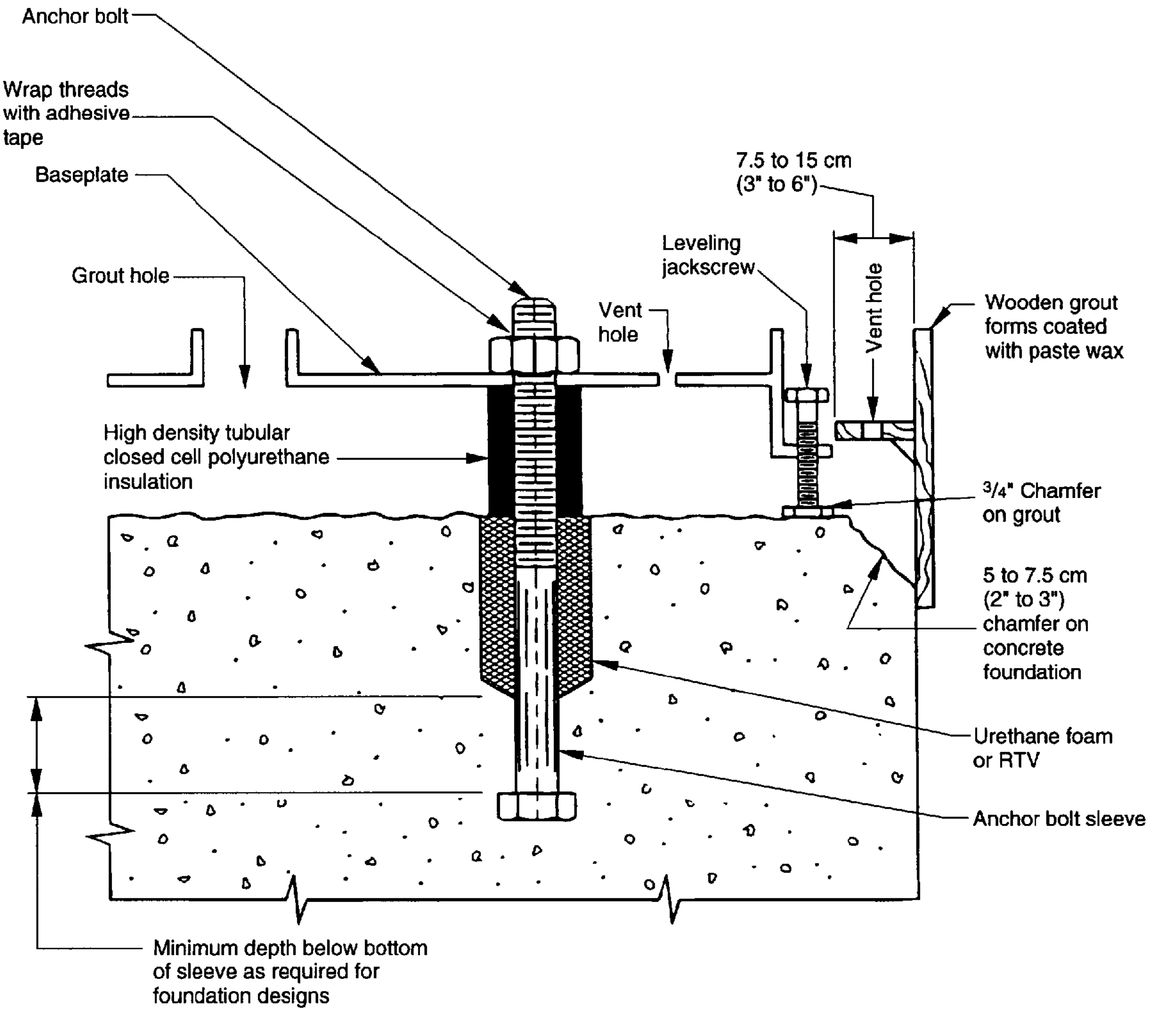
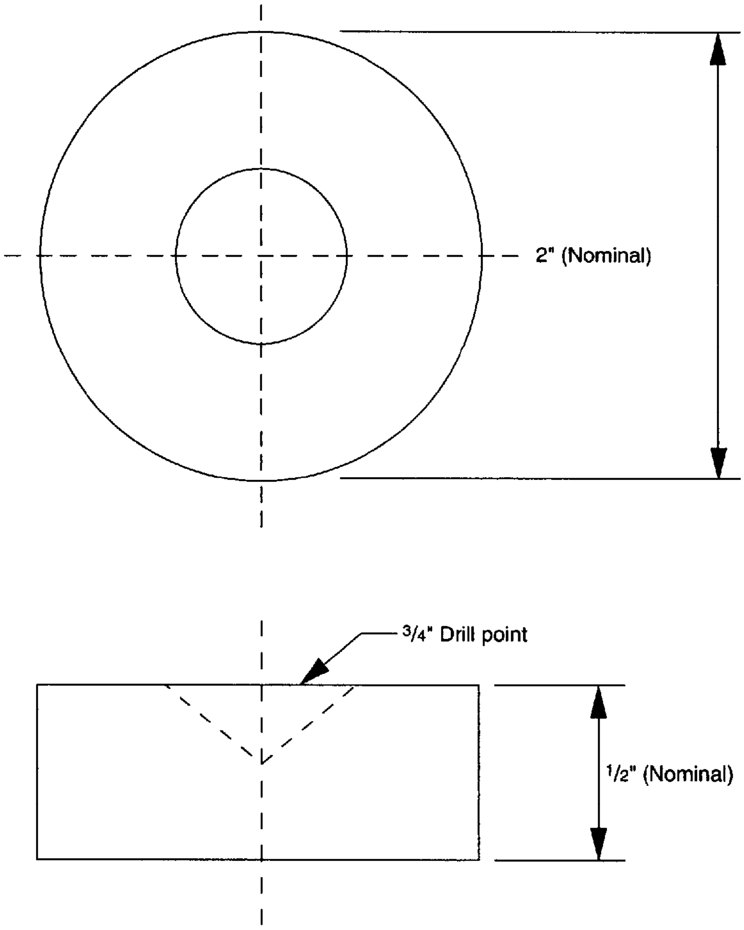


Figure F-1—Typical Grouting Installation of Baseplates for Pumps and General Purpose Equipment

APPENDIX G—TYPICAL MOUNTING PLATE LEVELING PADS



Notes:
1. Materials—Carbon steel
2. Cleanliness—Free of dirt, oil, rust, scale, and burrs

Figure G-1—Typical Mounting Plate Leveling Pads

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Recommended Practices for Machinery Installation and Installation Design

Chapter 6—Piping

Manufacturing, Distribution and Marketing Department

API RECOMMENDED PRACTICE 686
PIP REIE 686
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Process Industry Practices

American Petroleum Institute

Recommended Practices for Machinery Installation and Installation Design

CHAPTER 6—PIPING

Section 1—Definitions

1.1 blowdown system: A closed system connected to a machine used to depressure and decontaminate the machine preparatory to maintenance activities; also known as a *maintenance dropout system.*

1.2 breakout spool: A short, flanged length of pipe immediately connected to the machinery piping flanges. Lengths vary with the size of the pipe but range from 15 centimeters (6 inches) to 1 meter (3 feet). The purposes of this spool are to facilitate machinery installation, allow piping modification to reduce pipe strain, isolate the machinery, facilitate commissioning activities such as flushing or blowing lines, and allow removal of temporary inlet strainers; also known as a *dropout spool.*

1.3 condensing service: A gas stream that contains a vapor component that may condense to a liquid during start-up, operation, or shut-down of a compressor or blower. This may include pure vapors such as refrigerants as well as hydrocarbon gas streams. When condensate is present in the gas stream, the term *wet gas* may be used; *wet gas* may also be used as a synonym to *condensing service.*

1.4 dead-leg: A length of piping with no flow.

1.5 designated machinery representative: The person or organization designated by the ultimate owner of the equipment to speak on his behalf with regard to machinery installation decisions, inspection requirements, and so forth. This representative may be an employee of the owner, a third party inspection company, or an engineering contractor as delegated by the owner.

1.6 drop point: A vertical section of oil mist distribution piping that is usually smaller in diameter than the main oil mist header. This piping rises out of a tee in the main oil mist header, turns horizontally, and extends downward to the machinery being lubricated.

1.7 engineering designer: The person or organization charged with the project responsibility of supplying installation drawings and procedures for installing machinery in a user facility after machinery has been delivered. In general, but not always, the engineering designer specifies machinery in the user facility.

1.8 equipment installer: The person or organization charged with providing engineering services and labor required to install machinery in a user facility after machinery has been delivered. In general, but not always, the installer is the project construction contractor.

1.9 equipment user: The organization charged with operation of the machinery. In general, but not always, the equipment user owns and maintains the machinery after the project is complete.

1.10 final alignment: The aligning of two adjacent machinery shafts after the measurement of piping-imposed strains on the machinery are verified as being within the specified tolerances.

1.11 general-purpose equipment trains: Those trains that have all general-purpose elements in the train. They are usually spared, relatively small in size (power), or are in noncritical service. They are intended for applications where process conditions will not exceed 48 bar gauge (700 pounds per square inch gauge) pressure or 205°C (400°F) temperature (excluding steam turbines), or both, and where speed will not exceed 5000 revolutions per minute (RPM).

Note: General purpose equipment trains have all elements that are either manufacturer's standard or are covered by standards such as the following: ANSI/ASME B.73 horizontal pumps, small API Standard 610 pumps, fans, API Standard 611 steam turbines, API Standard 672 air compressors, API Standard 677 general purpose gears, API Standard 674 reciprocating pumps, API Standard 676 rotary positive displacement pumps, API Standard 680 reciprocating air compressors, and NEMA standard size motors.

1.12 isolation block valve: A valve used to isolate a process machine preparatory to maintenance; also known as a *block valve* or *isolation valve.*

1.13 mechanical piping analysis: An analysis of the piping connected to a machine to determine the stresses and deflections of the piping resulting from dynamic loadings such as pulsating flow. Determination of the type, location, and orientation of piping supports and piping guides results from this analysis.

1.14 minimum flow bypass: See **recycle line.**

1.15 nonslam check valve: A mechanically or hydraulically balanced check valve that allows closure of the valve in a controlled fashion. Wafer-style center-guided spring-loaded split-disc check valves or tilting-disc check valves are representative designs.

1.16 NPS: Nominal Pipe Size.

1.17 oil mist: A dispersion of oil droplets of 1 to 3 micron size in an air stream.

1.18 oil mist system: A system designed to produce, transport, and deliver oil mist from a central location to a remote bearing housing. This system consists of the oil mist console, distribution piping headers and laterals, application fittings, and the lubricant supply tank and pump.

1.19 oil mist console: A system consisting of the oil mist generator, oil supply system, air filtering system, oil mist header outlet, and necessary controls and instrumentation. Air and oil enter the console to produce oil mist.

1.20 oil mist generator: A device located inside the oil mist console that combines oil and air to make oil mist. Typical oil mist generators use a venturi to achieve mixing of the oil and the air.

1.21 oil mist header: A network of piping through which the oil mist is transported from the console where it is made to the machinery bearing housing where it is used.

1.22 oil mist distributor block: A small rectangular block that has four or more holes drilled and tapped in opposite faces. Drop points terminate in distributor blocks. An oil mist distributor block may also be described as an *oil mist manifold block.*

1.23 oil mist application fittings: Long-path orifices that cause the small oil droplet size in the header (dry mist) to be converted to larger size oil droplets (wet mist) to lubricate the bearings. Oil mist application fittings are also known as *reclassifiers.*

1.24 preliminary alignment: The aligning of two adjacent machinery shafts before measuring piping strain on the machinery.

1.25 pulsation analysis: An analysis of the piping system connected to a machine to determine the acoustical and mechanical effects of pulsating flow. For small machines a pulsation analysis may consist of comparison to other installations and/or use of proprietary pulsation device design charts, formulas, or graphs. For large, complicated machines a pulsation analysis may consist of a detailed digital or analog modeling of the machine and the piping. Unless otherwise specified, API Standard 618 should be used to provide guidance for the pulsation analysis.

1.26 purge mist: The application of oil mist to a machinery bearing housing or reservoir to provide a slight positive pressure. Machinery lubrication is provided by the normal ring oil or submerged bearing lubrication. This prevents contamination that could be caused by infiltration of corrosive agents or condensation of ambient moisture. Purge mist may also be described as *wet sump* mist lubrication.

1.27 pure mist: The application of oil mist to a machinery bearing housing to lubricate antifriction bearings. The oil mist passes through the bearing elements and oil droplets coalesce out of the air stream. All oil is drained from the machinery bearing housing and complete lubrication is provided by the mist alone. Pure mist may also be described as *dry sump* lubrication.

1.28 recycle line: A line from the discharge of a pump, blower, or compressor routed back to the suction system. A recycle line will usually include control elements such as meters or valves. The recycle line may connect directly into the suction line or may connect into suction vessels or liquid knockout vessels and may include a cooler; also known as *bypass line, minimum flow bypass*, or *kickback line.*

1.29 special-purpose equipment trains: Equipment trains with driven equipment that is usually not spared, is relatively large in size (power), or is in critical service. This category is not limited by operating conditions or speed.

Note: Special-purpose equipment trains will be defined by the user. In general, any equipment train such as an API Standard 612 turbine, API Standard 618 reciprocating compressor, API Standard 613 gear, API 617 Standard centrifugal compressor, or equipment with a gas turbine in the train should be considered to be special purpose.

1.30 static piping analysis: An analysis of the piping system connected to a machine to determine forces and moments on nozzle connections caused by various loading conditions such as pipe weight, liquid loads, and thermal expansion or contraction. These forces and moments are compared to vendor-allowable loads or national standards to ensure that nozzle loadings meet guidelines. This analysis includes specification of pipe anchors, guides, supports, and sometimes spring supports and expansion joints to control strain. Where large vertical piping displacements occur, machinery may sometimes be mounted on spring-supported baseplates to reduce nozzle loading.

1.31 suction knockout vessel or **liquid dropout vessel:** A vessel located in the suction line to a compressor or blower used to separate any entrained liquid from the gas stream. It may contain a demister mat and/or centrifugal separators to aid in this separation. Usually the compressor or blower takes suction from the top of the knockout vessel.

1.32 warm-up line: A line used to purge warm or hot fluid through a process machine. The intention is to heat up or maintain the temperature of a machine to a temperature greater than the surrounding ambient temperature.

Section 2—Machinery Piping Installation Design

2.1 Scope

2.1.1 This recommended practice (RP) is intended to provide guidelines for the installation and preinstallation design of piping that is connected to machinery in petroleum or chemical processing facilities. Equipment user-specified piping specifications shall be utilized for determining piping materials as well as piping fabrication and testing requirements.

2.1.2 This recommended practice covers rotating and reciprocating fluid-handling machinery and includes pumps, compressors, blowers, and turbines in both horizontal and vertical configurations.

2.1.3 It is recognized that forces and moments imposed on the machinery by the piping are unique to each installation. All piping directly connected to the machinery, excluding lube oil and seal flush, shall be reviewed by a qualified piping stress analyst to determine if a static piping analysis is required to ensure nozzle loads are within equipment user-defined standards. The piping engineering designer shall use sound engineering judgment in conjunction with equipment user-defined standards to design a piping system that minimizes loads imposed on the machinery.

Note: For most machinery, maximum allowable nozzle loads (forces and moments) are established by the machine manufacturer. The equipment user typically adopts these nozzle loads as the equipment user-defined standard. On the basis of equipment user experience and preference, nozzle loadings more or less restrictive than that of the machine manufacturer may be specified as the basis for piping design.

2.2 Accessibility for Operation and Maintenance

2.2.1 Unless otherwise specified, process and auxiliary piping and conduit shall be routed to allow access to machinery for operation, inspection, and maintenance.

2.2.2 All auxiliary equipment, piping, conduit, instruments, coolers, seal pots, and so forth, that are mounted separately from the machine and driver shall not interfere with removal of the machine or driver nor with access to the machinery for normal operation and maintenance. Refer to Figure B-1.

2.2.3 Unless otherwise specified, auxiliary support piping, conduit, instrumentation, and so forth, shall be designed for a single drop area on baseplate-mounted machinery.

Note: The intention of a single drop area is to avoid clutter around the baseplate. This maximizes accessibility for operation and maintenance and minimizes the quantity of piping and conduit that must be removed for machinery maintenance.

2.2.4 Unless otherwise specified by the designated machinery representative, inlet and outlet isolation block valves and blinding stations around machinery shall be accessible from grade near the machinery.

2.2.5 Branch connections (including vents, drains, pressure, injection, relief, and safety valve connections) in confined spaces, such as under machinery decks, shall be avoided.

2.2.6 Location of branch connections shall be chosen so that connections are not subject to damage during maintenance or from personnel stepping or climbing on the connection.

2.3 Isolation Requirements

Isolation block valves are required in the inlet and outlet process piping to and from all machinery. One- or two-piece spectacle blinds should be considered in the inlet and outlet piping to or from all machinery. Any temporary or permanent strainer shall be located between the inlet isolation block valve and the machinery inlet connection.

Note: Isolation using two closed block valves and a vent valve open to atmosphere located between the block valves is known as a "double block and bleed" arrangement. This is an acceptable alternative to spectacle blinds for machinery isolation, provided the process fluid is not toxic, corrosive, or flammable. When specified by the designated machinery representative, removal of a breakout spool and installation of a blind flange is also acceptable.

2.4 Piping Supports

Piping to and from machinery shall be adequately supported and controlled to meet the design requirements. Machinery inlet and outlet piping shall be supported as near to the machine as practical. This removes most of the static load and allows identification of piping fit problems during installation and easier removal of the machinery for maintenance. Only those supports specified as a result of the piping analysis shall be provided. Piping design requirements shall include allowable flange loadings, thermal expansion, pulsations, and so forth. These requirements may be set by the machinery manufacturer, industry standards, or the equipment user.

2.5 Provision for Field Welds

Unless otherwise specified by the designated machinery representative, the piping engineering designer shall include provision for a final piping field weld close to the machine to permit piping installation in accordance with the machinery flange fit-up requirements. All piping NPS 10 or larger shall include a final field weld close to the machine.

Note: Piping size and configuration typically determine whether a final field weld is required. For piping smaller than NPS 10, it may be permissible to shop fabricate piping and not perform a final field weld, providing piping to machinery flange fit-up requirements can be met.

2.6 Pressure Connections and Thermowells

2.6.1 Unless specified otherwise, pressure connections complete with isolation valves shall be provided on the inlet and outlet piping to and from all machinery. Additional pressure connections shall not be made to the machinery casing. The inlet pressure connection shall be located between any permanent or temporary start-up strainer and the machinery inlet piping flange. Refer to Figure B-3.

2.6.2 When temperature measurement thermowells are required, they shall be located in the process piping and not in the machine casing. These thermowells should be located as close as possible to the inlets/outlets of the machine.

2.7 Inlet Pipe and Valve Sizing

Inlet piping and valves shall be, at a minimum, the same size as the machinery inlet nozzle. Inlet piping and valves larger than the machinery inlet nozzle are acceptable.

Note: Care must be taken in reducing down to the proper size as this may be done differently for pumps than for compressors.

2.8 Inlet Strainers

2.8.1 PERMANENT STRAINERS

2.8.1.1 When specified, permanent strainers shall be provided upstream of machinery handling fluids likely to contain foreign material such as sand, scale, and debris, unless the machinery is explicitly designed to handle this material.

Note: The inlet strainer design should be evaluated to verify that the strainer screen will not collapse under any differential pressures expected during machinery commissioning or operation if the strainer screen becomes completely blocked.

2.8.1.2 Where large accumulations of foreign material are expected, a duplex strainer or two simplex strainers in parallel are required if the machine is not spared. If the machine is spared, a simplex strainer on each machine shall be provided.

2.8.1.3 Differential pressure indication shall be provided across the strainer or strainers.

2.8.1.4 Venting capability for strainers shall be provided.

2.8.1.5 Permanent strainers shall not be located closer than five pipe diameters to the machinery inlet nozzle.

2.8.2 TEMPORARY STRAINERS

2.8.2.1 For machinery that is not equipped with a permanent inlet screen or strainers, a removable temporary start-up screen or strainer shall be provided. This temporary screen or strainer shall be clearly identified by an extended handle or other device. This handle shall project beyond insulation materials. The open area of the screen or strainer shall have a minimum of 150 percent of the open area of the piping. Typical hole strainer size is 6 millimeters (1/4 inch). However, there may be applications where a coarser or finer screen is required. When fine mesh screen is required, the screen shall be on the upstream side of the strainer. These applications shall be identified by the piping engineering designer.

Note: Temporary screens or strainers are meant only for protection of machinery during commissioning, start-up, and a short period thereafter if required. It must be noted that this type of screen or strainer can adversely affect machinery performance as a result of its resistance to flow and by causing flow disturbances.

2.8.2.2 Acceptable temporary strainer designs include: conical, truncated conical, and T-type or similar design. The point of the conical strainer shall face upstream in the piping. Screens in T-type strainers shall point with the flow. Screen or strainer material shall be stainless steel or as specified by the piping engineering designer.

Note: Conical strainers may be installed with the point oriented downstream when explicitly specified by the equipment user.

2.8.2.3 The piping engineering designer or the supplier of the suction screen or strainer shall determine the maximum allowable differential pressure for the device. This information shall be provided to the designated machinery representative for use during machinery commissioning and start-up.

Note: The inlet screen or strainer design should be evaluated to verify that the screen will not collapse under any differential pressures expected during machinery commissioning or operation if the screen or strainer becomes completely blocked.

2.9 Machinery Outlet Piping

2.9.1 A check valve shall be installed in the discharge line of all pumps, compressors, or blowers, whether centrifugal or rotary, unless there is no possibility of a reversal of flow or pressure surge (such as water hammer) under any conditions. The check valve shall be located between the machine discharge flange and the discharge block valve.

Note: Discharge check valves do not usually provide a tight seal so should not be relied upon to provide pressure protection of the machinery.

2.9.2 Discharge piping and isolation block valves shall be the same size or larger than the machinery outlet nozzle. Discharge check valves larger than the machinery discharge nozzle are acceptable, providing check valve minimum velocity requirements are met. Discharge check valves smaller than the machinery discharge nozzle may be used, providing pressure drop is evaluated.

2.9.3 Check valves installed in vertical piping that require provision for draining liquid trapped above the check valve shall be equipped with an NPS 3/4 or larger bypass around the check valve. This bypass shall be attached to the body of the check valve and shall include a manual block valve. Alternatively, an NPS 3/4 or larger drain connection with block valve shall be provided above the check valve.

2.10 Vents and Drains

2.10.1 For piping runs NPS 3/4 or larger, all vent and drain connections shall be NPS 3/4 or larger. For run piping smaller than NPS 3/4, the vent or drain connection shall be no smaller than the run pipe.

Note: This requirement for NPS 3/4 vents and drains is intended to provide sufficient strength and rigidity to prevent damage due to externally applied loads.

2.10.2 Piping vents and drains shall be located in breakout spools on the inlet and outlet piping to the machine. These connections shall not be placed in angle sections of reducers. Machinery casing drain valves shall be located in a convenient location and not under the machine casing.

Note: On baseplate-mounted machinery, casing drains should be routed to the edge of the baseplate. For soleplate-mounted machinery, casing drains may be piped down to grade. Valves should be installed on each drain prior to any manifolding or piping away from the equipment. Drain valves should be mounted as near to the machinery as practical.

2.10.3 Drain lines from machinery shall be NPS 3/4 or larger.

2.10.4 Vent and drain lines shall be suitably arranged, isolated, and valved to prevent leakage flow between machines or between separate portions of the same machinery train.

2.10.5 For tabletop mounted machinery, drain valves shall be located beneath the deck as close to the machine as possible. These drain valves shall be accessible from the deck by valve handle extensions or from grade by chain-operated valves.

Note 1: Drain valves are located beneath the deck to avoid tripping hazards for operating personnel. Locating the drain close to the machine case minimizes a dead-leg, which can collect undesirable liquids that can freeze or cause corrosion.

Note 2: Valves NPS 1 1/2 and smaller should not be equipped with chain operators.

2.10.6 All permanent vent and drain valves not connected to a closed system shall be flanged or shall have female pipe threads. These valves shall be covered with a blind flange or shall be plugged with a solid pipe plug. The flange or pipe plug shall be of material having the same metallurgical and physical properties as the associated piping. If approved by the designated machinery representative, alternative flange or pipe plug materials may be used.

2.11 Warm-Up Lines

Machinery handling hot materials greater than 150°C (300°F) or high pour point materials shall be provided with warm-up lines to obtain and maintain machinery temperature. Warm-up lines shall be provided with sufficient flanges to allow the piping spool between the machine and the outlet check valve to be removed and/or aligned separately from the warm-up line.

Note: Warm-up line flanges allow removal of small piping prior to rigging of machine piping spools. This prevents inadvertent damage to the small piping during rigging.

2.11.1 One NPS 1 or larger reverse flow bypass line shall be provided around the discharge check valve.

2.11.2 For all double suction and multistage machines, at least two NPS 1 or larger reverse flow bypass lines shall be provided. One bypass line is around the discharge check valve. The second line bypasses the check valve and is connected into the machinery casing drain.

Note: Some machinery may require an orifice or globe valve in each warm-up line to break down pressure and control the flow rate. Care should be exercised to ensure detrimental machine rotation does not occur. See Figure B-3.

2.11.3 Warm-up lines shall be heat traced and insulated if the product will solidify at expected ambient temperatures. Warm-up lines shall be insulated to protect personnel from burns if located where personnel normally have access for operation or maintenance of the machinery.

2.11.4 Warm-up lines shall be evaluated for adequate flexibility by the piping designer due to the possibility of differential expansion between the machinery discharge line and the warm-up line.

2.12 Positive Displacement Machinery Pressure Relief

2.12.1 Positive displacement machinery shall be equipped with a pressure relief device. This pressure relief device shall be located between the machinery discharge connection and the first isolation block valve or blind.

2.12.2 Pressure relief device discharge piping shall be routed to a designated system.

Note: Typical designated systems include a flare, maintenance dropout or blowdown, thermal oxidizer, the atmosphere, scrubber, process trench, sump, storage tank, suction vessel or other process systems, or the machine suction line.

2.12.3 Pressure relief device discharge piping routed back to the machinery suction line shall enter the system between the suction isolation blind, block valve, or permanent strainer and the machine suction connection.

Note: Reference additional requirements of reciprocating compressors (see Section 3.2.5).

2.13 Piping Systems in Pulsating Service

2.13.1 A pulsation analysis and mechanical piping analysis shall be conducted on piping systems for reciprocating machinery or machinery subject to pulsating flow. These analyses shall be used to develop piping systems that minimize pressure pulsations and piping vibration. The pulsation and mechanical piping analyses shall be done in conjunction with a static piping analysis. All additional piping requirements and restraints identified as necessary by the mechanical piping analysis shall be rechecked with the static piping analysis.

Note 1: The nature of the analyses will vary with the size, complexity, and configuration of the system. For small, simple systems the analyses may be omitted or may be handled by manual methods. Large or complex systems may require a digital or analog study.

Note 2: Some rotary equipment such as lobe-type blowers generate pulsations that should be reviewed and pulsation compensation provided.

2.13.2 Pulsation dampeners, accumulators, volume bottles, orifices, and acoustically detuned piping systems shall be provided to reduce pressure pulsation levels in accordance with the pulsation analysis.

2.13.3 Pressure taps with isolation valves shall be provided to enable measurement of pulsations at the machine suction and discharge connections as well as other locations specified by the designated machinery representative.

2.13.4 Based on the data obtained from pulsation and mechanical piping analyses the piping routing, piping supports, restraints, and anchors shall be spaced to avoid resonant lengths and to restrain the generated dynamic forces.

2.13.5 No branch connection shall be installed without a justifiable need. The number of branch connections shall be kept to an absolute minimum.

2.13.6 Branch connections (such as vents, drains, pressure gauge connections, and so forth) shall be located at points where the run line is anchored.

2.13.7 Branch connections shall be installed as far from the source of vibration as practical.

2.13.8 Piping shall be routed as close to grade or to heavy concrete foundations as possible. Rigid anchors and restraints shall be used effectively to properly secure the piping.

2.13.9 Process lines shall be restrained by use of only those rigid pipe anchors, restraints, and friction slides determined necessary by the piping analyses.

2.13.10 Pipe anchors shall be anchored to concrete piers or structural steel. Piers and structural steel shall be designed to provide lateral stiffness needed to restrain dynamic forces.

2.13.11 Reinforcing steel for piers shall be properly developed in the supporting mat or foundation. Any piping supports to be added after initial installation shall be reviewed by a mechanical piping analysis. Supports required by the piping analyses added after initial installation shall be securely attached to the mat. Expansion bolts and other mechanical connections are not satisfactory for pulsating service and shall not be used.

2.13.12 Branch connections shall be kept as short as possible to minimize the vibrational moment arm. Where large masses such as relief or safety valves cannot be avoided, they shall be braced.

2.14 Miscellaneous Auxiliary Piping

2.14.1 Cooling water piping shall be made from a minimum NPS 1 Schedule 80 steel pipe. Cooling water piping shall be no smaller than the largest connection to the water jacket or heat exchanger.

2.14.2 Cooling water tubing shall be made of stainless steel with a minimum 1-millimeter (0.035-inch) wall thickness. Minimum acceptable size is 12-millimeters (0.5-inch) tubing diameter. Copper tubing is not acceptable.

2.14.3 When site thermodynamic performance measurements are to be made on a machine, sufficient pressure, temperature, flow, and sampling connections shall be provided.

Note: Instrument type, location, accuracy, and redundancy may have a significant impact on the ability to obtain data with sufficient accuracy to determine field performance. For specifics on pressure, temperature, flow, and sampling connections refer to the relevant Performance Test Code (PTC).

2.14.4 Elevation of the seal pot above the shaft centerline as well as the actual piping distance from the pot to the seal shall be in accordance with the recommendations of the mechanical seal manufacturer or the machine manufacturer.

2.14.5 Instrument connections shall be arranged to permit free drainage of condensed liquids.

Note: Drain valves should be avoided, as impulse lines may not be drained on a regular basis.

2.15 Commissioning Provisions

2.15.1 Where piping is to be steam cleaned or purged during commissioning, temperature limits and thermal effects shall be included in the design.

2.15.2 Where piping and vessels are to be chemically cleaned during commissioning, provisions to facilitate this cleaning shall be included in the piping design.

2.15.3 Steam inlet piping to machinery shall be designed such that steam blowing is possible for each branch and to each end use without major dismantling or difficult access. Any special steam blowing exits, supports, condensate drains, sample points, bypasses, and so forth, shall be included in the piping by the piping engineering designer.

2.15.4 The piping design of gas systems shall include provisions for draining and drying out the piping system after completion of hydrotesting.

Note: Temporary supports may be required during hydrotest to prevent overstressing piping or machinery nozzles that remain connected.

2.16 Oil Mist Systems

2.16.1 Oil mist main and branch headers shall not be valved.

Note: Valves introduce unnecessary flow disruptions that may cause the oil to coalesce from the mist or they may be inadvertently shut.

2.16.2 Piping unions shall be used at the oil mist console between the console and the main oil mist header.

Note: Unions allow disconnection of the mist header for cleaning and commissioning as well as replacement of the console.

2.16.3 Unless otherwise specified, oil mist main and branch headers, and drop point lateral and vertical piping shall be screwed, galvanized steel. Tubing used in the oil mist system shall be stainless steel.

2.16.4 Oil mist main and branch headers shall be sloped continuously back to the oil mist console. Only when obstructions prevent continuous sloping back to the console shall oil mist main and branch headers be sloped away from the oil mist console to a system designated by the equipment user.

Note: As oil mist is transported, some of the mist coalesces and accumulates as oil in the piping. With oil mist piping sloped back to the oil mist console, liquid oil accumulating in the piping drains back to the oil mist generator reservoir. The oil usage is much lower because only mist that reaches the machinery is consumed. Liquid oil can accumulate in a pipe and block the mist flow if the pipe is not sloped properly.

2.16.5 Unless specified otherwise by the designated machinery representative, oil mist main and branch headers shall be sloped a minimum of 2 centimeters per 5 meters (1 inch per 20 feet). Greater slope is acceptable.

2.16.6 Oil mist main and branch headers shall be supported on top of horizontal beams or pipe racks with structural angle. When approved by the designated machinery representative, oil mist main and branch headers may be suspended below beams or pipe racks.

2.16.7 Pipe sag of oil mist main and branch headers shall not exceed one-third of the pipe inside diameter. Unsupported spans of oil mist main and branch headers shall not be greater than the distance between adjacent beams.

2.16.8 Horizontal bracing shall not be used to support horizontal oil mist main and branch headers.

2.16.9 Main oil mist headers shall be run as close to the outside of the pipe rack as possible and in such a manner as to leave space for future additions of process piping in the pipe rack.

2.16.10 Oil mist branch headers shall be connected to the top of the main header with screwed tees.

2.16.11 Oil mist main and branch header piping shall be NPS 2 or larger.

Note: NPS 2 is usually adequate for most installations. A larger pipe size may be required in oil mist systems serving a large number of lubrication points. The size of the header should be large enough to limit the oil mist velocity to a maximum of 7 meters per second (22 feet per second) at the maximum oil mist generator capacity. Main and branch headers smaller than NPS 2 are discouraged due to the necessity of providing additional piping supports to prevent the increased sag resulting from the smaller pipe size and the greater vulnerability to mechanical damage.

2.16.12 Oil mist drop point lateral piping shall be NPS 3/4.

2.16.13 Oil mist drop point lateral piping shall come vertically off the top of the main header through a screwed tee.

2.16.14 Oil mist drop point lateral piping shall slope continuously to the main or branch header. When obstructions prevent continuous sloping back to the header, oil mist drop point lateral piping shall slope continuously to the drop point.

2.16.15 Unless otherwise specified by the designated machinery representative, oil mist drop point lateral piping shall be sloped a minimum of 1 centimeter per 5 meters (1 inch per 40 feet). Greater slope is acceptable.

2.16.16 Oil mist drop point vertical piping shall terminate and distribution blocks shall be located 1 meter (3 feet) above the machinery to be lubricated.

2.16.17 Oil mist drop point piping shall be located such that access for operation and maintenance of the machinery is not obstructed. Dismantlement of oil mist drop point piping or the distribution block to remove the machinery for maintenance is not acceptable.

2.16.18 Oil mist drop point lateral piping horizontal runs shall not exceed 10 meters (30 feet).

2.16.19 Block valves shall not be installed in oil mist drop point piping.

2.16.20 Oil mist drop point distribution blocks shall include a sight glass.

Note: The sight glass is typically a small, molded, clear plastic or glass device mounted at the bottom of the distribution block to provide an indication of condensed oil level in the drop point. Alternative designs are acceptable.

2.16.21 Oil mist drop point distribution blocks shall be equipped with a valve to permit the draining of oil. Distribution block drain valves shall be snap-acting, petcock, or other type that cannot open when subjected to vibration.

2.16.22 Oil mist application fittings (reclassifiers) shall be mounted in the distribution block. When specified by the designated machinery representative, oil mist application fittings (reclassifiers) may be mounted in the machinery bearing housing.

2.16.23 Oil mist feed lines from the distribution block to the machinery bearing housing shall be 6 millimeters (1/4 inch) or larger diameter stainless steel tubing.

2.16.24 Oil mist feed lines shall slope continuously downward to the machinery bearing housing. Right angle turns or bends shall be minimized.

Section 3—Machinery-Specific Piping Installation Design

3.1 Pumps

3.1.1 GENERAL REQUIREMENTS

3.1.1.1 Auxiliary piping to pumps such as gland liquid, flushing liquid, cooling water, quench steam, and so forth, shall be equipped with isolation block valves located at the pump.

3.1.1.2 Nonslam check valves shall be used in the discharge lines of centrifugal pumps in large systems. Acceptable nonslam check valves include wafer-style center-guided spring-loaded split-disc check valves or tilting-disc check valves.

Note: Large systems are typically those used to transfer water or other fluids in large volumes and/or long distances. Nonslam check valves should be considered for pumps with greater than 185 kilowatt (250 horsepower) nominal driver rating or NPS 12 or greater piping.

3.1.1.3 Pumps that are not self-venting and that handle volatile fluids at or near the fluid's vapor pressure shall have a vent back to the source or other suitable system. Vent piping shall not be less than NPS 3/4.

3.1.2 PUMP SUCTION PIPING

3.1.2.1 Pump suction piping shall be arranged such that the flow is as smooth and uniform as practicable at the pump suction nozzle. To accomplish this, the use of tees, crosses, valves, reduced port valves, strainers, near run-size branch connections, and short radius elbows shall be avoided near the suction nozzle.

3.1.2.2 The Net Positive Suction Head Available (NPSHA) for the suction piping configuration shall be checked and compared to the Net Positive Suction Head Required (NPSHR) for all pumps. For centrifugal pumps, NPSHA shall be greater than NPSHR in accordance with PIP REEP001, *Design of Centrifugal Pump Applications.* For pumps other than centrifugal pumps, NPSHA shall be greater than NPSHR in accordance with API Standard 674, *Positive Displacement Pumps—Reciprocating,* API Standard 675, *Positive Displacement Pumps—Controlled Volume,* or API Standard 676, *Positive Displacement Pumps—Rotary,* as applicable.

3.1.2.3 Suction piping shall be designed with no high points to collect vapors. If the fluid being pumped is near its vaporization temperature, the suction line shall be sloped a minimum of 10 millimeters per meter (1/8 inch per foot) toward the pump at all points to prevent the accumulation of bubbles.

Note: The direction of suction line piping slope should be as specified by the designated machinery representative.

3.1.2.4 Reducers used in horizontal suction lines shall be eccentric and shall be installed to avoid pocketing of vapors in the suction line. The flat side of the eccentric reducer shall be on top. Drain connections shall not be placed on the angle of the reducer. Reducer sections shall include provision for draining.

3.1.2.5 The reducer shall be concentric for overhead piping into a top suction pump.

3.1.2.6 The pump suction line shall have a straight run (typically five pipe diameters) between the suction flange and first elbow, tee, valve, reducer, permanent strainer, or other obstruction sufficient to ensure stable and uniform flow at the pump suction nozzle.

Note: A piping straight run length of five pipe diameters, based on the pump suction nozzle size, is usually sufficient to ensure stable and uniform flow at the pump suction nozzle. In some situations, the type and orientation of valves and elbows in the pump suction line may affect the flow distribution to the impeller and necessitate a longer piping straight run length. Flow straighteners may also be utilized to reduce the piping straight run length.

3.1.2.7 The last pipe elbow in the suction line to a pump shall be a long radius elbow.

3.1.2.8 Pump suction lines shall be routed to avoid changes in the temperature of the fluid being pumped. Lines containing cold high vapor-pressure fluids shall not be routed near hot lines or equipment, as the heat from the hot lines may vaporize the cold fluid.

3.1.2.9 For pumps taking suction from vacuum towers or columns, an equalizing line from the pump back to the vapor space in the tower or column shall be provided to vent the pump at start-up.

3.1.3 PUMP MINIMUM FLOW BYPASS

3.1.3.1 When the process or operating practice cannot ensure that the flow rate of the pump will be at or above the minimum continuous flow rate, a minimum flow bypass shall be provided. Minimum continuous flow shall be a calculated or measured value provided by the pump manufacturer and not an approximation.

Note: Pump minimum flow is based on considerations of hydraulic stability and thermal rise. The normal practice is to use the higher of these values for establishing minimum pump flow.

3.1.3.2 The minimum flow bypass line shall be routed from the pump discharge to the suction vessel, tank, or sump. An analysis shall be made that considers the thermodynamic properties of the liquid, the amount of liquid to be recirculated, and the size of the suction vessel, tank, or sump, as well as pump internal recirculation. When indicated by this analysis, a cooler shall be installed in the bypass line. The designated machinery representative shall agree with the return entry location of the minimum flow bypass line.

Note 1: With adequate cooling, consideration may also be given to routing the bypass line from the discharge to the suction line. This minimum flow bypass line should tie into the pump suction line as far as practical from the suction nozzle of the pump, but at least five pipe diameters upstream of the pump suction nozzle. Bypass control is often used on high specific speed pumps, such as axial flow pumps, because the power requirement decreases with increased flow.

Note 2: The entry of the bypass line into the pump suction line should be designed to minimize flow turbulence so as to avoid creating a pressure drop that could result in NPSH difficulties.

Note 3: Pumps should have a low-flow alarm or bypass system to alert the operator if the pumps can be operated periodically against a closed discharge control during normal operation and/or start-up.

3.1.3.3 Control of flow through the recirculation line may be by any acceptable instrumentation including a restriction orifice or a flow-sensing element with an associated control valve, a self-contained autorecirculation valve, or a combination of a flow-sensing element, solenoid valve, and restriction orifice.

3.1.4 VERTICAL PUMPS

3.1.4.1 Suction and discharge piping for vertical in-line pumps shall have adjustable supports. These supports shall be located within 1 meter (3 feet) of the pump's suction and discharge flanges. The adjustable supports shall have a means of locking their positions to preclude change due to vibration or unwarranted casual adjustment.

3.1.4.2 Vertical pumps shall be piped to drain any fluid that accumulates in the driver support structure. This drain line shall be NPS 1 or larger with a visible open end.

3.1.4.3 Vertical pumps shall include provision for the venting of gases from the seal gland plate. Vent connections shall be connected to a designated system or to the pump suction or discharge piping at a higher elevation than the seal gland plate.

Note: As the seal is located at the highest point in a vertical pump, venting of any trapped air or vapor ensures the pump seal chamber is liquid-full prior to starting the pump. Typical designated systems include a flare, maintenance dropout or blowdown, thermal oxidizer, the atmosphere, scrubber, or other process systems.

3.1.5 CANNED MOTOR PUMPS

3.1.5.1 All services where the pumped product contains particulates shall have a flush injection as described in API Standard 610, *Centrifugal Pumps for General Refinery Service,* plan 32, or API Standard 682, *Shaft Sealing Systems for Rotary and Centrifugal Pumps,* plan S 32.

3.1.5.2 The area directly behind the motor end of the canned motor pump must be clear of any obstruction for a distance equal to the length of the pump. This is necessary to allow disassembly of the pump in the field.

3.1.5.3 If the pump has an auxiliary flush, the flush piping shall be arranged so that none of the components are located in the area directly to the rear of the pump except for the final section of connecting tubing.

3.1.5.4 There shall be a breakout spool in the suction line between the suction strainer and the pump suction flange that is at least 30 centimeters (12 inches) long. This allows access to the impeller to perform a motor rotation check.

3.2 Compressors and Blowers

3.2.1 GENERAL REQUIREMENTS

3.2.1.1 Auxiliary process piping connected to compressors and blowers shall include isolation block valves and isolation blinds. This auxiliary piping includes connection to flare systems, suction vessel drain manifolds, compressor packing vents, distance piece drain manifolds, and so forth.

Note: These valves and blinds may be omitted for compressors and blowers in air service if the omission does not compromise operation or safety.

3.2.1.2 When a precommissioning test run is specified by the equipment user, the piping engineering designer shall include provisions for opening hand holes or manways on the suction vessel and piping and exhausting through restrained temporary piping.

Note: A precommissioning test run consists of operating a machine on air prior to the introduction of process gas such as nitrogen, hydrocarbon, and so forth, during the machinery commissioning phase. This test run is done with open flanges and/or valves removed so that the machine does not build pressure or generate temperature and can freely inlet and exhaust to the atmosphere.

3.2.2 SUCTION PIPING

3.2.2.1 Inlet piping to compressors and blowers shall be free of sections where liquid may accumulate during normal operation, start-up, and/or shutdown. Where such sections are unavoidable, suitable drain facilities shall be provided.

3.2.2.2 When horizontal reducers are installed in the inlet piping to compressors or blowers, they shall be eccentric with the flat side on the bottom of the pipe to prevent the accumulation of any liquids.

3.2.2.3 Suction piping to compressors in condensing service shall be designed for automatic condensate removal from low points in the compressor piping systems when the machine shuts down.

3.2.2.4 Suction vessels for compressors handling a wet gas that may condense during shutdowns shall be located as close as possible to the compressor. Suction piping layout shall be free of sections where standing liquid may accumulate and shall slope back toward the suction vessel. Adequate drains on the piping shall be provided to remove any standing liquids. Suction lines to wet gas compressors shall be heat traced and insulated.

3.2.2.5 Suction knockout vessels shall have demister pads and internal separators (if required) that assist in removing liquids.

Note: Suction knockout vessels are designed to separate any entrained liquids from the gas stream. Suction knockout vessels should be independent of any pulsation suppression devices that may also be installed. Drains on suction vessels should be large enough to allow removal of any debris expected during normal operation.

3.2.2.6 The design of inlet ducting, nonmetallic seals and expansion joints, filters, and silencers in inlet ducts shall be such that no parts of the ducting, seals, or joints can be drawn into the machine in the event of material failure.

3.2.2.7 The suction line to each compressor or blower section shall be provided with a permanent or temporary strainer.

Note 1: The screen size used in the strainer should be evaluated for each compressor installation. Nonlubricated compressors typically require finer mesh screens than lubricated compressors. Typical strainer construction consists of perforated plate with holes approximately 6 millimeters (1/4 inch) in diameter. If finer mesh screen is used, it is typically attached to the perforated plate of the strainer using the perforated plate for backing support. The fine mesh screen should be installed on the upstream side of the strainer. Other screen designs may be acceptable if approved by the designated machinery representative.

Note 2: The suction strainer/screen design should be evaluated to verify that the strainer/screen will not collapse under any differential pressures expected during compressor commissioning or operation if the strainer screen becomes completely blocked.

3.2.2.8 For compressor or blower suction lines NPS 20 and smaller, a flanged breakout spool with an in-line temporary strainer shall be located in the horizontal line as close as practical to any vertical run into the machine. Removal and cleaning of the strainer spool shall be considered in placement of the spool. Piping supports are required on each side of the spool piece. If the piping is supported by spring hanger or spring support, a locking device shall be permanently attached to the spring to lock the spring when the piping hanger or support is removed. Pressure connections shall be provided on both the upstream and downstream side of the screen or strainer.

Note: As an alternative, consider installing a T-type strainer to minimize cleaning efforts during commissioning and start-up.

3.2.2.9 When specified by the equipment user, compressor or blower suction lines larger than NPS 20 but less than NPS 30 shall have a permanent screen or strainer installed in the horizontal run of pipe downstream of the inlet block valve and as close as practical to any vertical run into the machine inlet. Pressure taps shall be provided on both the upstream and downstream side of the screen or strainer. The screen or strainer shall be able to withstand instantaneous loading assuming 100 percent blockage of the holes and maximum suction pressure. The suction line shall have flanged clean-out holes upstream and downstream of the screen or strainer. Clean-out holes shall be one-half of the suction line size up to a maximum of NPS 10.

Note: The requirement for a permanent strainer in large pipes is intended to facilitate removal of debris. It is also intended to avoid potential problems with the forces necessary to restrain a plugged temporary screen.

3.2.2.10 For "down-connected" tabletop mounted compressor or blower suction lines NPS 30 or greater, the suction line transition from horizontal to vertical shall be made using a tee with the long axis (run) oriented vertically. A blind flange or manway shall be provided at the lower end of the tee to provide access to physically inspect and remove debris from this line. Suction strainers are not required.

Note: As tees may sometimes cause flow disturbances, a removable elbow may be used if approved by the designated machinery representative.

3.2.2.11 When specified by the equipment user, compressor or blower suction lines greater than NPS 30 shall be provided with an additional tee/blind flange or manway in the horizontal run of pipe near the upstream vessel. This shall be conveniently oriented for access from an adjacent platform, ladder, and so forth. The intent is to allow 100 percent inspection of the compressor or blower suction piping from the suction vessel to the compressor or blower inlet flange.

Note: It is sometimes advantageous to clean debris from NPS 30 or larger pipe by entering the pipe, and sweeping it out by hand or using a vacuum cleaner. This can be more cost effective than large screens for catching debris. *Caution:* Entering pipe is considered working in a confined space.

3.2.3 RECYCLE LINES

3.2.3.1 Routing of compressor recycle lines shall be designed to prevent liquid from accumulating in piping low points.

3.2.3.2 Compressor recycle lines shall reenter the process stream on the top of the piping upstream of the suction vessel.

Note 1: The recycle line should be connected as far as practical from the suction of the compressor. Cooling for recycle lines may be required.

Note 2: Possible flow-induced vibration should be considered during design. A designated nozzle in the suction vessel may be an acceptable alternative design.

3.2.3.3 For systems handling corrosive or erosive gases or vapors, the location of the recycle line tie-in to the process line shall be reviewed by a corrosion/materials engineer or metallurgist for potential corrosion problems.

3.2.3.4 Antisurge recycle valves and discharge check valves shall be located as close as practical to the compressor. The discharge line shall be designed such that the volume of gas in the line between the compressor flange and the antisurge valve and the discharge check valve does not exceed the compressor manufacturer's design limit.

3.2.4 CENTRIFUGAL AND ROTARY COMPRESSORS AND BLOWERS

3.2.4.1 A straight run of piping with a minimum length as specified by the compressor or blower manufacturer shall be provided between the machine inlet nozzle and the first elbow or tee. If this straight run length is not specified by the machine manufacturer, a straight run of at least five pipe diameters shall be provided. The minimum length shall be calculated using the diameter of the compressor or blower inlet nozzle.

3.2.4.2 A nonslam (damped) check valve shall be provided in the discharge pipe run from all compressors or blowers.

3.2.4.3 The discharge line for compressors and blowers shall be designed such that the volume of gas in the line between the discharge flange and the antisurge valve and the discharge check valve does not exceed the compressor or blower manufacturer's design limit.

Note: This requirement relates to transient response of the compressor control system and affects compressor stability.

3.2.4.4 A mechanical stop shall be provided on inlet throttle control valves when utilized on centrifugal compressors or blowers with constant speed drivers. This mechanical stop shall be set to allow minimum flow through the machine as recommended by the machine manufacturer.

Note: Some flow control may be provided by variable-speed drives, and/or inlet control valves, or guide vanes. For constant-speed motor drivers, throttling of the inlet valve provides reduced load for start-up.

3.2.4.5 Suction piping configuration for double flow centrifugal compressors or blowers shall be geometrically symmetrical.

3.2.5 RECIPROCATING COMPRESSORS

3.2.5.1 For compressors handling condensing gases, the suction piping from the liquid knockout vessel shall be routed overhead to the compressor suction pulsation dampener vessel. For noncondensing gases, the piping may be routed to grade before going into the suction pulsation dampener vessel.

3.2.5.2 Unless otherwise specified, reciprocating compressor discharge lines shall not have check valves. However, if the compressor is equipped with a recycle line, a check valve shall be provided and located downstream of the recycle line. The piping engineering designer shall verify that the check valve is suitable for extended service in pulsating flow.

Note: Conventional swing check valves are usually not suitable for use in pulsating flows because frequent flow reversals result in premature valve failure.

3.2.5.3 Vent lines from reciprocating compressor pressure packing in condensing service shall be routed to a drain pot to remove liquids before being routed to the vapor disposal system. Vent and drain lines shall be routed so as not to obstruct any access covers or openings.

3.2.5.4 For reciprocating compressors handling condensing materials, the suction piping from the suction vessel to the compressor shall be heat traced and insulated to prevent liquid condensation in the piping. The compressor suction pulsation vessels shall also be heat traced and insulated. Vessels and piping covered by insulation shall be properly protected from corrosion.

3.2.5.5 A pressure relief device or devices shall be provided for each compressor cylinder or stage of a reciprocating compressor. These relief devices may be located in either the discharge piping or on the liquid knockout vessels. Relief devices shall be located between the compressor cylinder and any permanent blinds or block valves.

Note: Pressure relief devices should be sized and rated to avoid exceeding the lesser of piping pressure ratings, pulsation vessel pressure ratings, cylinder pressure ratings, or rod loads. Though rod load is a factor to be considered in the sizing and rating of reciprocating compressor discharge pressure relief protection, installation of discharge pressure relief protection does not, by itself, ensure rod loading requirements will not be exceeded. Rod load is a function of the differential pressure across a cylinder as well as inertia. Suction pressures less than or greater than the operating range indicated by the compressor manufacturer may result in unacceptable rod loads despite discharge relief protection.

3.2.5.6 Pressure relief device discharge piping shall be routed to a designated system.

Note: Typical designated systems include a flare, maintenance dropout or blowdown, thermal oxidizer, the atmosphere, scrubber, or other process systems.

3.2.5.7 Piping shall meet the design criteria specified by the pulsation analysis, piping mechanical analysis, and static piping analysis.

3.2.5.8 Drains from compressor distance pieces, packing vents, leakoffs from unloaders, and distance piece vents shall be routed in accordance with API Standard 618 or as specified by the designated machinery representative. Drain lines shall be routed so as not to obstruct any access covers or openings. Process and vent piping shall not be routed over the compressor crankcase. The area above the compressor crankcase shall be kept clear of all piping.

3.2.5.9 Compressor pulsation vessel drains should be manifolded into a single drain line. Drain line primary block valves shall be provided at each pulsation vessel. Additional drain valves shall be provided at the manifold. When a deck is provided, the manifold shall be located at grade near the edge of the decking.

3.2.5.10 When compressor piping is to be chemically cleaned, it shall be designed to facilitate this cleaning without extensive piping removal.

3.3 Steam Turbines

3.3.1 Inlet piping to steam turbines shall be free of sections where liquid may accumulate during normal operation, start-up, and/or shutdown. Where such sections are unavoidable, suitable drain facilities shall be provided. See Figure B-2.

3.3.2 Reducers installed in the inlet piping to steam turbines shall be eccentric with the flat side on the bottom to prevent the accumulation of any liquid.

3.3.3 Steam turbine gland leakoff lines shall be routed to headers as close as possible to the turbine. The transfer line shall be at least one pipe size larger than the connection furnished on the turbine.

3.3.4 An NPS 1 or larger bypass around the inlet block valve shall be provided to allow control during warm-up, carbon ring break-in, and overspeed trip tests.

3.3.5 Piping arrangements for steam piping into the turbine shall include provision for the temporary reorientation of steam inlet lines for the precommissioning "blowing" of the line. Piping arrangements shall also include provision for the installation of targets if targets are to be utilized in the precommissioning "blowing" of the line.

3.3.6 See Appendix C—Steam Piping for Turbines, for additional information on steam turbine piping design.

Section 4—Machinery Piping Installation

4.1 General Requirements

4.1.1 Piping shall not be connected to the machinery until grouting, machinery shaft preliminary alignment, and final field welding have been completed.

4.1.2 Unsupported piping shall not be installed on the machinery. Piping hangers and supports shall be installed as specified by design to minimize piping applied strain on the machinery.

4.1.3 Layout and installation of field run piping and conduit shall be jointly coordinated to provide operation and maintenance accessibility.

Note: The intention is that the piping and electrical/instrumentation equipment installers will work together in the field routing of piping and conduit. The objective is a machinery installation where the piping and conduit do not block access for operation and maintenance.

4.1.4 Electrical power and instrumentation connections to machinery shall be made with conduit of sufficient length and flexibility to not interfere with machinery alignment.

Note: Like piping, conduit to motors or instruments can impose strains on machinery. Since either flexible or rigid conduit may be used, the intent is to minimize conduit-imposed strain on the machinery. If rigid conduit is used, it may be necessary to measure conduit-imposed strains on the machinery in a manner similar to that performed for piping.

4.1.5 Suction and discharge piping for vertical in-line pumps shall have adjustable supports. These supports shall be located within 1 meter (3 feet) of the pump's suction and discharge flanges. With pipe supports adjusted and all piping made up, the pump shall be in solid contact with the foundation mounting plate. The adjustable supports shall have a means of locking their positions to preclude change due to vibration or unwarranted casual adjustment.

4.1.6 Extreme care is to be exercised at all times to ensure that fluid passages of machinery are free from dirt, foreign objects, and other contamination. The importance of cleanliness cannot be overemphasized. Temporary blinds shall be installed at the machinery flanges to prevent dirt and debris from entering the machinery during installation. All threaded openings are to be plugged with a threaded pipe plug to prevent contamination. Plastic pipe plugs are unacceptable and shall not be used.

4.1.7 Any solid preservatives such as desiccant bags shall be removed from the machinery prior to connection of piping.

4.1.8 Duct tape and plastic shall not be used for covering the ends of pipe flanges as it is prone to tearing loose and lodging within the machine.

Note: A solid metal cover with rubber gasket to cover flange openings during installation is preferred. These metal covers should remain in place until the piping is connected to the machinery.

4.1.9 Rags and towels shall not be used to stuff into the open ends of pipe or flanges.

4.2 Field Installation of Auxiliaries

4.2.1 Field-installed auxiliary equipment, piping, conduit, instruments, coolers, seal pots, consoles, and so forth, shall be mounted separately from the machine and driver. These items shall not interfere with removal of the machine or driver nor with access to the machinery for normal operation and maintenance. Refer to Figure B-1.

4.2.2 Auxiliary support piping, conduit, instrumentation, and so forth, shall be located for a single drop area on the machinery baseplate or soleplate. It is unacceptable to have piping, conduit, and other support systems installed at multiple locations on the base making maintenance and operation difficult.

4.2.3 Openings for branch connections of NPS 1 or smaller shall be made by drilling the run pipe. Torch cutting of any opening smaller than NPS 1 diameter is not acceptable.

4.2.4 Process-compatible pipe joint compounds approved by the designated machinery representative shall be used for all threaded connections. PTFE tape pipe sealant and/or antiseize lubricants shall not be used to make up any threaded connections in lubricating oil, seal fluid, buffer gas, process, or utility connections to any machine.

Note: Antiseize lubricants are not acceptable pipe joint compounds.

4.2.5 The use of threaded pipe and fitting connections shall be minimized.

4.2.6 To ensure proper thread engagement, all threaded connections shall have 2 to 5 exposed pipe threads after making up the joint.

4.2.7 The diameter and field routing of pipe or tubing to and from seal pots shall be approved by the designated machinery representative.

4.3 Hydrotest Restrictions

4.3.1 Piping hydrotest shall not be done through any type of machinery including vertical and horizontal pumps, steam turbines, blowers, or compressors. Separate hydrotest blinds shall be installed or the inlet and outlet piping spools shall be removed to isolate the machinery during hydrotest.

4.3.2 The piping hydrotest layout around vertical barrel or can pumps shall be designed to prevent water from entering the pump barrel or can.

4.3.3 Hydrotesting of the piping shall be performed after preliminary piping alignment and fit-up to the machinery. The equipment installer shall exercise care to prevent the draining of hydrotest liquids into the machinery.

Note: Hydrotesting may be required if piping welds are made to achieve piping alignment. However, hydrotest blinds and field welds can result in changes in piping-to-machinery alignment. The intention is that piping should be preliminarily aligned to the machinery, major piping modifications made, and hydrotesting completed before final piping alignment checks are made with hydrotest blinds removed.

4.4 Stray Electrical Currents

Stray currents from welding or electrical heating stress relieving can cause damage to seals, bearings, and other machinery components. Stray electrical currents can also magnetize machinery components that can later generate damaging currents. The following requirements in 4.4.1–4.4.4 shall be met for all field welds around machinery:

4.4.1 Welding ground cables shall be attached adjacent to the place where the weld is being made. The welding clamps shall be clamped onto the pipe near the weld and the welding machine properly grounded. Spring-type alligator clamps shall not be used.

Note: A double ground cable located on each side of the weld within a distance of less than 30 centimeters (12 inches) is recommended.

4.4.2 Ground leads shall not be attached to any part of the machinery, auxiliary systems, or supports for any reason.

4.4.3 Should it be necessary to attach piping to the machinery for the purpose of field welding or electrical field stress relief of pipe strain, the machinery shall be isolated from the pipe flange by using a full-circle 3-millimeter (1/8-inch) thick composition gasket. Insulated bolts or studs shall then be installed. A continuity check shall then be performed to prove the electrical isolation of the machine from the piping.

Note: The composition gasket is used to electrically insulate and protect the machinery from stray electrical currents.

4.4.4 Machinery magnetic flux density readings shall be measured and recorded before and after welding. If residual magnetism is in excess of 1 millitesla (10 gauss), degaussing shall be required.

Note: The intent is to prevent possible machinery bearing damage due to residual magnetism caused by stray electrical currents.

4.5 Design Verification

Prior to checking final piping alignment to the machinery the piping system shall be complete as follows in 4.5.1–4.5.7:

4.5.1 Pipe hydrotesting and drying out of the system shall be finished and all hydrotest blinds removed.

Note 1: Test blinds must be removed and major field welds completed before piping alignment checks are made, as hydrotest blinds and field welds can result in changes in piping-to-machinery alignment.

Note 2: Where possible, field welds required for piping alignment should be located between the isolation block valves and the machinery nozzles to permit the hydrotesting of short spools.

4.5.2 All permanent supports (fixed, sliding, spring supports, and hangers) shall be installed and adjusted.

4.5.3 All temporary supports and hangers shall be removed.

4.5.4 All the system piping components and machinery shall be at the same ambient temperature within a range of 10°C (18°F) before starting final piping alignment checks.

4.5.5 The piping engineering design inspector shall verify that the machine inlet and outlet piping is properly constructed in accordance with the piping design. This inspection shall include verification of gasket material, gasket size, the material, size, and length of flange bolts, studs, and nuts.

4.5.6 Before proceeding with piping alignment checks, the piping engineering design inspector shall verify that spring hangers and spring supports are installed with the preset spring hanger stops in position so that the springs are locked at the cold load setting. The piping engineering design inspector shall also verify that there are no visible gaps between the piping and fixed piping supports.

4.5.7 The machine shall be inspected to verify that it is still removable. This means that sufficient flanged and threaded piping connections exist to completely remove the machinery from the mounting plate for maintenance without requiring the cutting or welding of pipe or tubing.

4.6 Piping Alignment Requirements

4.6.1 Flanges of connecting piping shall not be sprung into position.

Note: If the following criteria are met there is typically little difficulty in meeting shaft deflection requirements.

4.6.2 Pipe flange bolt holes shall be lined up with machinery nozzle bolt holes within 1.5 millimeters (1/16 inch) maximum offset from the center of the bolt hole to permit insertion of bolts without applying any external force to the piping.

Note: The intent of this requirement is to ensure that flange bolts can be easily installed without the application of external force.

4.6.3 The machine and piping flange faces shall be parallel to less than 10 micrometers per centimeter (0.001 inch per inch) of pipe flange outer diameter up to a maximum of 750 micrometers (0.030 inch). For piping flange outer diameters smaller than 25 centimeters (10 inches), the flanges shall be parallel to 250 micrometers (0.010 inch) or less. For special-purpose machinery or when specified, pipe to machinery flange spacing measurements shall be recorded on the Piping Alignment Data Sheet shown in Figure B-4 in Appendix B. For raised face flanges, feeler gauge readings are to be taken at the raised face.

4.6.4 Flange face separation shall be within the gasket spacing plus or minus 1.5 millimeters (1/16 inch). Only one gasket per flanged connection shall be used.

4.7 Piping Alignment

The objective of the following requirements is to verify that strains imposed by the piping on the machinery are minimized. Less strain imposed on the machine casing results in less distortion of running clearances and better machine performance and reliability.

Note: The basic method of verifying pipe strain consists of bolting up the piping to the machine flanges while measuring the deflection of the machine shaft with dial indicators. This is done with spring hanger and spring support stops installed so that the springs are locked in the cold position to prevent spring function from masking shaft movement caused by piping-imposed strains. Excessive movement of the machine shaft as the piping is bolted up indicates that the pipe is imposing excessive strain on the machine. Spring hanger and spring support stops are then removed as a means of indicating any gross mismatch between the piping and the supports. Due to the weight of the liquid, caution should be exercised when spring hanger or spring support stops are removed and the piping is liquid-full. The equipment installer should be aware of the design basis (empty or liquid-full) before removing spring hanger or spring support stops.

4.7.1 Machinery inlet and outlet piping systems shall be separately worked into position to bring the piping flanges into satisfactory alignment with the matching machinery flanges. Moving the machinery to achieve piping alignment is not acceptable and shall not be permitted.

4.7.2 Bringing the flanges of the pipe into alignment may be done by a number of means; however, all temporary supports for piping alignment (such as chain falls and wedges) shall be removed during final alignment readings and piping bolt-up. Piping shall be supported by permanent fixed and spring supports and hangers. Piping shall not be binding on pipe guides or restraints. If spring hanger or spring support stops are not installed, the spring hangers or spring supports shall be adjusted to the cold load settings and stops installed before proceeding with piping alignment checks.

Note 1: Methods for achieving piping alignment include shimming supports, adjusting spring hanger tie-rod turnbuckles, retorquing flanges, installing piping support spacers, selectively heating one side of the pipe, ring heating, cutting and rewelding, or completely refabricating the piping. The method or methods selected are determined by the piping configuration and materials and will be different for each installation.

Note 2: Spring hanger and spring support stops must be in place to ensure the piping system is rigid during the piping alignment check. This ensures that spring movements do not mask pipe strains. However, the equipment installer should exercise care that the stopped spring hanger or support is not used as a jack or chain hoist to force the piping into position. With spring stops in place and the load plate bound up against the coil side stop, it may be difficult to know the magnitude of load being applied.

4.7.3 Adjusting the spring tension of spring hangers or spring supports as a method of achieving piping alignment is not acceptable.

Note: Spring hangers and spring supports are selected by the piping engineering designer to compensate for piping movements caused by pressure, thermal, and dynamic changes. Adjusting spring tension results in changes in the force exerted by the spring hanger or support. The spring hanger or support may no longer function as originally designed.

4.7.4 Piping movement shall be observed when spring hanger and support preset stops are removed back to the first fixed anchor point. If any spring hangers or supports are "topped-out" or "bottomed-out," the piping design and spring hanger or support selection shall be verified by the piping engineering designer. Further pipe strain checks shall not be made until corrections are made to the piping system. Preset stops shall then be reinstalled in the spring hangers and supports to lock them into cold position.

Note: In general, there should be little movement of the piping when spring hanger and spring support stops are removed. The position of the spring hangers and spring supports should remain on their cold settings. Some upward movement may be expected on liquid lines. Larger liquid lines will usually move more than smaller lines.

4.7.5 If flange alignment is to be accomplished by heating or welding of the piping, the procedure shall be approved for each type of pipe material in advance by a welding engineer or materials specialist.

4.7.6 Piping shall be disconnected from the machinery before selectively heating one side of the pipe as a method of achieving piping alignment.

Note: When diamond heating (selectively heating one side of the pipe in a diamond pattern) is used, the piping should be free of the machine to allow it to move. If the piping is fixed to the machine and diamond heating is used, the piping may impose excessive strains on the machinery resulting in machine distortion or flange breakage. When ring heat (heating the piping in a circumferential band near the machinery) is used, the piping should be attached to the machinery with an insulating gasket. The intention with ring heat is to force the piping flange to conform to the machine flange.

4.7.7 Pipe strain shall be measured while all piping connections are being made to the machine. This includes lube oil piping, cooling water piping, auxiliary piping such as steam, air, and flushing medium, as well as process piping and electrical conduits.

4.7.8 For pieces of machinery with common piping such as pairs of pumps, both shaft alignments shall be monitored during piping-up operations. Additionally, all of the machinery shall be bolted up at the same time with indicator readings taken on each shaft simultaneously.

4.8 Pipe Strain Measurement

4.8.1 An alignment bracket shall be installed on the coupling hub or shaft of the machine being checked for pipe strain.

4.8.2 Indicators shall be mounted on the coupling hub to measure vertical and horizontal movement on the opposite machine as the pipe flange bolts are being tightened using a torque wrench.

4.8.3 Bolt-up of the piping flanges to the machinery flanges shall proceed with the largest flanges first. Bolt-up must be completed in a continuous effort without disturbing the location of the dial indicators.

4.8.4 Initial tightening of the flange bolts shall be snug (10 percent of total torque). Flange bolts shall then be tightened to 30 percent of total torque. The flange bolts shall then be tightened to 100 percent of total final torque. Piping bolt torque values shall be specified by the piping engineering designer or the machinery manufacturer taking into account whether bolt threads are lubricated or nonlubricated.

4.8.5 The maximum shaft movement in either the vertical or horizontal directions after the flange is tightened shall be 50 micrometers (0.002 inch) or less. If the shaft movement is more than 50 micrometers (0.002 inch), the piping flange shall be loosened from the machinery and corrections made to the piping or supports. The flange gasket shall then be replaced and the procedure repeated. For special purpose machinery or when specified, machine shaft movement during piping bolt-up shall be recorded on the Piping Alignment Data Sheet shown in Figure B-4.

Note: Movement greater than 50 micrometers (0.002 inch) is permissible during the tightening procedure.

4.8.6 For canned motor pumps bolted to a mounting plate, pipe strain shall be checked by monitoring deflection of the casing. Indicators shall be mounted to measure horizontal and vertical movement of the rear end cover and the casing of the pump relative to the mounting plate as the piping is being bolted up. Maximum allowable deflection is 125 micrometers (0.005 inch).

Note: When canned motor pumps are not bolted to mounting plates, it is acceptable to attach an indicator bracket to one piping flange and measure the deflection of the other flange as flange bolts are tightened.

4.8.7 Reciprocating compressor piston rod run-outs shall be measured before and after connection of process gas piping to the compressor cylinders and/or pulsation vessels and compared to the compressor manufacturer's allowable run-outs or API Standard 618, as applicable. Piston rod run-outs exceeding allowable run-outs are not acceptable, and the process gas piping shall be modified to reduce measured piston rod run-outs.

4.9 Spring Hanger and Spring Support Function Check

4.9.1 After satisfactory piping alignment has been obtained, spring hanger and spring support function shall be verified.

4.9.2 All spring hanger turnbuckle locknuts shall be verified as tight.

4.9.3 With dial indicators on the coupling, movement of the machinery shaft shall be observed as the preset stops are removed to activate the spring hangers and spring supports.

4.9.4 All spring hanger and spring support load indicators shall be inspected to verify that the springs remained at their cold load setting. If spring hangers or spring supports are not at the cold load settings, they shall be adjusted to the cold load settings.

4.9.5 If there is movement at the machinery coupling, then machinery alignment shall be verified as being within the specified tolerances. These machinery alignment tolerances shall be specified by the designated machinery representative and may be different for different types of machinery.

4.9.6 If any of the spring hangers or spring supports are topped or bottomed out or if the machinery alignment is no longer within the specified tolerances, the piping design and spring hanger and spring support selection shall be verified by the piping engineering designer.

4.10 Oil Mist Piping Installation

4.10.1 All oil mist piping shall be routed and supported in the field with all joints exposed to view. No underground piping is acceptable.

4.10.2 Oil mist piping shall be fabricated to minimize the use of piping fittings. Reducing swage nipples and reducing couplings shall be used in place of reducing bushings.

4.10.3 No welded joints in the oil mist piping system are permitted.

4.10.4 Cut pipe or tubing shall be deburred or reamed so that there is no reduction of the inside diameter or any burrs at the pipe cut.

4.10.5 All piping joints shall be threaded. Threaded connections shall only be made with a light lubricating oil. PTFE Teflon® tape shall not be used to make up any threaded connections in the oil mist system. Unless explicitly approved otherwise by the designated machinery representative, alternative pipe thread sealants shall not be used.

Note: Oil mist application fittings (reclassifiers) contain small diameter orifices. Typical pipe thread sealants harden in service, forming particles. These particles migrate through the oil mist system and can plug oil mist application fittings (reclassifiers). Oil mist flow to the machinery bearings is then blocked and eventual bearing failure can result.

4.10.6 Each piece of pipe and all fittings shall be swabbed with a clean, lint-free, unused cloth or wiper prior to joining and threading connections. The equipment installer shall exercise care to keep the interior of all piping, tubing, and machinery clean.

4.10.7 Oil mist branch header to main header connections as well as drop point lateral to header connections shall be made at the top of the header pipe.

4.10.8 The oil mist application fittings (reclassifiers) shall be connected to the machinery bearing housings with the tubing arranged to allow normal operation and maintenance access without moving the application fitting (reclassifier) or the tubing.

4.10.9 Oil mist tubing shall be installed so that oil will not be trapped. Tubing benders shall be used for bending so that the tubing will have no kinks, wrinkles, or flattened spots.

4.10.10 Machinery that has previously been grease-lubricated shall have the grease fitting and vent passages cleaned before connection to the oil mist system.

4.10.11 Unless provided by the original machinery manufacturer, machinery bearing housings lubricated using purge mist shall have a permanent vent connection. The vent connection shall consist of stainless steel tubing 10 centimeters (4 inches) long attached to the top of the bearing housing and bent to point directly downward to serve as a vent. Alternative vent arrangements may be acceptable when approved by the designated machinery representative.

4.10.12 For machinery lubricated using purge mist and a constant level oiler, the constant level oiler shall be modified so that a rising oil level can overflow from the oiler.

Note: On purge mist installations, constant level oilers provide the primary lubrication to the bearings. Mist oil that coalesces within the bearing can raise the oil level in the bearing housing. If bearing housing oil level is allowed to rise too high, bearing elements can overheat due to oil churning. Typical constant level oiler modifications consist of drilling a small hole in the side of the oiler cup located slightly above the normal oil level.

4.10.13 For machinery lubricated using pure mist, an oil sight glass shall be installed in the bearing housing drain connection.

Note 1: The sight glass is typically a small, molded, clear plastic or glass device mounted at the bottom of the bearing housing to provide an indication of coalesced oil level and condition.

Note 2: If a coalesced oil return system is used, alternative drain configurations may be required.

4.10.14 Machinery bearing housing oil mist connections shall remain plugged until all oil mist system commissioning is completed and the oil mist console is placed in operation.

4.11 Miscellaneous Requirements

4.11.1 After final piping bolt-up, final shaft alignment shall be verified and all machinery shall be hand rotated to ensure that neither binding nor case distortion has occurred during piping installation. Piping spring hanger and spring support stops shall be installed during final shaft alignment checks.

4.11.2 All spring hanger turnbuckle locknuts shall be verified as tight.

4.11.3 The piping installation checklist (Appendix A) shall be completed by the equipment installer and forwarded to the equipment user as specified.

APPENDIX A—MACHINERY PIPING INSTALLATION CHECKLIST

		Initials	Date
4.1	**General Requirements**		
4.1.1	Grouting, preliminary shaft alignment, and field welding completed?	_______	_______
4.1.2	Piping hangers and supports installed per design to avoid applying strain on the machinery?	_______	_______
4.1.3	Layout and installation of piping and conduit jointly coordinated?	_______	_______
4.1.4	Electrical power and instrumentation connections to machinery made with conduit sufficiently flexible?	_______	_______
4.1.5	Suction and discharge piping for vertical in-line pumps have adjustable supports located within 1 meter (3 feet) of the pump's suction and discharge flanges?	_______	_______
	Pump in solid contact with the foundation mounting plate?	_______	_______
	Adjustable supports locked in position?	_______	_______
4.1.6	Temporary blinds installed at the machinery flanges to prevent dirt and debris from entering the machinery?	_______	_______
	All threaded openings plugged with a threaded pipe plug to prevent contamination?	_______	_______
	No plastic pipe plugs used to plug openings?	_______	_______
4.1.7	Any solid preservatives such as desiccant bags removed prior to connection of piping?	_______	_______
4.2	**Field Installation of Auxiliaries**		
4.2.1	All auxiliary equipment, piping, conduit, instruments, coolers, seal pots, consoles, and so forth, mounted separately from the machine and driver?	_______	_______
	These items do not interfere with removal of the machine or driver nor with access to the machinery for normal operation and maintenance?	_______	_______
4.2.2	Auxiliary support piping, conduit, instrumentation, and so forth, located for a single drop area on the machinery baseplate or soleplate?	_______	_______
4.2.3	Openings for branch connections of NPS 1 or smaller made by drilling the run pipe?	_______	_______
4.2.6	All threaded connections have 2 to 5 exposed pipe threads after making up the joint?	_______	_______
4.3	**Hydrotest Restrictions**		
4.3.1	Machinery isolated for hydrotesting of piping?	_______	_______
4.3.3	Preliminary piping alignment and fit-up completed?	_______	_______
4.4	**Stray Electrical Currents**		
4.4.1	A double ground cable located on each side of the weld within a distance of less than 30 centimeter (12 inches) installed?	_______	_______
	The welding clamps clamped onto the pipe and welding machine grounded?	_______	_______
4.4.2	Ground leads not attached to any part of the machinery, auxiliary systems, or supports?	_______	_______

		Initials	Date
4.4.3	Machinery isolated from the pipe flange by using a full-circle 3-millimeter (1/8-inch) thick composition gasket with insulated bolts or studs?		
	Continuity check performed to prove the electrical isolation of the machine from the piping?		
4.4.4	Magnetic flux density measured and recorded before and after welding?		

4.5 Design Verification

		Initials	Date
4.5.1	Pipe hydrotesting and drying out of the system finished and all hydrotest blinds removed?		
4.5.2	All permanent supports and hangers installed and adjusted?		
4.5.3	All temporary supports and hangers removed?		
4.5.4	All the system piping components and machinery at the same ambient temperature within a range of 10°C (18°F) before starting final piping alignment checks?		
4.5.5	The piping engineering design inspector verifies that the machine inlet and outlet piping is properly constructed in accordance with the piping and instrumentation drawings?		
4.5.6	The piping engineering design inspector verifies that spring hangers are installed with the preset spring hanger stops in position such that the springs are locked at the cold load setting before proceeding with piping alignment checks?		
	The piping engineering design inspector verifies that there are no visible gaps between the piping and fixed piping supports?		
4.5.7	The machine inspected to verify that it is still removable?		

4.6 Piping Alignment Requirements

		Initials	Date
4.6.1	Flanges of connecting piping not sprung into position?		
4.6.2	Pipe flange bolt holes lined up with machinery nozzle bolt holes within 1.5 millimeters (1/16 inch) maximum offset from bolt hole center?		
4.6.3	The machine and piping flange faces parallel to less than 10 micrometers per centimeter (0.001 inch per inch) of pipe flange outer diameter up to a maximum of 750 micrometers (0.030 inches)?		
	If piping flange outer diameters are smaller than 25 centimeters (10 inches), are the flanges parallel to 250 micrometers (0.010 inch) or less?		
	Piping Alignment Data Sheet (see Figure B-4) completed?		
4.6.4	Flange face separation within the gasket spacing plus or minus 1.5 millimeters (1/16 inch)?		

4.7 Piping Alignment

		Initials	Date
4.7.2	All temporary supports for piping alignment (such as chain falls and wedges) removed during final alignment readings and piping bolt-up?		
	Piping supported by permanent fixed and spring supports and hangers?		
	Piping not binding on pipe guides or restraints?		
4.7.4	No spring hangers or supports "topped-out" or "bottomed-out" when stops removed?		
	Stops reinstalled as preparation for final pipe strain check?		

		Initials	Date
4.7.5	Heating procedure approved in advance by welding engineer or materials specialist?	______	______
4.7.6	Piping disconnected from machinery prior to heating as method of correcting pipe strain?	______	______

4.8 Pipe Strain Measurement

		Initials	Date
4.8.2	Indicators mounted on the coupling hub to measure vertical and horizontal movement on the opposite machine as the pipe flange bolts are being tightened using a torque wrench?	______	______
4.8.4	Initial tightening of the flange bolts snug (10 percent of total torque)?	______	______
	Flange bolts then tightened to 30 percent total torque?	______	______
	Flange bolts then tightened to 100 percent of total final torque?	______	______
	Total Torque: ___________	______	______
	Lubricated Threads: ___ Nonlubricated Threads: ___	______	______
4.8.5	The maximum shaft movement in either the vertical or horizontal directions after the flange is tightened 50 micrometers (0.002 inch) or less?	______	______
	Machine shaft total vertical movement: _________		
	Machine shaft total vertical movement: _________		
	Final piping alignment measurements recorded on the Piping Alignment Data Sheet, Figure B-4?	______	______

4.9 Spring Hanger and Spring Support Function Check

		Initials	Date
4.9.1	Spring hanger and spring support function verified as acceptable? (No spring hangers or spring supports topped or bottomed out and machinery shaft alignment within the specified tolerances.)	______	______
4.9.2	All spring hanger turnbuckle locknuts verified as tight?	______	______
4.9.4	All spring hanger and support load indicators at cold load settings?	______	______

4.10 Oil Mist Piping Installation

		Initials	Date
4.10.1	All oil mist piping joints exposed to view?	______	______
4.10.2	Reducing swage nipples and reducing couplings used in place of reducing bushings?	______	______
4.10.3	No welded joints in the oil mist piping system?	______	______
4.10.4	Cut pipe or tubing deburred or reamed so that there is so reduction of the inside diameter or any burrs at the pipe cut?	______	______
4.10.5	All piping joints threaded?	______	______
	Threaded connections only made with a light lubricating oil?	______	______
	PTFE (Teflon®) tape not used?	______	______
4.10.6	Each piece of pipe and all fittings swabbed with a clean, lint-free, unused cloth or wiper prior to joining and threading connections?	______	______
4.10.7	Oil mist branch header to main header connections as well as drop point lateral to header connections made at the top of the header pipe?	______	______
4.10.8	The oil mist application fittings (reclassifiers) connected to the machinery bearing housings with the tubing arranged to allow normal operation and maintenance access without moving the application fitting (reclassifier) or the tubing?	______	______

		Initials	Date
4.10.9	Oil mist tubing installed such that no oil will be trapped?	______	______
	Tubing benders used for bending such that the tubing will have no kinks, wrinkles, or flattened spots?	______	______
4.10.10	Machinery that has previously been grease-lubricated has the grease fitting and vent passages cleaned before connection to the oil mist system is made?	______	______
4.10.11	Machinery bearing housings lubricated using purge mist has permanent vent connection?	______	______
4.10.12	Constant level oiler modified so that a rising oil level can overflow from the oiler for machinery lubricated using purge mist and a constant level oiler?	______	______
4.10.13	Oil sight glass installed in the bearing housing drain connection for machinery lubricated using pure mist?	______	______

4.11 Miscellaneous Requirements

4.11.1	Final shaft alignment verified after final piping bolt-up?	______	______
	Machinery hand rotated to ensure that neither binding nor case distortion has occurred?	______	______
4.11.2	Spring hanger turnbuckle locknuts tight?	______	______
4.11.3	This piping installation checklist forwarded as specified?	______	______

PIPING INSPECTOR ______________________________ **DATE**______________________________

APPENDIX B—MACHINERY INSTALLATION PIPING DIAGRAMS

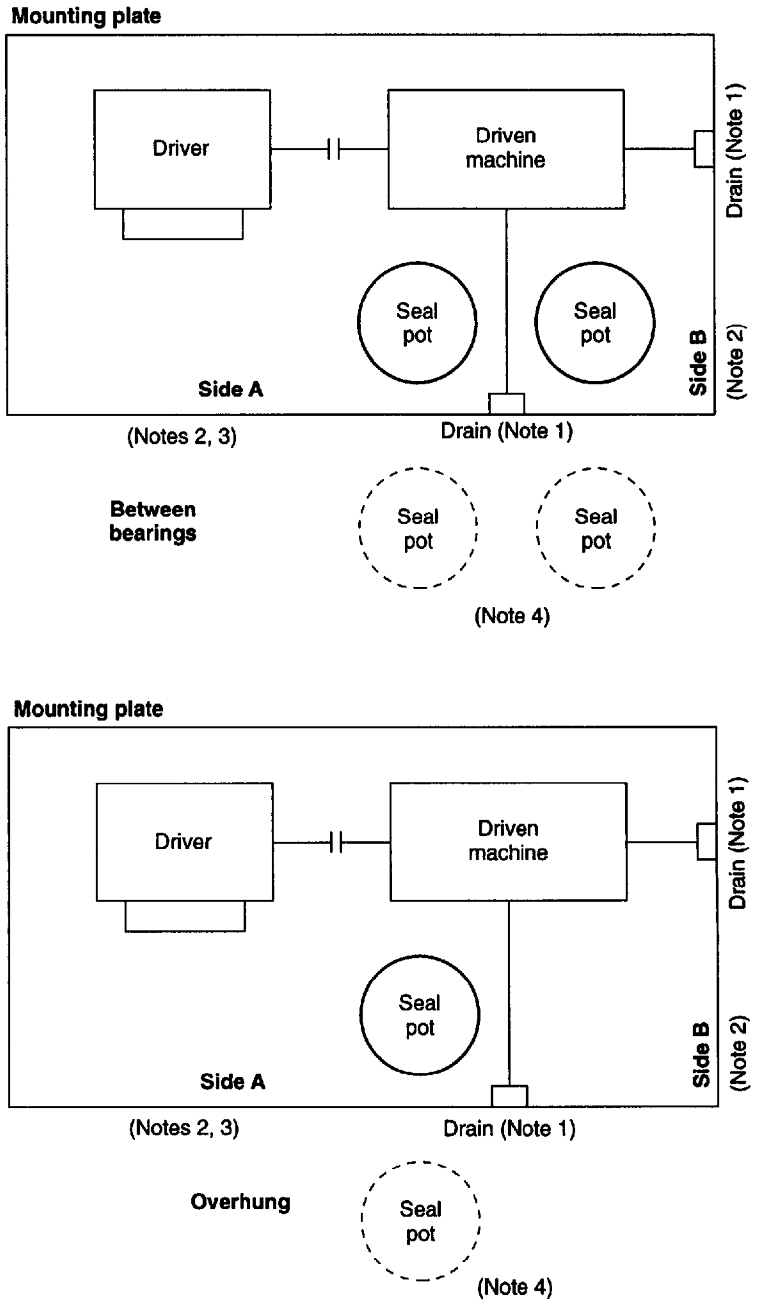


Figure B-1—Typical Seal Pot Location

Notes:
1. Drain located at Side A or Side B.
2. All tubing and auxiliary piping routed to Side A or Side B.
3. Electrical connections made on Side A.
4. When specified, alternate seal pot locations alongside mounting plate are acceptable.

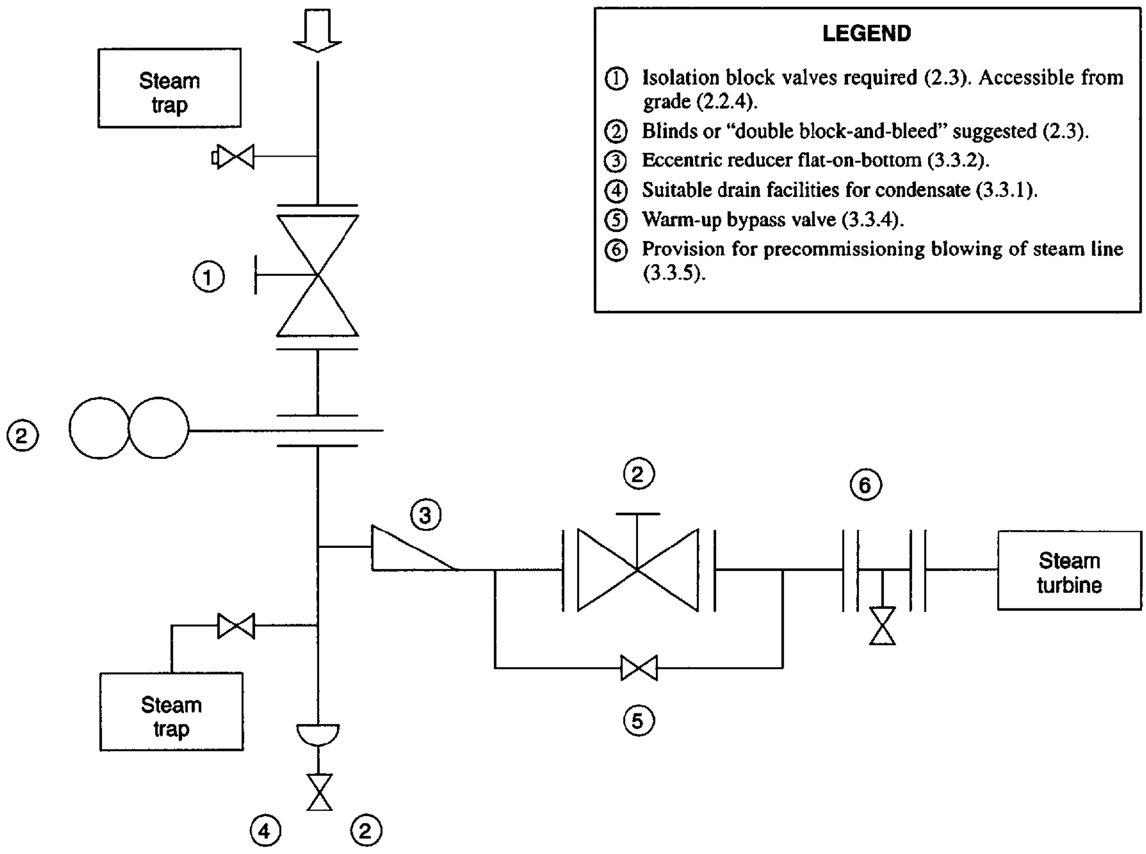


Figure B-2—Typical Steam Turbine Inlet Piping

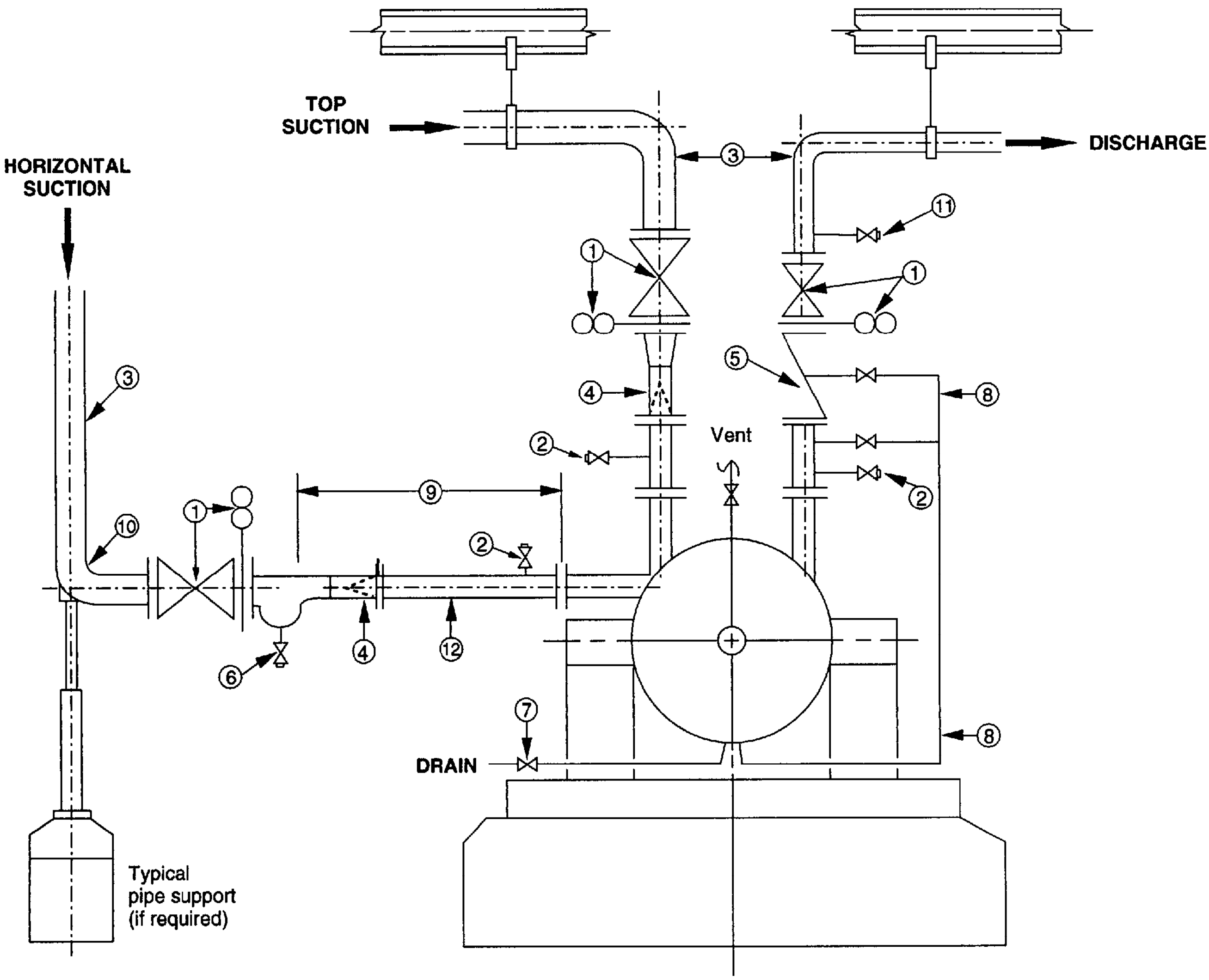


Figure B-3—Machinery Typical Piping Schematics

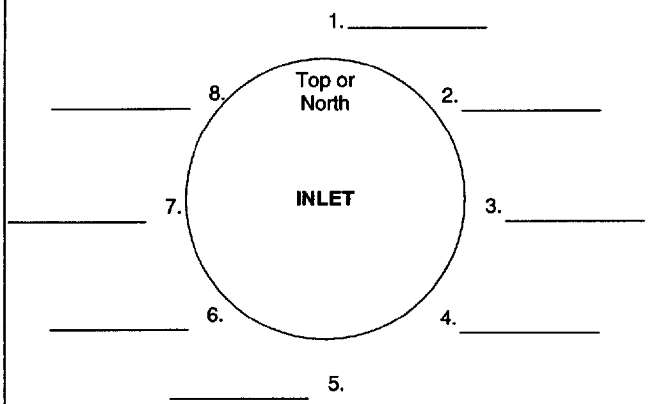
LEGEND

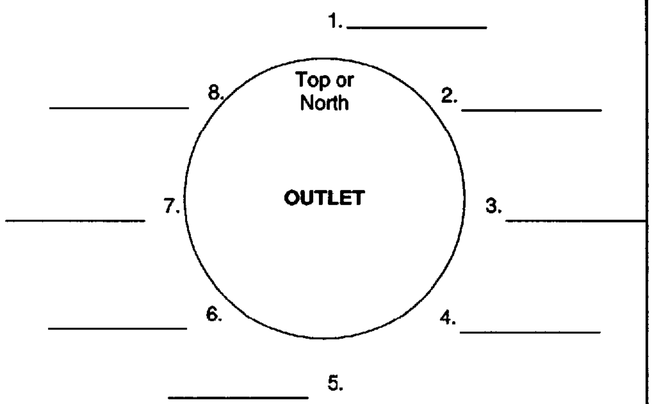
① Isolation block valves required. Blinds suggested (2.3). Accessible from grade (2.2.4).
② Pressure measurement connections required with isolation valves (2.6.1).
③ Suction and discharge piping and valves same size or larger than machine nozzle (2.7) and (2.9.2).
④ Inlet strainer required (2.8).
⑤ Discharge check valve required (2.9).
⑥ Vent and drain piping NPS 3/4 or larger (2.10.1).
⑦ Drains routed to edge of baseplate (2.10.2).
⑧ Warm-up lines for hot fluids (2.11).
⑨ Suction line straight run requirement (3.1.2.6).
⑩ Last pipe elbow to be long radius (3.1.2.7).
⑪ Drain valve above vertical check valve (2.9.3).
⑫ Provision for field weld (2.3).

Machinery Installer: ______________________ Machinery Identification: ______________________

Feeler Gauge Readings Between Gasket Faces

Flange Size: ______________________ Flange Size: ______________________





Maximum Allowable Tolerances: (difference between high & low readings)

- 10 micrometers / centimeter (0.001 inches / inch) of flange outside diameter, not to exceed 750 micrometers (0.030 inches)
- Piping smaller than NPS 10: 250 micrometers (0.010 inches) or less.
- Only 4 feeler gauge readings, equally spaced, required on flanges 15 centimeters (6 inches) outside diameter and smaller.

Pipe Strain Readings

Note:
- For horizontal machinery—Dial indicator readings on coupling hub flange.
- For vertical machinery—Dial indicator readings on driver-mount flange.

Net Indicator Readings	Inlet Flange Bolt-Up	Outlet Flange Bolt-Up
Horizontal Orientation (1)	+ or – ________ μm. or in.	+ or – ________ μm. or in.
Vertical Orientation (2)	+ or – ________ μm. or in.	+ or – ________ μm. or in.

(1) For vertical machinery, the horizontal orientation is perpendicular to pipe centerline when viewed from top.
(2) For vertical machinery, the vertical orientation is parallel to pipe centerline when viewed from top.
(3) Maximum shaft movement in either direction is 50 micrometers (0.002 inches).

Remarks: ____

Piping Inspector: ______________________________ Date: ______________

Figure B-4—Piping Alignment Data Sheet

APPENDIX C—STEAM PIPING FOR TURBINES

The inlet and exhaust piping (including feedwater heating connections) for a steam turbine may have a marked effect on the satisfactory operation of the turbine and driven machine. Due to the close internal clearance, it is not advisable to have excessive forces that may cause deflection of the turbine case and supports and reduce internal clearances below a safe limit or result in excessive coupling misalignment; coupling alignment must be maintained within close limits for satisfactory operation. Small lightweight high-speed turbines are especially susceptible to casing distortion. For these reasons the steam piping should be analyzed and properly laid out to prevent excessive forces from being transmitted to the turbine flanges.

Piping may exert forces from three basic causes: the dead weight, thermal expansion, and thrust due to expansion joints. Since thermal expansion also causes movement of the turbine flanges, this must be considered a cause of pipe reaction. Because of the many locations of inlet and exhaust flanges and probable piping arrangements, it is not possible to present a piping arrangement to cover all cases. The purpose of this appendix is to cover some of the basic principles of piping, particularly as applied to turbines. Piping design is covered quite thoroughly by manuals put out by the major piping fabricators and contractors, and it is not the intention of this appendix to duplicate what may be found in these manuals.

Piping to the turbine flanges comes under the jurisdiction of the ASME *Boiler and Pressure Vessel* Code, the ASA Code for Pressure Piping, or the American Bureau of Shipping. The applicable code will determine the size and type of pipe used and will not be discussed in this appendix.

EXHAUST PIPING

Low-pressure and vacuum lines are usually large and relatively stiff. It is common practice to use an expansion joint in these lines to provide flexibility. If an expansion joint is improperly used, it may cause a pipe reaction greater than the one it is supposed to eliminate. An expansion joint will cause an axial thrust equal to the area of the largest corrugation times the internal pressure. The force necessary to compress or elongate an expansion joint can be quite large, and either of these forces may be greater than the limits for the exhaust flange. In order to have the lowest reaction, it is best to avoid absorbing pipe line expansion by axial compression or elongation. If it is found that expansion joints are required, it is essential that they be properly located and their function determined.

Figure C-1 shows an expansion joint in a pressure line. The axial thrust from the expansion joint tends to separate the turbine and the elbow. To prevent this, the elbow must have an anchor to keep it from moving. The turbine must also absorb this thrust and in doing so becomes an anchor. This force on the turbine case may be greater than can be allowed. In general this method should be discouraged.

Figure C-2 shows the same piping arrangement as Figure C-1 except for the addition of tie rods on the expansion joint. The tie rods limit the elongation of the joint and take the axial thrust created by the internal pressure so it is not transmitted to the turbine flange. The tie rods eliminate any axial flexibility, but the joint is still flexible in shear, that is, the flanges may move in parallel planes. The location of this type of joint in the piping should be such that movement of the pipe puts the expansion joint in shear instead of tension or compression.

Figure C-3 is an arrangement frequently used, having tie rods as indicated. This arrangement will prevent any thrust due to internal pressure from being transmitted to the exhaust flange and retains the axial flexibility of the joint. It may be used for either vacuum or pressure service.

Figure C-4 shows a suggested arrangement for a condensing turbine with an up exhaust. This arrangement is recommended and frequently used. Due to the large exhaust pipe size normally encountered on condensing turbines, the exhaust piping will be relatively stiff, and an expansion joint must be used at some point to take care of thermal expan-

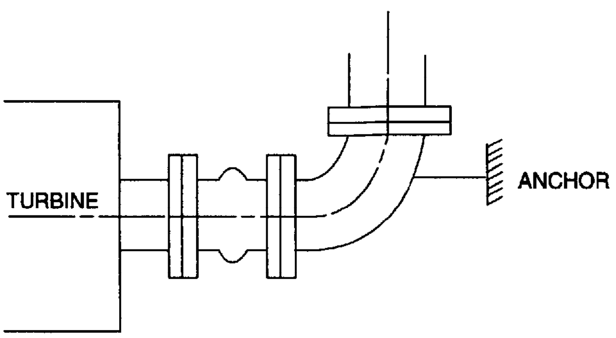


Figure C-1

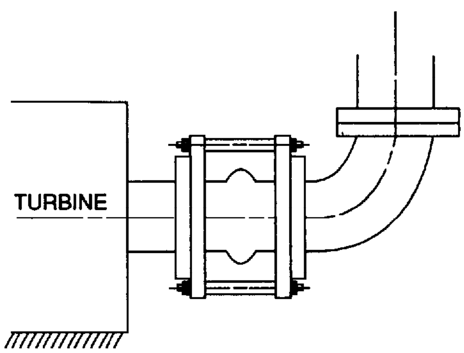


Figure C-2

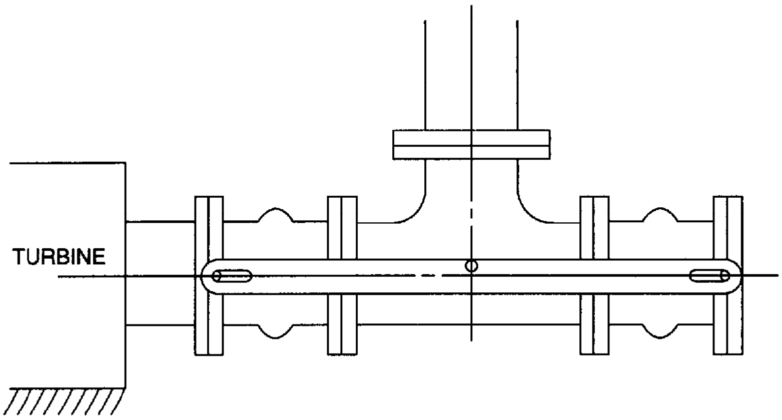


Figure C-3

sion. An unrestricted expansion joint placed at the exhaust flange of the turbine will exert an upward or lifting force on the turbine flange, which in many cases is excessive. Figure C-4 provides the necessary flexibility to take care of thermal expansion without imposing a lifting force on the turbine. The expansion joint is in shear, which is the preferred use. The relatively small vertical expansion will compress one joint and elongate the other, which causes a small reaction only and will be well within the turbine flange limits.

On smaller and high-pressure exhaust lines it is frequently better to rely on the flexibility of the piping than on an expansion joint. Only after a careful analysis of the piping shows the need for an expansion joint should they be used.

In order to have flexibility in piping, short direct runs must be avoided. By arranging the piping in more than one plane, torsional flexibility may be effectively used to decrease the forces.

Figure C-5 shows a short direct run to an exhaust header. If the header is free to float in a horizational plane, thermal expansion of the exhaust line will put very little direct thrust on the exhaust flange. If the header is fixed, the thermal expansion will tend to cause either the turbine or header to

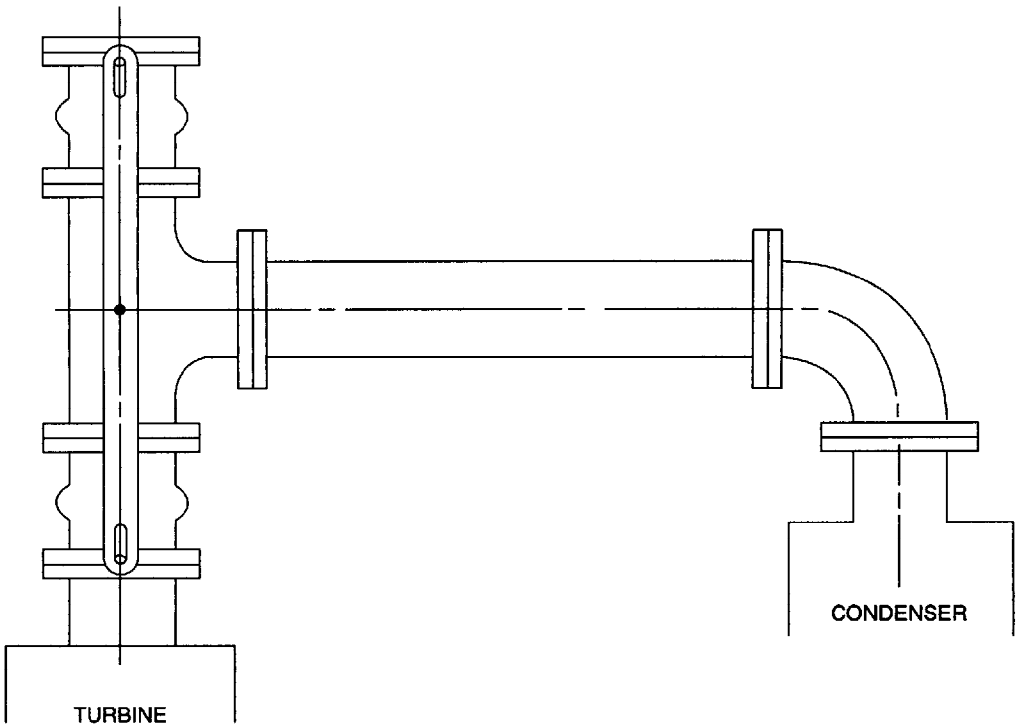


Figure C-4

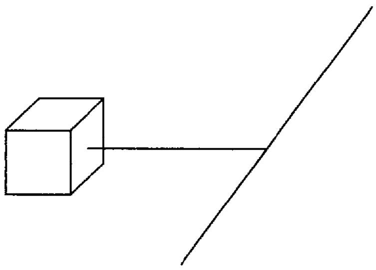


Figure C-5

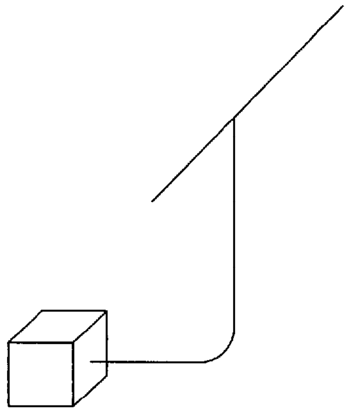


Figure C-6

move and may cause damage. If thermal expansion causes the header to move in an axial direction, it will transmit a force and moment to the exhaust flange. Figure C-5 is not recommended, as it is difficult to prevent excessive forces from being transmitted to the exhaust flange. Figure C-6 is a variation of Figure C-5 and the same comments apply.

Figures C-7, C-8 and C-9 show piping arrangements in 1, 2, and 3 planes where long runs of pipe are used to get flexibility. The length of the runs necessary for flexibility depends on the size and schedule of the pipe. In these cases it is assumed that the turbine is a fixed point and the point of connection to the header "A" is fixed. If "A" is free to move, it may relieve some of the forces caused by thermal expansion. If "A" is free and thermal expansion of the header causes it to move, it may cause additional forces to be transmitted to the turbine. With existing piping installations or new piping systems, it is necessary to examine the entire system and locate the fixed points from which deflection and movements may be measured. Guides, tie rods, and stops should be used to limit movements where necessary, to pre-

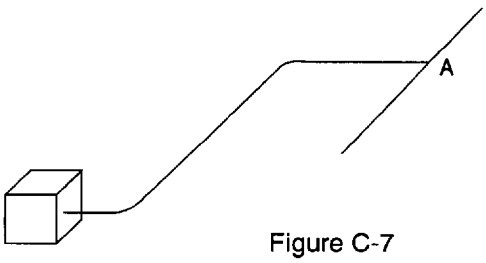


Figure C-7

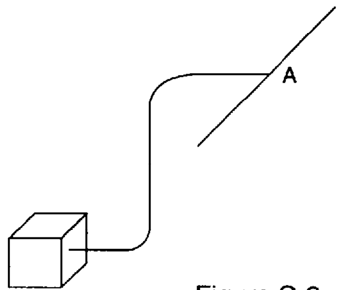


Figure C-8

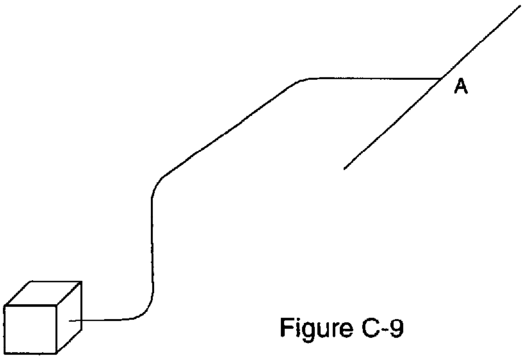


Figure C-9

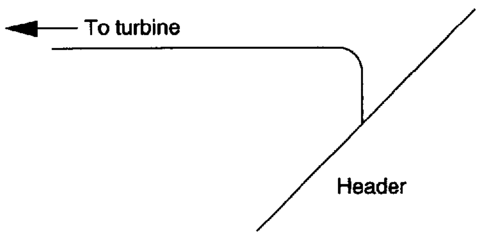


Figure C-10

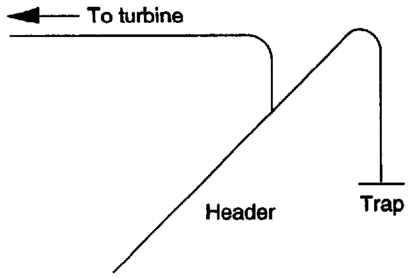


Figure C-11

vent excessive piping movement from creating forces and moments that exceed the turbine flange limits.

STEAM INLET PIPING

The forces on the steam inlet flange are normally due to thermal expansion. Expansion joints are seldom used due to the high pressures encountered; therefore, utilizing the pipe flexibility is the only means of keeping the forces below the specified limits. Figures C-7, C-8, and C-9 apply to inlet piping as well as exhaust lines, except that the take-off from a steam header should be on the top.

Figure C-10 shows the recommended method of taking a steam line from a header. Since any steam line, even with superheated steam, may have entrained moisture or condensate running along the bottom of the pipe due to radiation losses, boiler priming, or ineffective trapping, taking steam off the top of the header assures dry steam under normal conditions.

If a steam inlet line is at the end of a steam header, it should be taken off as shown in Figure C-11. Since any accumulation of condensate in the header will be carried along until it is trapped out or reaches the end of the header, the turbine on the end of the header may get a lot of water. The header should continue past the last steam take-off with a vertical drop-leg to accumulate the condensate to be trapped out. The use of a large, well-trapped drop-leg makes a very effective separator that will help to protect the turbine from large volumes of water such as caused by priming of a boiler.

Avoid low spots or pockets in inlet piping that may accumulate water. A pipe partially filled with water may continue to pass the quantity of steam required by a turbine until the steam passage becomes too restricted by the water. At this point the steam will start to move the water, which builds up as a wave and is carried along as a slug of water that can cause serious damage to the piping and the turbine. This is more prevalent in oversize steam lines where the steam velocity is too low to carry all the entrained moisture along.

A new piping system should be blown out by disconnecting the steam line at the turbine and running it to atmosphere. Blow the line out by opening a shut-off valve as near the boiler as possible so a high steam velocity is attained in the piping. Alternate blowing and cooling will tend to loosen scale, welding heads, and debris so it will be blown out.

PIPING SUPPORTS

In the previous discussion the weight of the piping has not been considered. The dead weight of the piping should be entirely supported by pipe hangers or supports. There are basically two types of supports, rigid and spring. Rigid supports are necessary when an unrestricted expansions joint is used. Rigid supports may be used to limit the movement of a line to prevent excessive deflection at any point. A rigid support is not satisfactory where thermal expansion may cause the pipe to move away from the support.

On the two types of rigid supports shown in Figure C-12, the rise of the turbine case due to temperature would lift the base elbow from the support so the turbine would have to support the weight of the pipe. The expansion of the vertical run of pipe would relieve the pipe hanger of its load so the turbine would again have to support the weight of the pipe.

If an expansion joint with restraining tie rods is used, either a rigid pipe hanger or a base elbow with a sliding or rolling contact surface may be used as shown in Figure C-13.

When the thrust due to an expansion joint is less than the exhaust flange limits and no restraining tie rods are used, the pipe must have an anchor as shown in Figure C-14. Since this condition rarely exists, it is better to use one of the better arrangements such as shown in Figure C-13, and eliminate as much pipe reaction as possible rather than just stay within the limits.

Spring hangers or supports are best suited to carry the dead weight when there is thermal expansion to be considered. The movement of the pipe will change the spring tension or compression a small amount and the hanger loading

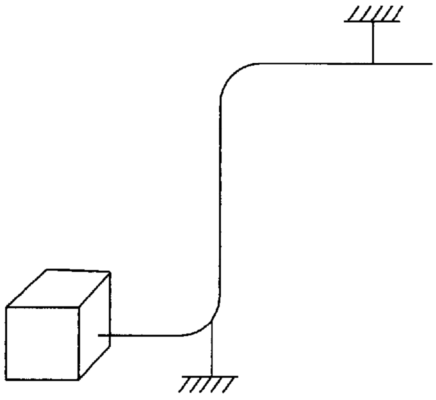


Figure C-12

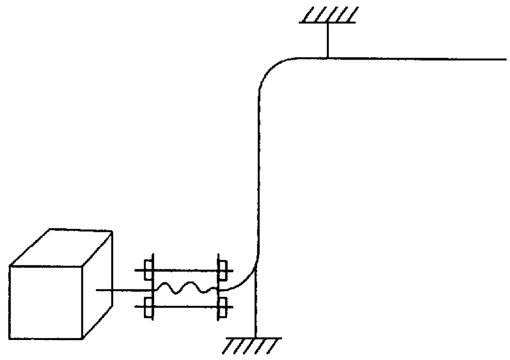


Figure C-13

a small amount but will not remove the load from the hanger. The published manuals on pipe design provide information on hanger spacing to give proper support. In addition to this, it may be necessary to add additional supports or move existing supports if resonant vibration appears in the piping.

A spring support should not be used to oppose the thrust of an expansion joint, because when the pressure is removed from the line the spring support will exert a force the same as the expansion joint, only in the opposite direction.

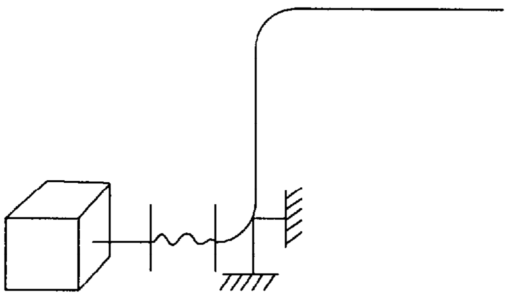


Figure C-14

Recommended Practices for Machinery Installation and Installation Design

Chapter 7—Shaft Alignment

Manufacturing, Distribution and Marketing Department

API RECOMMENDED PRACTICE 686
PIP REIE 686
FIRST EDITION, APRIL 1996

Process Industry Practices

American Petroleum Institute

CONTENTS

Recommended Practices for Machinery Installation and Installation Design

CHAPTER 7—SHAFT ALIGNMENT

Section 1—Definitions

1.1 alignment: The process of reducing the misalignment of two adjacent shafts connected by a coupling so that the center of rotation for each shaft is as near collinear as practical during normal operation.

1.2 ambient offset: The practice of misaligning two shaft centerlines at ambient conditions to account for the estimated relative changes in shaft centerlines from ambient conditions to operating conditions.

1.3 angular misalignment: The angle between the shaft centerline of two adjacent shafts. This angle is normally reported in slope of millimeters of change per decimeter of linear distance (mils per inch) (1 mil = 0.001 inch) (see Figure 1).

Note: Most misalignment is combination misalignment. It can be resolved into a parallel offset at a given point along the fixed machine centerline and angular misalignment in both the horizontal and vertical planes. The offset is dependent on the location along the fixed machine centerline where it is measured, normally the center of the coupling spacer.

1.4 bolt bound: Where any hold-down bolt is not free in the bolt hole, so that the ability to move the moveable element in a machinery train horizontally or axially is constrained.

1.5 combination misalignment: When the centerlines of two adjacent shafts are neither parallel nor intersect (refer to Figure 2). This misalignment is normally described in both angular and offset terms.

1.6 designated machinery representative: The person or organization designated by the ultimate owner of the equipment to speak on his behalf with regard to machinery installation decisions, inspection requirements, and so forth. This representative may be an employee of the owner, a third party inspection company, or an engineering contractor as delegated by the owner.

1.7 distance between shaft ends (DBSE): The axial dimension between two adjacent machinery shaft ends.

1.8 elastomeric coupling: A coupling that obtains its flexibility from the flexing of an elastomeric element.

1.9 equipment installer: The person or organization charged with providing engineering services and labor required to install machinery in a user facility after machinery has been delivered. In general, but not always, the installer is the project construction contractor.

1.10 equipment user: The person or organization charged with operation of the rotating machinery. In general, but not always, the equipment user owns and maintains the rotating machinery after the project is complete.

1.11 equipment train: Two or more rotating equipment machinery elements consisting of at least one driver and one driven element joined together by a coupling.

1.12 flexible-element coupling: A type of rotating machinery coupling that describes both disk and diaphragm couplings. A flexible-element coupling obtains its flexibility from the flexing of thin disks or diaphragm elements.

1.13 gear coupling: A type of rotating machinery coupling that obtains its flexibility by relative rocking and sliding motion between mating, profiled gear teeth.

1.14 general purpose: Refers to an application that is usually spared or is in noncritical service.

1.15 operating temperature (thermal) alignment: A procedure to determine the actual change in relative shaft positions within a machinery train from the ambient (not running) condition and the normal operating temperature (running) condition by taking measurements from startup to normal operating temperature while the machine(s) is (are) operating, or after the shafts have been stopped but the machines are still near operating temperature.

1.16 parallel offset misalignment: The distance between two adjacent and parallel shaft centerlines (see to Figure 3). This offset is normally reported in a unit (millimeters or mils) at the flex element location.

1.17 special purpose: An application for which the equipment is designed for uninterrupted, continuous operation in critical service and for which there is usually no spare equipment.

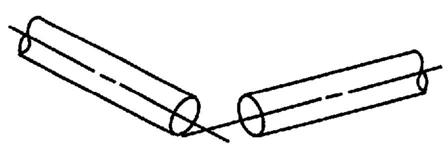


Figure 1—Angular Misalignment

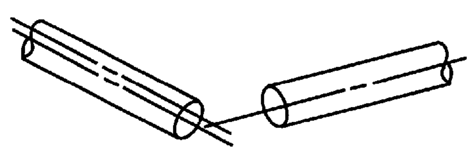


Figure 2—Combination Misalignment

1.18 total indicated runout (tir): The runout of a diameter or face determined by measurement with a dial indicator (also known as *total indicator reading*). The indicator reading implies an out-of-squareness equal to the reading or an eccentricity equal to half the reading.

1.19 vendor: The agency that manufactures, sells, and provides service support for the equipment.

Section 2—Introduction and Conflicting Requirements

2.1 Introduction

Good shaft-to-shaft alignment of rotating machinery is essential for long-term operation. Operating history by users has indicated it is good practice and cost effective to limit the operating misalignment to low values. Good shaft alignment reduces the forces acting on rotating shafts, bearings, and other wearing components. This ultimately leads to longer, more reliable operation of machinery trains. The main consideration is to reduce, as much as practical, the operating misalignment of two rotating shaft elements connected by a coupling element.

For the purpose of this chapter, a machinery train consists of two rotating shafts connected by a coupling. Trains with more than one coupling are divided into two or more single coupling trains and treated in sequence.

One of the most important factors in ensuring that alignment of machinery is good at the completion of installation is the early involvement of the designated machinery representative during construction.

2.2 Scope

This recommended practice is limited to horizontally mounted machinery elements where at least one element is free to move in the horizontal, vertical, and axial directions. Any equipment trains in a user facility, where one or more of the elements in the train is covered by API rotating equipment standards and/or ASME horizontal pumps standards, may be covered by this practice. Vertically installed and other equipment "assemblies" that are aligned by means of rabbet or machined fits are not covered by this chapter. It is the responsibility of the supplier and purchaser to provide acceptable alignment before this type of machinery is installed in the field. The user may consider checking the alignment of this type of equipment when it is installed in the field. The procedures may be developed jointly between the user, equipment installer, and equipment supplier. Also excluded is internal equipment alignment of rotating shaft to stationary elements or internal alignment of equipment by adjusting support positions (for example, reciprocating compressors alignment by web deflection).

2.3 Conflicting Requirements

Any conflicts between this recommended practice and/or the equipment vendor's procedures or tolerances shall be referred to the user or the designated machinery representative. In general the most restrictive shall apply.

Section 3—General Requirements

3.1 Installation Data

Prior to alignment, the designated machinery representative shall provide data sheets and equipment arrangement drawings with, as a minimum, the information required in 3.1.1 through 3.15 completed for each equipment train. It shall be the designated machinery representative's scope to obtain the necessary alignment-related information from all vendors no matter how the equipment train is purchased or packaged and to coordinate all information necessary for alignment. Further, the designated machinery representative is responsible for providing the alignment information to the equipment installer in the specified format.

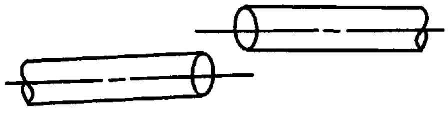


Figure 3—Parallel Offset Misalignment

3.1.1 Define movable and fixed machines in a train.

3.1.2 Provide equipment outline drawings with the distance between shaft ends (DBSE) and/or coupling spacer gap length.

3.1.3 When required, ambient offset alignment ideal target readings shall be supplied.

Note 1: The coupling spacer or distance between shaft ends (DBSE) readings and ambient offset readings are to be at operating conditions. All factors that can have an influence upon the relative position of the equipment centers of rotation or shaft axial position need to be considered. This includes, but is not limited to, factors such as load, ambient temperature, process pressure, and process temperature.

Note 2: In general, for special-purpose equipment trains the equipment vendor will provide expected thermal growth changes and ambient offset.

3.1.4 Provide the locations of dowel pins, centering keys, keyways, bashings, and other similar items, when they are part of the equipment or required by the user.

3.1.5 The type of alignment method to be used.

3.2 Format

3.2.1 The user may specify the checklist and alignment data sheets from this practice. Alternately, the user or designated machinery representative may furnish installation checklists and data sheet forms for documentation of equipment alignment in the field.

3.2.2 Data sheets for trains consisting of more than two shafts that must be aligned shall be jointly agreed between the equipment installer and the user.

Note: The standard data sheet format may be used if a data sheet is made for each coupling and the two machinery elements connected by the coupling.

3.3 Ambient Offset

3.3.1 Ambient offset alignment readings shall be provided by the user's designated machinery representative for general-purpose equipment trains with gearboxes.

3.3.2 Ambient offset alignment readings for special-purpose equipment trains shall be included on the data sheets by the designated machinery representative.

Note: For special-purpose equipment, the vendor with overall unit responsibility normally will provide the thermal growth and ambient offset readings for the train. It is up to the designated machinery representative to ensure this information is included on the data sheets.

3.4 Operating Temperature Alignment

The user will identify which equipment trains are to be operating temperature aligned by the equipment installer.

Note: Operating temperature alignment may be required when the equipment train operates above 150°C (300°F). Operating temperature alignment may be required on equipment trains where the user or the equipment vendor has experienced alignment-related vibration problems. It may also be required on equipment trains (prototype equipment trains) where the vendor has insufficient data to accurately predict equipment growth.

3.5 Alignment Fixtures and Tools

3.5.1 The equipment installer shall provide alignment fixtures (brackets) for the type of alignment specified by the user or user's designated representative. For general-purpose equipment trains, alignment brackets may be built by the equipment installer or may be a commercially available type specified by the user. Unless otherwise specified, for special-purpose equipment the alignment fixtures shall be made for each special-purpose equipment train. The design of the fixture shall be jointly agreed upon by the equipment installer and the user or the user's designated representative.

3.5.2 The equipment installer shall furnish the special tools and computers and/or calculators required for the type of alignment specified.

3.5.3 Unless specifically exempted in the agreement between the user and the equipment installer, all special tools, alignment fixtures, and alignment brackets shall be tagged with equipment train item (identification) number and turned over to the user at the end of the project.

3.5.4 When the equipment installer is required by the user to perform operating temperature alignment requiring special tools, the equipment installer shall be responsible for providing the special tools unless specifically excluded from the installer's scope of supply. The equipment installer shall permanently tag and turn over to the user the operating temperature alignment fixtures and jigs at the completion of the project.

3.5.5 The use of magnetic alignment fixtures (brackets) is not permitted.

3.6 Service Representative Hold Points

The user or the designated machinery representative in conjunction with the equipment installer shall jointly identify on the project construction plan any equipment vendor's service representative alignment witness "hold" point necessary to maintain the equipment warranty.

Section 4—Alignment Types

4.1 General

The user or the designated machinery representative and the equipment installer shall mutually agree on the appropriate type of alignment to be used for rotating equipment trains.

4.2 Dial-Indicator-Based Alignment

4.2.1 Unless otherwise specified, the equipment installer shall use the reverse rim (dial) indicator method to align equipment trains.

4.2.1.1 General requirements for reverse rim (dial) indicator method are listed in 4.2.1.2 through 4.2.1.7.

4.2.1.2 Reverse dial (rim) alignment shall be performed while turning both shafts at the same time in the direction of rotation.

Note: It is acceptable but generally less efficient to do reverse dial (rim) alignment by installing a bracket on only one shaft at a time so long as both shafts are moved at the same time.

4.2.1.3 Equipment shall be turned by hand whenever possible. When this is not possible, a strap wrench shall be employed. Pipe wrenches or any other turning devices that may mark the shaft or coupling are not allowed even if the shaft or coupling is protected during turning.

4.2.1.4 The alignment brackets shall not be used to rotate equipment. The only exception is for alignment brackets that have been specifically designed to rotate equipment without disrupting the indicators.

4.2.1.5 Readings shall be at 90 degree increments in the horizontal and vertical planes.

4.2.1.6 The installer shall use a level or other positive means to locate the vertical and horizontal planes.

4.2.1.7 For readings to be considered valid, the readings and zero shall repeat within 0.02 millimeter (1 mil). The algebraic sum of the horizontal readings shall also be equal to the algebraic sum of the vertical readings within 0.05 millimeter (2 mils).

4.2.2 When specified, rim and face alignment may be used.

Note: Rim and face alignment is recommended when the coupling hub or shaft end flange diameter is greater than the spacing between indicators or one of the train elements cannot be turned.

4.2.2.1 General requirements for rim and face indicator method are listed in 4.2.2.2 through 4.2.2.6.

4.2.2.2 Both shafts shall be turned together unless it is not possible to rotate one of the machinery element shafts during the alignment process.

4.2.2.3 Equipment shall be turned by hand whenever possible. When this is not possible, a strap wrench shall be employed. Pipe wrenches, chain wrenches, or any other turning devices that may mark the shaft or coupling are not allowed even if the shaft is protected during turning.

4.2.2.4 The alignment brackets shall not be used to rotate equipment. The only exception is for alignment brackets that have been specifically designed to rotate equipment shafting without disrupting the indicators.

4.2.2.5 Rim readings shall be taken with a dial indicator. When rim readings are made to a stationary shaft or hub, the equipment installer shall confirm the machined surface of the stationary machine is concentric to the centerline of rotation.

4.2.2.6 Face readings shall be taken with a dial indicator whenever possible. When there is insufficient space or one of the shafts cannot be rotated, micrometer measurements to an accuracy of 0.01 millimeter (0.5 mil) are to be used.

4.3 Nondial-Indicator-Based Alignment

4.3.1 Laser alignment shall be used when specified by the user or the designated machinery representative.

Note: Laser alignment is alignment by a laser beam where the laser is mounted on one shaft, and a receiver or reflector is mounted on the other. The deviation in the beam is measured as the shaft is turned. There are several commercially available systems, each with different options for alignment configuration and transducer mounting.

4.3.1.1 General requirements for laser alignment are listed in 4.3.1.2 through 4.3.1.9.

Note: The calibration date for the laser alignment apparatus should always be checked prior to its use. As a general rule, laser alignment tools should have their calibration checked every six months.

4.3.1.2 Interpretation of the data shall be done by an alignment computer supplied with the laser alignment system and configured for the equipment train dimensions and ambient offset.

4.3.1.3 The laser alignment equipment shall be installed for a period of time sufficient for the temperature of the brackets to equalize with the surroundings.

4.3.1.4 Both shafts shall be rotated at the same time in the direction of rotation. Equipment shall be turned by hand whenever possible. When this is not possible, a strap wrench shall be employed.

4.3.1.5 Pipe wrenches or any other turning devices that may mark the shaft or coupling are not allowed even if the shaft is protected during turning.

4.3.1.6 Alignment fixtures shall not be used to rotate the equipment.

4.3.1.7 The location where readings are taken shall be measured with a level or other device to positively locate the reading points in the horizontal and vertical plane.

4.3.1.8 Laser alignment equipment shall be operated by personnel trained in its use.

4.3.1.9 The equipment installer shall comply with all safety and control requirements for electrically powered equipment.

4.4 Operating Temperature (Thermal) Alignment

4.4.1 There are several recognized systems for determining the change in alignment between ambient conditions and operating conditions. The designated machinery representative and the equipment installer shall agree on which equipment trains operating temperature alignment will be used and the recognized system to be used. Several of the currently recognized methods for operating temperature alignment are outlined in Appendix D, paragraph D.4.

Note: Methods that involve shutting the equipment down and attempting to get alignment readings while the machine cools down are normally unacceptably inaccurate. In some cases where the machines can be checked by heating to operating conditions while the equipment is stopped, it may be acceptable to do operating condition alignment. An example of this would be to monitor alignment readings as a pump is preheated to operating temperature by back-flowing through the pump.

4.4.2 When operating temperature alignment is required, alignment checks shall be done with the equipment in operation. The procedure and tolerances for operating temperature alignment shall be mutually agreed upon by the designated machinery representative and the equipment installer.

Note: If an equipment train exhibits misalignment-related symptoms during initial plant start-up or site testing, check first that the operating conditions are in-line with the predicted conditions. Other potential causes, such as pipe strain, should also be investigated. See the piping section of this recommended practice for pipe strain requirements and checks. If an equipment train continues to exhibit misalignment symptoms, the user or designated machinery representative may coordinate with the equipment installer to fit an operating temperature alignment system that will indicate changes in relative shaft position of equipment from ambient conditions up to operating conditions.

4.4.3 The equipment installer may be directed during testing or start-up to adjust ambient offset of an equipment train provided with an operating temperature alignment system. The ambient cold offset data shall be provided by the designated machinery representative.

Section 5—Field Alignment Requirements

5.1 Prealignment

Prior to alignment of an equipment train, the prealignment activities outlined in 5.1.1 through 5.1.13 shall be completed by the equipment installer.

5.1.1 A prealignment meeting shall be held between the designated machinery representative and the installer's personnel responsible for machinery alignment activities.

5.1.2 The foundation shall be cured and mounting plate installed and leveled in accordance with the procedures outlined in other sections.

5.1.3 The equipment shall be installed on the mounting plate or plates with the component that is designated fixed, centered in the hold-down bolts.

5.1.4 Prior to beginning alignment activities, the coupling hubs shall be installed in accordance with the equipment arrangement drawing and instructions. Coupling hub run-out readings shall be taken at the coupling hub rim on machined surfaces perpendicular to the centerline of rotation. Readings shall also be taken on the face of the coupling hub machined surfaces as far as practical from the shaft center of rotation. Installed coupling hubs shall have 0.05 millimeter (2 mils) or less total indicator run-out (TIR) or the equipment vendor's requirements, whichever are more restrictive. This limitation applies both to the coupling rim as well as to the coupling face.

Note 1: Special-purpose equipment coupling hub run-out requirements often will be more restrictive.

Note 2: General-purpose equipment with elastomeric-style couplings where there are no machined surfaces provided on the coupling hub may be exempted.

5.1.5 Prior to grouting, a preliminary shaft alignment shall be made. Final alignment tolerance need not be achieved, but the equipment installer shall confirm that the required axial, horizontal, and vertical alignment tolerances are achievable during final alignment without modifications to the machinery or hold-down bolts. The designated machinery representative shall approve the machinery preliminary alignment prior to grouting.

5.1.6 Grouting of the machinery mounting plate shall be completed, cured, and approved.

5.1.7 Appropriate tools and alignment fixtures shall be on hand. If dial indicator alignment is to be done, the sag measurement for the fixture to be used shall be completed and recorded.

5.1.8 The torque requirements for the equipment feet hold-down bolting are established in accordance with the vendor's specification or user's requirements. If there is no figure available from the equipment vendor, then Appendix E may be used.

5.1.9 The equipment installer shall confirm there is on hand necessary lifting equipment, suitable jacks, or jackbolts to elevate the movable equipment sufficiently to install shims. If jackbolts were not provided, the equipment installer shall provide suitable means to horizontally and axially move and restrain machinery accurately to 0.02 millimeter (1 mil).

5.1.10 The equipment installer shall confirm equipment hold-down bolts and any special washers supplied are on hand. Undercut hold-down bolts are unacceptable.

5.1.11 Before starting alignment, the equipment shall be disconnected from piping and conduit as much as possible. All process piping (including driving and exhaust steam piping on turbines) shall be disconnected.

5.1.12 Except in special cases agreed upon by the user, both the movable and fixed equipment shall be free to turn.

5.1.12.1 Pumps with mechanical seals shall have the seal locking tabs disengaged before turning the equipment to obtain alignment readings.

5.1.12.2 Any packing or blocking material that interferes with shaft rotation shall be removed.

5.1.12.3 Provide lubrication for bearings during turning.

5.1.13 Equipment outline drawings and vendor's instructions shall be available. Data sheets with desired final readings shall be provided for the type of alignment specified.

5.2 Qualifications

5.2.1 The equipment installer for a project shall demonstrate the competence of his alignment personnel to perform alignment of general-purpose equipment trains to the satisfaction of the designated machinery representative. It is not the user's responsibility to train the equipment installer's personnel in analytical or graphical methods of alignment.

Note: The ability of the equipment installer's mechanical personnel (millwrights) to perform alignment to the user requirements for general-purpose equipment is a significant factor in reducing the time and improving the cost effectiveness of a project.

5.2.2 The equipment installer shall obtain the assistance of an experienced qualified person or persons to assist the installer's mechanical personnel (millwrights) with alignment of special-purpose equipment trains. The designated machinery representative shall be consulted and agree on the selection of the qualified person(s). The qualified person may be a user's rotating equipment specialist, qualified equipment vendor's service representative, installer's machinery alignment specialist, or a third party machinery alignment specialist. The designated machinery representative shall witness and accept final alignment with and without pipes connected, or any other critical points defined by the user.

5.3 Documentation and Witness of Alignment

5.3.1 It is the responsibility of the equipment installer to record and maintain all alignment records and data sheets in the user-specified format. At the completion of the project, the equipment installer shall provide original copies of alignment records along with other project rotating equipment records to the user.

5.3.2 The equipment installer shall provide notice to the designated machinery representative of witness (hold) points. The notification period shall be agreed on between the equipment installer and the designated machinery representative. As a guideline, the notification should be 24 hours for local (resident) representatives. Five working days' notice may be necessary when the representative is not local or when vendor's service representative witness "hold" point is required.

5.4 Alignment Tolerances

5.4.1 AXIAL SPACING TOLERANCE

5.4.1.1 For flexible-element couplings, the coupling spacer gap length or distance between shaft ends (DBSE) shall be set as specified on the construction package data sheet or general arrangement drawing, ±0.25 millimeters (±10 mils) unless a closer tolerance is specified by the vendor.

5.4.1.2 For spacer couplings, the coupling spacer free length shall be measured and used when setting the spacer gap length.

5.4.1.2.1 When available, the expected shaft thermal growth shall be included in the calculation of the spacer gap length for general-purpose equipment.

5.4.1.2.2 For special-purpose equipment, the expected relative movement of the shafts shall be accounted for in the setting of spacer gap length.

5.4.1.2.3 Axial alignment shall be done after the motor magnetic center is marked during field or factory run-in. The motor shaft shall be located on magnetic center.

5.4.1.2.4 Spacer gap length for steam turbines and process equipment with hydrodynamic thrust bearings shall be set with the shaft against the active thrust bearing.

5.4.1.3 The axial tolerance for DBSE or spacer gap length of equipment trains with gear or elastomeric couplings shall be set as required by the coupling or machinery vendor. The DBSE or spacer gap length shown on equipment arrangement drawing or coupling vendor's drawings shall be held within ± 0.75 millimeters (± 30 mils) unless a closer tolerance is specified.

5.4.2 SHIM REQUIREMENTS

5.4.2.1 The maximum allowable number of shims under any equipment support foot is five.

5.4.2.2 The movable machine shall have a minimum of 3 millimeters (0.125 inch) of 300 series stainless steel shims under each support foot. The maximum shim stack height shall not exceed 12 millimeters (0.5 inch). Only one 3-millimeter (0.125-inch) or thicker shim per mounting foot is allowed. The use of tapered shim packs, laminated shims, brass shims, aluminum shims, and shims thinner than 0.05 millimeter (2 mils) is not permitted. Ground shims shall have a surface finish of 64 R_a or better. Shims shall be finished flat to within 0.1 millimeter per decimeter (1 mil/inch) of length. It is not acceptable to cut shims from rolled shim stock. Precut shims from a commercial source acceptable to the user are required. Alternately, shims may be furnished by the equipment vendor or cut to size and ground from plate.

Note: The practice of cutting shims from rolled shim stock by hand in the field often leads to rolled and crimped edges and is not considered to be good practice for equipment installation.

5.4.2.3 The stack-up of shims under the equipment support point used for alignment shall be measured. Individual shims shall be measured and totaled. The total stack thickness shall be recorded on the alignment data sheet. Measurement shall be recorded to the nearest 0.02 millimeter (1 mil). For relatively large shims, the measurement will be in two or more locations to confirm the flatness requirement.

Note: Large shims are ≥ 150 millimeters (6 inches) long or have an area ≥ 150 square centimeters (25 square inches).

5.4.2.4 All shims shall be full-bearing. This includes precut commercial shims used under the feet of general-purpose equipment and NEMA frame motors. Shims for special-purpose equipment shall be supplied from the equipment vendor. If a shim must be made on site, it shall be patterned from the equipment vendor's shim or support foot.

5.4.2.5 Alignment shims used on centerline or near centerline-supported equipment shall not extend beyond the machined support pads.

5.4.3 BOLTS AND BOLT CLEARANCE

5.4.3.1 Undercutting of hold-down bolts for alignment is not permitted.

5.4.3.2 Lock washers are not permitted at machinery hold-down bolts.

5.4.3.3 If special washers are not provided by the equipment vendor or standard washers yield when the hold-bolts are torqued to the required value, the installation contractor shall provide thick ground washers at the hold-down bolts. In the absence of suitable washers from the equipment vendor, the equipment installer shall obtain washers that do not permanently deform. The user may provide the size (thickness, outside diameter, and inside diameter) and material requirements for the washers.

Note: Due to the clearance necessary for hold-down bolts, standard thickness washers often are insufficient to distribute the bolt clamping force to the equipment foot without excessive deflection or yielding of the washer.

5.4.3.4 Hold-down bolts shall not be bolt bound. Unless otherwise specified by the user, after final alignment the hold-down bolt hole shall be reasonably centered based on visual examination.

5.4.3.5 The equipment installation contractor shall record the following on the data sheets for special-purpose equipment: (a) the size of the hold-down bolt, (b) confirmation that the minimum clearance is acceptable, and (c) the torque to tighten the bolt. Tables E-1 and E-2 in Appendix E shall be used for torque value unless otherwise specified by the user or the equipment vendor.

Note: Some types of equipment have hold-down bolts that are not to be tightened fully and are set to allow thermal expansion. The vendor's installation manual should be consulted to determine if there are movable feet under any hold-down bolt and tighten accordingly.

5.4.4 SOFT-FOOT

5.4.4.1 The soft-foot check shall be done with piping disconnected from the equipment body to be checked. A soft-foot check shall be made during final alignment on each equipment foot. Maximum permissible movement is 0.05 millimeter (2 mils) at each foot.

5.4.4.2 All hold-down bolts shall first be tightened. If available, use the torque specified by the equipment vendor at the support foot hold-down bolts. If there are no torque requirements specified by the vendor, then use Table E-1 and E-2 in Appendix E. Measurement shall be taken as the bolt is loosened. The hold-down bolt shall be tightened before going to the next foot. Unless approved by the user, soft-foot checks shall be made on each foot of the equipment and not at the coupling.

Note: Often equipment trains have hold-down feet that are not accessible with a dial indicator and still have room to apply a wrench to a hold-down bolt. The designated machinery representative may allow the soft-foot checks to be made by checking shaft end movement in both the vertical and horizontal direction.

5.4.4.3 After soft-foot checks are made, the installer shall confirm hold-down bolts at equipment sliding feet are tightened in accordance with the vendor's instructions.

5.4.5 Alignment readings shall be recorded before and after connecting the piping and conduit. See Chapter 6—Piping, paragraph 5.8.5, for allowance. Additionally, the alignment both before and after the piping is connected shall be within the alignment acceptance criteria of 5.4.6.

5.4.6 The installer shall align all machinery trains to either the tolerance given in 5.4.6.1 or 5.4.6.2 unless the vendor's tolerance is more restrictive. Alignment tolerances are after factors such as thermal offset and alignment bracket sag are accounted for.

5.4.6.1 When using reverse rim (dial) indicator methods or laser alignment equipment that resolves alignment into reverse rim equivalent readings, the maximum out of tolerance is 0.5 millimeters per meter (0.5 mils per inch) at both indicator locations.

Note: Actual misalignment is TIR/2 divided by the distance between indicators.

5.4.6.2 When using rim and face alignment or alignment computers that resolve misalignment into angularity, the alignment tolerance is 0.03 degrees. This angle must be determined at each hub on spacer couplings. When using rim and face alignment methods to align machinery trains with elastomeric couplings or close coupled machines, the angularity shall not be greater than 0.03 degrees and the offset at the center of the coupling shall not exceed 0.02 millimeter (1 mil).

5.4.7 During alignment and pipe strain checks, the bearing bracket support foot on single stage overhung pumps shall be loosened. For final acceptance, the bearing bracket support shall be shimmed and tightened. The maximum amount of movement at the coupling during the tightening process shall be 0.05 millimeter (2 mils).

5.4.8 After completion of alignment and installation of piping, all equipment shall be turned by hand or strap wrench to ensure that detrimental case distortion has not occurred.

5.4.9 Final alignment shall not be done until the process piping has been hydrotested. If the piping is disturbed after final alignment has been accepted by the user, train alignment shall be rechecked and approved by the user. If equipment movement was not monitored during the piping changes, the entire alignment check shall be redone starting with the piping disconnected and the flanges separated.

5.5 Sag

5.5.1 The maximum allowable sag for dial indicator brackets/fixture system used for alignment is ≤ 0.8 millimeters per meter (≤ 0.8 mils per inch) of span.

5.5.2 Sag shall be measured by the installation contractor. Each dial indicator and fixture combination to be used during alignment of a given equipment train will be measured for sag prior to equipment alignment.

5.6 Gear Procedures

5.6.1 The gear vendor shall provide the relative change between the at-rest and the operating centerline of the gears. If not given by the gear vendor, Figures F-1 and F-2 in Appendix F may be used to locate the running loaded position of the gear and pinion relative to the bearing clearance. The mechanical movement shall be added to the thermal growth when determining ambient offset.

Note: Whenever a train with a gear with hydrodynamic bearings is aligned, the shaft lift due to gear reaction forces must be accounted for as well as the thermal growth. The shaft lift of the gear and/or pinion at load within the bearing clearances may be more than the equipment alignment tolerance.

5.6.2 For double helical gears, the axial spacing between the shaft end of the gear and adjacent equipment shall be determined after the gear (low-speed) shaft is set in the center of the thrust bearing float. The pinion is centered axially.

5.6.3 The gearbox shall be considered to be the fixed element. Prior to alignment of coupled equipment to the gear, gear soft-foot and tooth contact pattern and area checks shall be made and approved by the user. Shimming of gears to correct gear contact pattern is not permitted unless approved by the user and the gear vendor. If a shim must be used to adjust gearbox height it shall be a ground shim (spacer) under the entire gearbox support area. Gear tooth contact pattern, contact area, and soft-foot shall be approved by the designated machinery representative after the shim (spacer) is installed.

Note: Shimming of a gearbox to correct gear contact pattern is usually indicative of a manufacturing error in the gearbox or a poor/nonlevel gearbox support base. Gear tooth contact pattern and area are very important to the life of a gear and must be within the gear vendor's guidelines. Manufacturing tolerances are very close, and relatively small distortion of the gear case during initial installation can significantly reduce gear life.

5.7 Bearing Type

Ambient offset shall account for special case bearing types where running position centerline may deviate significantly from the rest position.

Note: The type of bearing can significantly alter the running position versus rest position of the shaft centerline. An example of this is a four-pad tilt pad bearing with load between pads.

5.8 Fixed Component

General guidelines for determination of fixed and moveable elements in a train are outlined in 5.8.1 through 5.8.3.

5.8.1 Trains with a gear shall have the gear as the fixed element.

5.8.2 For trains without a gear, the equipment with the most rigid process nozzle shall be considered as the fixed element.

5.8.3 For trains with a motor, the motor shall be the movable element.

5.9 Dowels

5.9.1 Tapered dowels with threaded outer ends shall be used for doweling equipment. Threads are to be used for removing dowels.

5.9.2 With the exception of gearboxes (see 5.9.4), equipment feet for general-purpose trains shall not be doweled unless specified by the user.

5.9.3 Equipment shall be doweled by the equipment installer in accordance with the instructions of the user's designated machinery representative. Dowels shall be installed after final alignment. When operating temperature alignment is to be done by the equipment installer, dowels shall be installed after final alignment.

5.9.4 Gears shall be doweled after alignment. Unless otherwise specified by the user or gear vendor, a gear shall be doweled as close as possible to the vertical centerline of the pinion. Dowels shall be installed after alignment with the piping connected, but before the equipment train is operated.

5.9.5 The thermal growth in the horizontal and vertical direction shall be included in the calculated alignment for gear trains. This thermal offset shall be calculated from the dowel position in the horizontal direction and from the support position in the vertical direction. For initial alignment, an average temperature of 66°C (150°F) may be used for calculation of the ambient offset if there is no information available from the equipment vendor.

APPENDIX A—ALIGNMENT CHECKLIST

		Initials	Date
5.1	**Prealignment**		
5.1.1	Prealignment meeting held.	______	______
5.1.2	Foundation cured and mounting plate installed.	______	______
5.1.3	Equipment installed and fixed machine centered on holes.	______	______
5.1.4	Coupling hubs run-out rim and face readings are ≤ 0.05 millimeter (≤ 0.002 inches) or the manufacturer's requirement, whichever is less.	______	______
5.1.5	Initial alignment made and approved by user's representative.	______	______
5.1.6	Grout installed.	______	______
5.1.7	Fixtures and tools on hand.	______	______
5.1.8	Torque requirements for the hold-down bolts ___________.	______	______
5.1.9	Equipment available to lift the movable machine and move it in the horizontal and axial directions.	______	______
5.1.10	The washers are thick enough at the hold-down bolts, and if not, obtain sufficiently thick washers.	______	______
5.1.11	All piping is disconnected.	______	______
5.1.12	Fixed and movable machine shafts free to turn.	______	______
5.1.12.1	Pump seal locking devices disengaged.	______	______
5.1.12.2	Packing or blocking material removed.	______	______
5.1.12.3	Lubrication provided for bearings.	______	______
5.1.13	Drawings and data sheets available.	______	______
	Final Alignment		
5.4	**Alignment Tolerances**		
5.1.11	All piping is disconnected.	______	______
5.1.12	Fixed and movable machine shafts free to turn.	______	______
5.4.1	Movable and fixed machine rotors DBSE or coupling spacer gap length = ______ when set to running position.	______	______
5.4.1.2	Coupling spacer free length = ______.	______	______
5.4.1	DBSE or coupling spacer gap length corrected for thermal growth required = ______ and is within ± 0.25 millimeters (± 0.010 inches) of required DBSE or actual coupling spacer free length for and flex couplings. For gear and elastomeric couplings the requirement is ± 0.75 millimeters (± 0.030 inches).	______	______
5.4.2.1	Maximum five shims under any support.	______	______
5.4.2.2	Shims 300 series stainless steel or better material, not laminated and flat to 1/1000. At least 3 millimeters (0.125 inch) but not more than 12 millimeters (0.5 inch) under movable machine foot. No more than one ≥ 3 millimeters (≥ 0.125 inch) thick shim under any foot.	______	______

APPENDIX A—ALIGNMENT CHECKLIST (CONTINUED)

		Initials	Date
5.4.2.4	Shims are full bearing.	______	______
5.4.3.1	Bolts are not undercut.	______	______
5.4.3.3	Washers are not lock washers and do not yield when hold-down bolts are tightened.	______	______
5.4.3.4	Hold-down bolts are not bolt bound and reasonably centered in bolt holes.	______	______
5.4.4.2	Hold-down bolts tight to manufacturer's/user's instructions.	______	______
5.4.4	Soft-foot is not more than 0.05 millimeters (0.002 inches).	______	______
5.5.1.1	Sag of alignment fixture recorded = _____ and ≤ 0.8 millimeters per meter (≤0.8 mils per inch).	______	______
5.4.5	Alignment within tolerance (1.4.6) before pipes and conduit attached.	______	______
5.4.5	Pipe strain checks made in accordance with procedure in Chapter 6—Piping; Section 4 Paragraph 1.8.1 through 1.8.5.	______	______
5.4.5	Alignment within tolerance (1.4.6) after pipes and conduit attached.	______	______

APPENDIX B—REVERSE RIM (DIAL) DATA SHEET

Project Number__________

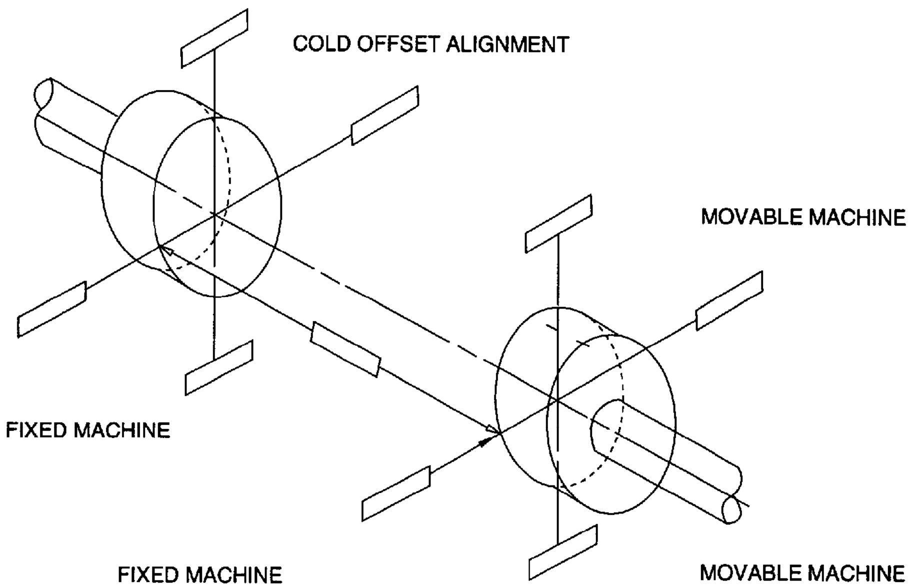
Plant: ________________________ Unit: ________________________

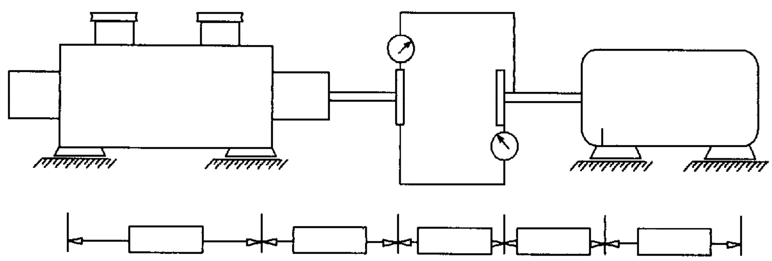
Movable: Item: ________________________ Manufacturer: ________________________

Type: ________________________ Serial No.: ________________________

Fixed: Item: ________________________ Manufacturer: ________________________

Type: ________________________ Serial No.: ________________________



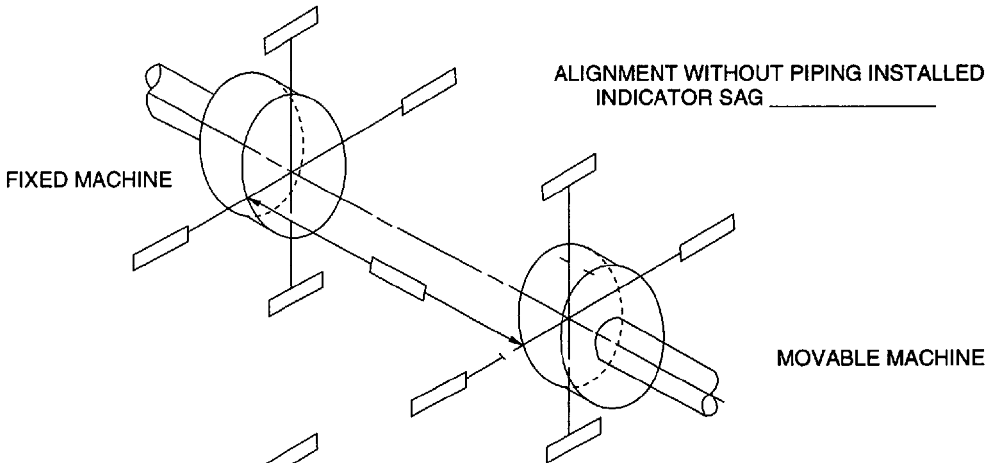


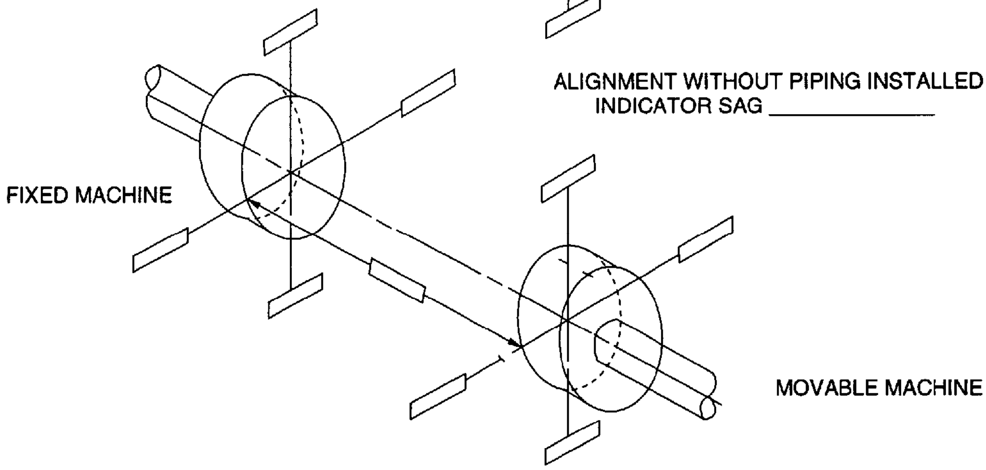
PREPARED BY ________________________ DATE ________________________

APPENDIX B—REVERSE RIM (DIAL) DATA SHEET (CONTINUED)

Project Number__________

Movable: Item: ____________________
Type: ____________________
Fixed: Item: ____________________
Type: ____________________





Shims Tabulation

Fixed IB Left	____________	Move. IB Left	____________
Fixed IB Right	____________	Move. IB Right	____________
Fixed OB Left	____________	Move. OB Left	____________
Fixed OB Right	____________	Move. OB Right	____________

Note: All shims are recorded looking to the fixed machine from the movable machine.

WITNESSED BY ______________________________________ DATE ____________________

APPENDIX C—RIM AND FACE DATA SHEET

Project Number__________

Plant: ______________________ Unit: ______________________

Movable: Item: ______________________ Manufacturer: ______________________

Type: ______________________ Serial No.: ______________________

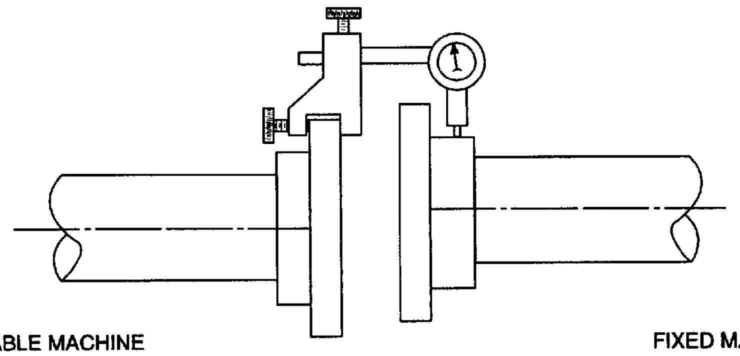
Fixed: Item: ______________________ Manufacturer: ______________________

Type: ______________________ Serial No.: ______________________

Indicator bar sag: ____________ Indicator bar number: ____________

RIM READINGS

Set proper face readings before taking rim readings



MOVABLE MACHINE

FIXED MACHINE

Swept diameter × __________

D = Axial distance between shaft hubs × __________

INDICATOR READINGS: "Left" and "Right" indicator readings are determined by looking from the back of the movable machine toward the fixed machine.

THEORETICAL and Tolerance	ACTUAL (PIPE OFF) Corrected for Axial Float	ACTUAL (PIPE ON) Corrected for Axial Float
Top ____	Top ____	Top ____
Left ____ Right ____	Left ____ Right ____	Left ____ Right ____
Bottom ____	Bottom ____	Bottom ____

PREPARED BY ______________________________ DATE ______________

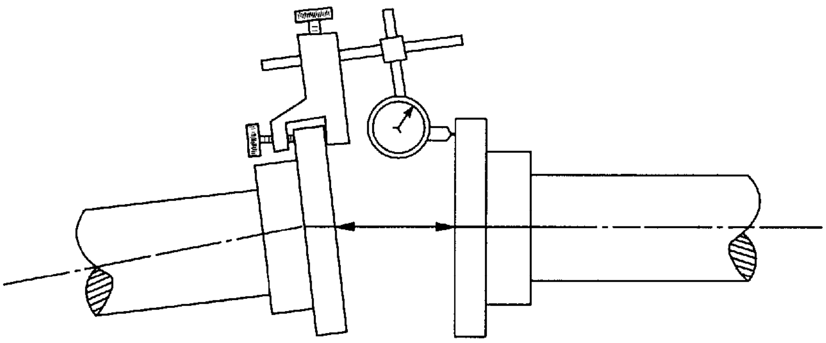
APPENDIX C—RIM AND FACE DATA SHEET (CONTINUED)

Project Number__________

Movable: Item: ______________________________
Type: ______________________________
Fixed: Item: ______________________________
Type: ______________________________

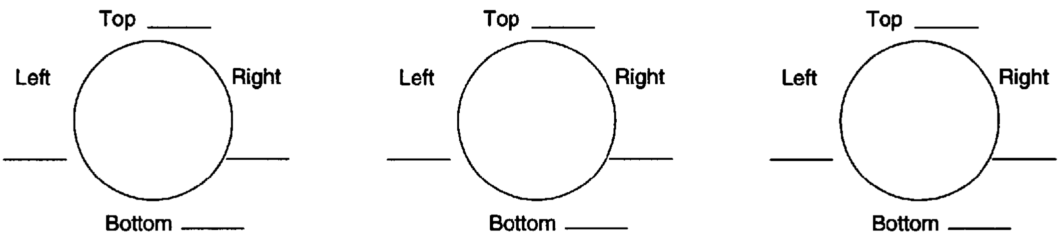
Indicator bar sag: ______________ Indicator bar number: ______________

FACE READINGS



INDICATOR READINGS: "Left" and "Right" indicator readings are determined by looking from the back of the movable machine toward the fixed machine.

THEORETICAL and Tolerance	ACTUAL (PIPE OFF) Corrected for Bar Sag	ACTUAL (PIPE ON) Corrected for Bar Sag



Shims Tabulation

Fixed IB Left	______________	Move. IB Left	______________
Fixed IB Right	______________	Move. IB Right	______________
Fixed OB Left	______________	Move. OB Left	______________
Fixed OB Right	______________	Move. OB Right	______________

Note: All shims are recorded looking to the fixed machine from the movable machine.

WITNESSED BY ____ DATE ______________________

APPENDIX D—TYPES OF ALIGNMENT

D.1 Reverse Rim (Dial) Alignment

D.1.1 *Reverse rim (dial) alignment* is the process of determining the misalignment of two adjacent rotating machinery elements by radial dial indicator readings taken on the coupling hub rim or shafts of two machines while they are rotated at the same time (see Figure D-1). The key aspect is that the dial indicators are rotated about the machinery shaft's center of rotation. The process is normally done while turning both shafts together and taking readings as close as possible to vertical and horizontal planes.

D.1.2 ADVANTAGES AND DISADVANTAGES

D.1.2.1 Advantages

1. Most maintenance personnel are familiar with this alignment method.
2. By spanning a spacer coupling, angular misalignment measurements are more sensitive. A span of 400 millimeters (16 inches) gives angular misalignment readings four times more sensitive than face readings of a typical 100-millimeter (4-inch) diameter hub. Most couplings for new equipment in petrochemical facilities have spacers much longer than the hub diameter.
3. The requirement to remove the coupling spacer is eliminated with proper design of the alignment brackets. This reduces wear and tear on the coupling.
4. When both shafts are turned together, the errors of coupling hub run-out are eliminated. It is also possible with care to achieve equal accuracy with the shafts uncoupled. For new installations it is recommended that the coupling spacer be left out to reduce the wear and tear on the coupling and bolts. At construction sites, it is likely the coupling spacer or fasteners will be lost or damaged if the coupling is assembled and subsequently removed. The equipment train driver shall be positively prevented from inadvertent energization before the coupling spacer is installed.
5. Axial float errors are eliminated by eliminating the face readings.
6. It lends itself to both graphical and calculated methods of alignment correction.
7. There are several general purpose reverse dial indicator shaft adapter kits commercially available. Generally these commercially available kits are designed for minimum sag.

D.1.2.2 Disadvantages

1. Both machines must be turned to align them unless special brackets are made. Accurate repeatable readings are difficult to obtain.
2. Indicator sag must be measured and included in the calculations.
3. To be done properly, brackets must be made to fit the machinery train correctly and still swing the shafts together 360 degrees without interference.
4. Purchasing commercial or manufacture reverse dial indicator brackets can be costly.
5. It is not as accurate for equipment where coupling diameter is greater than DBSE length.
6. Any hub surface disconformity in the mechanically indicated surfaces must be compensated for when rotating only one shaft at a time.

D.2 Rim and Face Alignment System

D.2.1 *Rim and Face alignment* is the process of determining misalignment between two adjacent shafts by measuring the differences in distance between shaft end or coupling faces (face readings) and the difference in the center of rotation with dial indicator radial readings (rim readings). The angular misalignment is determined by the face readings, and the parallel

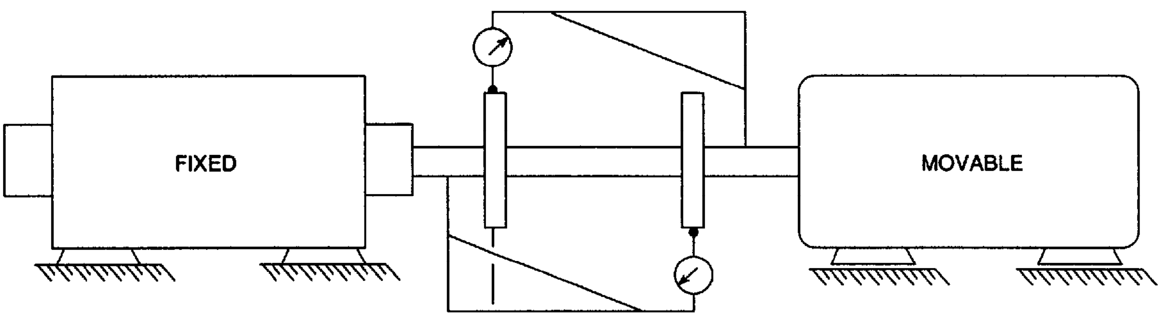


Figure D-1—Reverse RIM (Dial) Alignment

misalignment at the dial is determined by dial indicator readings in the radial direction on the rim of the coupling or shaft. Relative face distance is determined at two points in the vertical direction and two points in the horizontal direction. This may be done by micrometer, or dial indicator. Rim readings (two in the horizontal plane and two in the vertical plane) are taken with a dial indicator mounted on a bracket fixed to one shaft. When possible, both shafts are rotated together. Three dial rim and face readings, as shown in Figure D-2, should be used whenever practical.

D.2.2 ADVANTAGES AND DISADVANTAGES

D.2.2.1 Advantages

1. It is more accurate than double reverse dial when the machinery train is close coupled and the dial indicator span is less than the coupling hub diameter.
2. The face readings give the angularity and the rim readings give the offset at the dial indicator. This is intuitive to most mechanics and millwrights and easier to understand than reverse dial (rim) alignment.
3. Dial indicator rim and face readings only require one shaft to be rotated. This should only be done when necessary because dimensional errors in hubs or shaft ends will cause an error in the readings.
4. Any hub surface disconformity in the mechanically indicated surfaces must be compensated for when rotating only one shaft at a time.

D.2.2.2 Disadvantages

1. Unless the three dial rim and face method is used to subtract shaft end-play, it is likely to give erroneous face readings as the shaft is rotated.
2. Rim readings must be corrected for sag.
3. For machinery with spacer couplings, the face readings do not have as good resolution as reverse dial readings. Most equipment specifications require coupling spacers of 5 inches or more for ease of maintenance and to reduce the coupling alignment change from cold to hot operation.

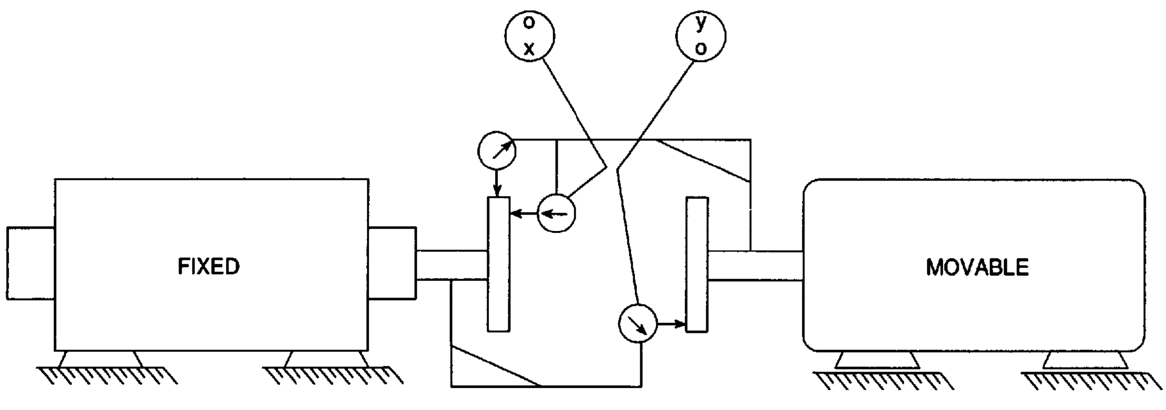
D.3 Laser Alignment Systems

D.3.1 *Laser alignment* is the process of determining misalignment by a laser beam where the laser is mounted on one or both shafts and a receiver or reflector is mounted on the other. Both shafts are turned at the same time. The deviation in the laser beam is measured as the shaft is turned. The interpretation of the data is done by configuring an alignment computer supplied with the laser alignment system.

D.3.2 ADVANTAGES AND DISADVANTAGES

D.3.2.1 Advantages

1. The calculations are directly fed into the alignment computer by the instrument, eliminating operator errors.
2. Potential accuracy of laser instruments is better than dial indicators.
3. The required moves and actual misalignment in the horizontal and vertical plane or angle is directly read out.
4. There is no sag in the readings. Very good for long DBSE alignments.
5. Universal brackets are provided for the instrument, which allows for setup on most machines without special fabrications.
6. There is a relatively short training period for new mechanics (millwrights) in order to become proficient in machinery alignment.



$$\text{FACE DISPLACEMENT} = X - \left(\frac{X + Y}{2}\right)$$

Figure D-2—Three Dial Rim and Face Alignment

7. The laser alignment equipment normally provides a print-out of the alignment for record purposes. This eliminates translation errors and provides consistency from one mechanic (millwright) to the next.

D.3.2.2 Disadvantages

1. The initial cost is relatively high and mechanics (millwrights) must be trained to use the laser alignment equipment.
2. The mechanic (millwright) does not get the feel for the actual alignment process because dial indicator calculations or graphs are eliminated. It is recommended that laser alignment only be done by persons familiar with dial indicator alignment.
3. The mechanic (millwright) must be sure the instrument is suitable for the area classification or obtain a safety permit.
4. Vibration of the machinery can cause the instrument to be nonfunctional.
5. Both shafts must be turned or special jigs provided to align equipment where the shaft cannot be turned.

D.4 Operating Temperature Alignment

D.4.1 *Operating temperature alignment* is the process of determining the relative change in alignment from the ambient conditions to operating conditions.

D.4.2 OPERATING TEMPERATURE ALIGNMENT SYSTEMS

The generally recognized systems for hot alignment of rotating equipment trains are described in D.4.2.1 to D.4.2.5.

D.4.2.1 A frequently used type of operating temperature alignment for hot service pumps is to back-flow hot fluid through a pump while it is not in service. The change in alignment is monitored from the ambient condition to the hot condition. This is not usually as accurate as other methods where the equipment is in operation (as listed in D.4.2.2 through D.4.2.5) but is often sufficient for many general-purpose pumps.

D.4.2.2 Alignment indicator stands are set up with a constant temperature coolant flowing through them. The readings are taken with dial indicators or proximity probes on machined surfaces attached to the bearing brackets. The change in the dial indicators or proximity probe gap is measured as the machinery train is operated at normal conditions. These measurements are used to verify ambient offset readings.

D.4.2.3 Accurate measurements are made between fixed benchmarks located on the machinery train bearing brackets and the foundation when the equipment is not running. The equipment is then started and run at operating conditions and the measurements are repeated. The relative change in the measurements are related back to ambient condition alignment readings.

D.4.2.4 Optical operating temperature alignment is similar to the physical measurement of benchmarks, except precision optical readings are taken of benchmarks when the machine is at ambient conditions and after it is put in service.

D.4.2.5 Low sag brackets with four proximeter probes are attached inside the coupling cover to the bearing housing. The relative change is related directly back to initial proximeter readings and reverse dial indicator readings taken when the machinery train was at ambient conditions.

APPENDIX E—HOLD-DOWN BOLT TORQUE TABLES

Table E-1—2,110 Kilograms per Square Centimeter Internal Bolt Stress

Nominal Bolt Diameter (mm)	Torque (newton-meters)	Compression (kilograms)
M12	31	1,778
M16	110	3,311
M24	363	7,447
M30	1,157	18,247
M52	3,815	37,136

Notes:
1. All torque values are based on bolts with threads well lubricated with oil.
2. In all cases the elongation of the bolt will indicate the load on the bolt.

Table E-2—30,000 Pounds per Square Inch Internal Bolt Stress

Nominal Bolt Diameter (inches)	Number of Threads (per inch)	Torque (foot-pounds)	Compression (pounds)
$^1/_2$	13	30	3,780
$^5/_8$	11	60	6,060
$^3/_4$	10	100	9,060
$^7/_8$	9	160	12,570
1	8	245	16,530
$1^1/_8$	8	355	21,840
$1^1/_4$	8	500	27,870
$1^1/_2$	8	800	42,150
$1^3/_4$	8	1,500	59,400
2	8	2,200	79,560
$2^1/_4$	8	3,180	102,690
$2^1/_2$	8	4,400	128,760
$2^3/_4$	8	5,920	157,770
3	8	7,720	189,720

Notes:
1. All torque values are based on bolts with threads well lubricated with oil.
2. In all cases the elongation of the bolt will indicate the load on the bolt.

APPENDIX F—GEARBOX SHAFT MOVEMENT

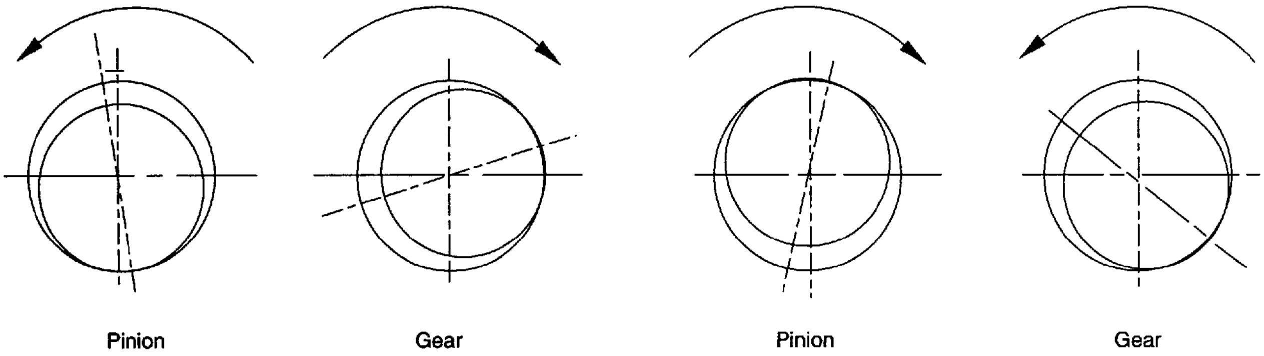


Figure C-1—Pinion Driving (Gear Driven)

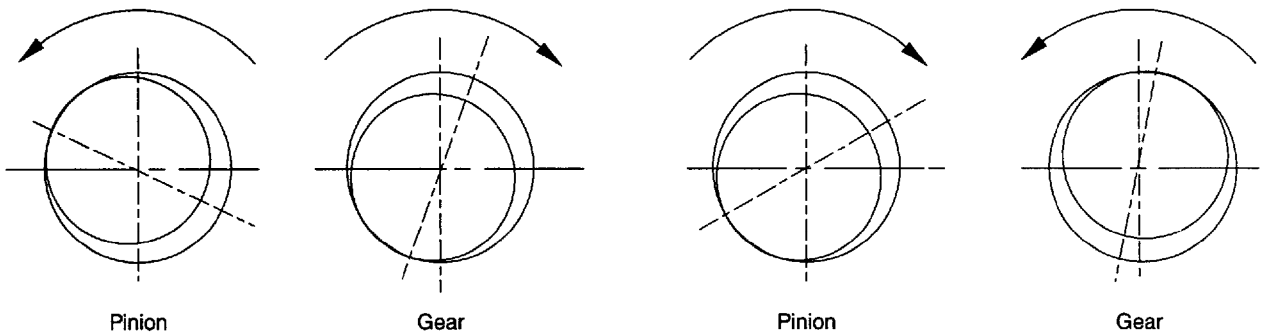


Figure C-2—Pinion Driven (Gear Driving)

Recommended Practices for Machinery Installation and Installation Design

Chapter 8—Lubrication Systems

Manufacturing, Distribution and Marketing Department

API RECOMMENDED PRACTICE 686
PIP REIE 686
FIRST EDITION, APRIL 1996

Process Industry Practices

American Petroleum Institute

CONTENTS

Recommended Practices for Machinery Installation and Installation Design

CHAPTER 8—LUBRICATION SYSTEMS

Section 1—Definitions

1.1 designated machinery representative: The person or organization designated by the ultimate owner of the equipment to speak on his behalf with regard to machinery installation decisions, inspection requirements, and so forth. This representative may be an employee of the owner, a third party inspection company, or an engineering contractor as delegated by the owner.

1.2 engineering designer: The person or organization charged with the project responsibility of supplying installation drawings and procedures for installing machinery in a user facility after machinery has been delivered. In general, but not always, the engineering designer specifies machinery in the user facility.

1.3 equipment user: The organization charged with operation of the rotating equipment. In general, but not always, the equipment user owns and maintains the rotating equipment after the project is complete.

1.4 equipment installer: The person or organization charged with providing engineering services and labor required to install machinery in a user facility after machinery has been delivered. In general, but not always, the installer is the project construction contractor.

1.5 equipment train: Two or more rotating equipment machinery elements consisting of at least one driver and one driven element joined together by a coupling.

1.6 oil mist header: A network of piping through which the oil mist is transported from the console where it is made to the machinery bearing housing where it is used.

1.7 oil mist console: A system consisting of the oil mist generator, oil supply system, air filtering system, oil mist header outlet, and necessary controls and instrumentation. Air and oil enter the console to produce oil mist.

1.8 oil mist application fittings: Long path orifices that cause the small oil droplet size in the header ("dry mist") to be converted to larger size oil droplets ("wet mist") to lubricate the bearings. Oil mist application fittings are also known as *reclassifiers*.

1.9 oil mist distributor block: A small rectangular block that has four or more holes drilled and tapped in opposite faces. *Drop points* terminate in distributor blocks. An oil mist distributor block may also be described as an *oil mist manifold block*.

1.10 oil mist: A dispersion of oil droplets of 1 to 3 micron size in an air stream.

1.11 oil mist system: A system designed to produce, transport, and deliver oil mist from a central location to a remote bearing housing. This system consists of the oil mist console, distribution piping headers and laterals, application fittings, and the lubricant supply tank and pump.

1.12 pure mist: The application of oil mist to a machinery bearing housing to lubricate antifriction bearings. The oil mist passes through the bearing elements, and oil droplets coalesce out of the air stream. All oil is drained from the machinery bearing housing and complete lubrication is provided by the mist alone. Pure mist may also be described as *dry sump* lubrication.

1.13 purge mist: The application of oil mist to a machinery bearing housing or reservoir to provide a slight positive pressure. Machinery lubrication is provided by the normal ring oil or submerged bearing lubrication. This prevents contamination that could be caused by infiltration of corrosive agents or condensation of ambient moisture. Purge mist may also be described as *wet sump* mist lubrication.

Section 2—Lubrication System Installation Design

2.1 Scope

2.1.1 This chapter of Recommended Practice 686 establishes the minimum requirements for the machinery installation design, preservation, installation, and cleaning of new or overhauled machinery that either provides or requires lubrication for process or utility purposes.

2.1.2 Equipment providing lubrication includes equipment such as lube and seal oil systems, central air/oil systems, and oil mist lubrication packages.

2.1.3 Equipment requiring lubrication includes (as a minimum) equipment such as vertical and horizontal centrifugal and positive displacement pumps, centrifugal and positive displacement compressors, blowers, fans, agitators, horizontal and vertical gear boxes, steam and internal combustion turbines, expanders, electric motors, electric generators, and packages such as refrigeration packages, plant instrument air packages, and extruders.

2.1.4 This chapter of Recommended Practice 686 is not a design specification; however, design criteria that enhance and/or facilitate the preservation, cleaning, inspection, assembly, and start-up of lubrication systems and details such as bearing cavities, bearing housings, and complete lube and seal oil supply systems are included.

2.1.5 This chapter of Recommended Practice 686 does not include criteria for product lubricated equipment such as canned motor pumps, grease lubricated equipment, or cylinder lubrication such as for reciprocating compressors.

2.2 Installation Design Requirements

2.2.1 The design shall provide for easy access to fill and drain connections and provide easy access for operation and maintenance.

2.2.2 The design shall provide for drains that drain the components and systems as completely as practical without leaving the need for flushing the remainder.

2.2.3 The design shall provide for adequately sized and properly placed vents and drains to ensure complete removal of any material used during chemical cleaning and pickling.

2.2.4 The design shall provide for fill and drain passages and connections that are sufficient in size and oriented such that servicing can be performed without spilling and does not need special equipment.

2.2.5 The piping system shall be provided with high point vents.

2.2.6 Threaded openings (such as in small pumps) can be plugged with a threaded pipe plug; others shall be provided with block valves and flange connection with blind flanges.

2.2.7 A specific lube oil flushing diagram should be provided that clearly indicates temporary bypasses, screens, and so forth, required for lube oil flushing. A marked-up process and instrumentation diagram will suffice for this purpose.

2.2.8 Component and system cleaning specifications, including the flushing diagram, shall be approved by the user.

2.2.9 Equipment and oil systems shall be shipped clean, minimizing the need for cleaning and flushing in the field. The manufacturer shall demonstrate that oil passages and oil-containing components are free of dirt and debris prior to shipment.

2.2.10 In situations where oil mist is used to protect equipment during storage or when the equipment is idle, procedures and oil mist systems shall be agreed upon between the manufacturer and the user.

Section 3—Lubrication System Installation

3.1 Receiving and Protection

3.1.1 In the event that the lubrication system or equipment will not operate within 6 months, a long-term preservation program shall be agreed upon between the vendor and equipment user. The program shall clearly state the responsibilities of the individual parties.

3.1.2 An inspection procedure shall be established indicating intervals and special activities to be performed, such as equipment condition, inspection, preservation, and shaft rotation while the equipment is idle. (Refer to the Job Site Receiving and Protection section, chapter 3, of this recommended practice.)

3.1.3 The manufacturer's/vendor's instructions shall be followed unless otherwise specified. These instructions shall be agreed upon between equipment user and vendor.

3.1.4 The equipment shall be protected against mechanical damage and internal and external corrosion at all times.

3.1.5 When specified, a temporary oil mist preservation system shall be provided in accordance with 3.2 below.

3.2 Temporary Oil Mist Systems

3.2.1 When more than 10 pieces of equipment are to be stored for a period longer than 6 months from time of shipment, an oil mist protection should be considered.

3.2.2 Oil mist should be used to protect the bearings, bearing housings, seal areas, and process end of the equipment.

3.2.3 For equipment provided with permanent mist lubrication connections, these connections shall be used in conjunction with the temporary oil mist system.

3.2.4 Equipment cavities not normally mist lubricated during permanent operation will need to be fitted with mist supply and vent connections, typically NPS 1/4.

3.2.5 The oil mist system must be designed and sized for preservation service. Mist flow to each application point can be less than that required for lubrication during normal operation.

3.2.6 The mist generator should be equipped with an air pressure regulator, pressure relief valve, level gauge, and mist pressure gauge instrumentation as a minimum.

3.2.7 The mist header should be NPS 2 galvanized schedule 40 pipe supported and sloped at least 5 millimeters per meter (0.06 inches per foot).

3.2.8 Plastic tubing may be used to connect the mist header to the mist application point.

3.2.9 The equipment should be connected to the system within 24 hours after arrival on the storage or plant construction site to protect equipment against internal and external corrosion as prescribed and agreed upon by the equipment vendor and the equipment user.

3.2.10 The compatibility of preservatives and sealants with process streams and machinery components materials must be evaluated by the user's designated machinery representative. Care should be taken to avoid contamination of synthetic oil and oil passages with hydrocarbon flush oil.

3.2.11 The oil used in the mist system should be a good quality, paraffin-free turbine oil. A temperature-sensitive, vapor-emitting oil should not be used.

3.2.12 Equipment under preservation must be maintained by rotating shafts and periodically draining condensed oil from the cavities.

3.2.13 Under no circumstances should a machine be rotated without the specific approval of the manufacturer's representative and/or the user's designated machinery representative.

3.2.14 Drained oil must be disposed of per the equipment user's established environmental protection procedures.

3.2.15 Interruption of oil mist preservation, such as during transport of equipment from storage to the construction site, should be minimized.

3.2.16 Oil mist preservation (or other preservation procedures) must be immediately re-established once the equipment is placed on its foundation.

3.3 Cleaning

It cannot be overemphasized that the cleanliness of the lube oil system is crucial to the operational reliability of the process equipment and the lube oil supply system. It is also very time consuming to clean the system once assembled and in operation.

3.3.1 The equipment installer and equipment user shall determine and agree on the locations where temporary bypasses, screens, and so forth, shall be located. Unless specifically approved by the user's designated machinery representative, no circulation of any material shall take place through the bearings as long as the bearing area and the system are not proven to be clean by means of the cleanliness test described below.

3.3.2 All interconnecting piping shall be thoroughly cleaned before it is installed by blowing large quantities of steam, air, or nitrogen through the piping or by flushing the piping with a solvent approved by the user. Care must be exercised to ensure that the precleaned interconnecting piping is kept clean during its installation.

3.3.3 Flow restrictions such as orifices and probes must be removed to obtain optimum velocities during the cleaning and subsequent flushing procedures. All equipment removed shall be tagged and inventoried for later reinstallation into its proper location.

3.4 Mechanical Cleaning of Piping

3.4.1 All loose foreign material such as scale, sand, weld splatter particles, and cutting chips shall be removed from the inside of piping assemblies and reservoirs, filter housings, and so forth.

Note: Hammering on the outside of piping with a nonmarring hammer will aid in freeing weld splatter, scale, dirt, and rust.

3.4.2 Where accessible, the inside of piping should be wire brushed.

3.4.3 Pipes must be blown out with steam or clean dry air after hammering and brushing. When steam or high-pressure water washing is performed, subsequent blowing with clean dry air or nitrogen is required.

3.4.4 On piping where satisfactory cleaning by mechanical means alone is in doubt, additional chemical cleaning or hydro-blasting methods should be considered.

3.5 Chemical Cleaning of Carbon Steel Piping Systems

3.5.1 Chemical cleaning applies only to carbon steel pipe. Stainless steel pipe could be damaged by pickling solutions and, therefore, should only be cleaned with solvents or steam.

Note: Chemical cleaning or pickling can best be performed by service companies specializing in the cleaning of old and new piping. Construction contractors are typically not equipped to perform this procedure.

3.5.2 Flushing materials containing chlorinated hydrocarbons such as 1,1,1-trichloroethane should be used with caution in stainless steel piping systems, as this can result in chloride stress corrosion cracking.

3.5.3 Warning tags should be installed on components such as oil pumps and control valves, which are isolated from the piping during chemical cleaning.

3.5.4 Where chemical cleaning or pickling is required, the following typical procedure may be used:

a. To follow the progress of cleaning, representative "dirty" metallic coupons should be installed at several strategic locations. The coupon presence shall be clearly indicated on the outside of the piping system for later removal after the cleaning procedure is complete.

b. A 2 percent caustic solution (in water) should be circulated at 80–90°C (175–195°F) to remove oil- and grease-type protective films that may be in the equipment.

c. Approximately 3 hours of circulation is required to adequately remove preservative films. Sufficient flushing velocities must be created to properly remove foreign materials from the piping passages.

d. The system must then be drained and flushed with clean water and blown with air or steam to remove any pockets of solution that may remain.

e. The system is then filled with a citric acid solution containing approximately 10 kilograms (20 pounds) of acid per 400 liters (100 gallons) water. The solution should be maintained at a temperature of 80–90°C (180–190°F) and circulated for a minimum of 2 hours. The initial circulating solution should have an acidity of approximately pH 3. Test coupons should be checked to ensure that they are clean before stopping the circulation. After the test coupons indicate a clean system, ammonia is added in a sufficient quantity to bring the acidity up to pH 8.0 and circulated for approximately 30 minutes.

Note: This procedure both neutralizes and passivates the system.

f. A final passivation with a 0.25 weight percent caustic plus 0.25 weight percent soda ash (or nitrox passivator) in water should be performed. The system should be drained and blown dry with nitrogen or clean filtered air.

g. If the system is not ready for immediate oil flushing, then a nitrogen purge should be established to protect the chemically cleaned surfaces.

3.6 Flushing of Oil Systems

3.6.1 It is the intent of this practice that equipment and oil systems be in a clean condition when received from the manufacturer, requiring minimal flushing after installation. If the equipment is known to be dirty, it may be cost-effective to use a less expensive flush oil that will be discarded after flushing.

3.6.2 After cleaning (mechanical and/or chemical), and only when the system is considered completely dry, the filter elements shall be reinstalled. Temporary bypass piping shall also be installed around all equipment bearings and shaft-driven lube oil pump if applicable.

3.6.3 The system should be filled with lubricating oil, of the same type and grade as will be used in operation. If applicable, and if feasible, each pump shall be operated. Operation of parallel pumps at the same time may aid in dislodging solid contaminants. The temperature of the oil should be alternated between 40°C (100°F) and 70°C (160°F) every 4 hours. Using reservoir heaters may assist in this process.

Note 1: Sparging the flushing oil with nitrogen, "hammering" the fittings, using mechanical vibrators, and cycling oil temperature are ways of loosening dirt particles.

Note 2: Heating and cooling can be obtained by alternate circulation of hot water (not steam) and cold water through the cooler(s). The thermal expansion and contraction will help to loosen any residue in the pipe. The piping should be tapped with a nonmarring hammer at all flanges and welds to assist in loosening any weld spatter or pipe scale.

Note 3: Care must be exercised in this procedure so as to not exceed the temperature design limitations of the oil cooler, as damage could occur.

3.6.4 Oil flows must be manipulated to achieve complete and effective flushing of all piping and equipment. An objective of good flushing is to establish high-velocity turbulent flow in all piping and equipment. This cannot be done in the complete system at any one time, so valving must be selectively and periodically manipulated to ensure high-velocity flow through each control valve, bypass line, and auxiliary item.

3.6.5 Replace the oil filter elements if there are signs of plugging or when the differential pressure rises more than 1 kilogram per square centimeter (15 psid) (or as specified by the manufacturer) above the original clean filter reading.

3.6.6 Circulate at 12-hour intervals and check for system cleanliness. The procedure for circulation and checking for cleanliness shall be repeated until the vendor and/or the designated machinery representative are satisfied with the condition of the system. Cleanliness of the oil may be checked at convenient discharge locations with a telltale (such as clean white gauze cloth) as indicated on the lube oil flushing diagram (refer to Section 2, 2.2.7).

3.6.7 Remove all equipment temporary bypass piping and reinstall the permanent oil supply and return piping with temporary 100-mesh screens backed with minimum 20-mesh screens installed just upstream of the bearing housing flange connection(s). Continue flushing the system as previously outlined until an 8-hour flush through a clean set of screens yields no magnetic particles, no particles gritty to the touch, and a negligible dirt count on each screen.

Note 1: On large systems, portions of the system proven to be clean do not have to have the screens reinstalled.

Note 2: If the screens indicate the system is not clean after one or two such cycles, recleaning of the piping downstream of the filters should be considered.

3.6.8 Under no circumstance should the machine be rotated without the specific approval of the manufacturer's representative and/or the designated machinery representative.

3.6.9 A sample should be taken at the completion of the oil flushing procedure from the reservoir bottom and checked for water content and dirt contamination.

Note: The presence of any water in the oil system may indicate a cooler leak.

3.6.10 In the event that the lube oil is found to be contaminated with water, the oil is to be processed with an oil reclaimer until clean oil (free of water and particles) is proven; or the contaminated oil shall be removed, the reservoir cleaned, and a fresh charge of clean oil installed.

3.7 Final Assembly

3.7.1 Connect all permanent oil piping as it is designed to operate.

3.7.2 All temporary screens shall be removed from the oil piping, and the permanent gaskets installed.

3.7.3 If possible, the oil pump suction strainer(s) should be cleaned.

3.7.4 All flow orifices and instrumentation previously removed are to be installed and connected as they are designed to operate.

3.7.5 Install new filter element(s).

3.8 Preoperation Checks for Oil System

3.8.1 Prior to final operation, the lube oil pump pressure relief valve shall be checked for proper operation and setting. The manufacturer's instruction manual should be referenced for specific setting procedures.

3.8.2 All pressure reducing valves to maintain the design oil pressures at the rotating equipment shall be adjusted and set to specification.

Note: The oil temperature must be allowed to rise to the design operating temperature before setting the oil pressure control valves for the system.

3.8.3 Place the oil system in operation as it was intended to operate and check each branch for proper pressure and flow. Check any sight glasses for quantity and quality (such as foaming) of flow.

3.8.4 Check oil pumps and drivers for excessive vibration or temperature.

APPENDIX A—LUBE OIL SYSTEMS INSTALLATION DESIGN CHECKLIST

		Initials	Date
2.2	**Installation Design Requirements**		
2.2.1	Easy access to fills and drains.	______	______
2.2.1	Design provides easy access for maintenance and operation.	______	______
2.2.3	Adequate size and placement of vents/drains for cleaning.	______	______
2.2.4	Size and orientation of fills/drains minimize spilling.	______	______
2.2.5	High point vents present where needed.	______	______
2.2.6	Drains with pipe plugs or block valves with blinds.	______	______
2.2.7	Lube oil flushing diagram adequate.	______	______
2.2.8	Cleaning specifications and flush diagram approved by user.	______	______
2.2.8	Lube oil specifications agreed between user/vendor.	______	______
2.2.9	Equipment and oil systems flushed and clean before shipment by manufacturer.	______	______
2.2.10	Oil mist protection reviewed by manufacturer and user (if applicable).	______	______

Checked By ______________________________ Date ______________________

APPENDIX B—LUBE OIL SYSTEMS INSTALLATION CHECKLIST

		Initials	Date
3.1	**Receiving and Protection**		
3.1.2	Inspection, preservation, rotation procedure established.	_______	_______
3.1.3	Long-term preservation program agreed upon by user and vendor.	_______	_______
3.1.3	Vendor/user agreed on instructions for installation, oil mist preservation system (if applicable), cleaning and flushing were followed.	_______	_______
3.2	**Temporary Oil Mist Systems**		
3.2.3	Oil mist lubrication connections (if applicable) were used for preservation mist.	_______	_______
3.2.4	Oil mist supply and drain connections (if applicable) sufficient and placed at all required locations.	_______	_______
3.2.5	Oil mist system adequate for preservation service.		
3.2.6	Oil mist system provided with necessary instrumentation, header and branches, and so forth.	_______	_______
3.2.9	Equipment protected against damage and internal/external corrosion as prescribed and agreed upon by vendor and user.	_______	_______
3.2.10	Preservatives/sealants compatibility reviewed with process and materials of construction.	_______	_______
3.2.11	Type and origin of oil recorded.		
3.2.12	Equipment preservation maintenance performed as required.		
3.3	**Cleaning**		
3.3.1	Agreement on physical location of bypasses and screens.	_______	_______
3.3.2	All interconnect piping internally without rust, debris, scale, deposits, weld splatter, and dry.	_______	_______
3.3.3	Orifices, valves, and similar obstructions removed for cleaning-flushing.	_______	_______
3.5	**Chemical Cleaning**		
3.5.1	Verified that piping system is carbon steel.	_______	_______
3.5.3	Warning tags installed on isolated equipment.	_______	_______
3.5.4.f	Verified adequacy of system cleanliness after chemical cleaning.	_______	_______
3.5.4.g	Nitrogen purge applied.	_______	_______
3.6	**Flushing of Oil Systems**		
3.6.2	Verified that system is completely drained and dry before final oil fill.	_______	_______
3.6.2	Clean filters installed for oil flushing.	_______	_______
3.6.2	Bypasses installed as agreed between vendor and user.	_______	_______
3.6.7	100-mesh screens installed before bearing areas.	_______	_______
3.6.7	Oil circulation checked for optimum cleaning effect.	_______	_______
3.6.9	Oil samples free of water and particles.		

		Initials	Date
3.7	**Final Assembly**		
3.7.1	All permanent piping properly installed.	______	______
3.7.2	Temporary screens removed.	______	______
3.7.4	Piping, valves, orifices, instrumentation installed with proper gaskets and as designed.	______	______
3.7.4	Controls adjusted per instructions.	______	______
3.7.5	New filter elements installed.	______	______
3.8	**Preoperation Checks for Oil System**		
3.8.1	Lube oil pump pressure relief valves checked for proper operation and setting.	______	______
3.8.2	Lube oil pressure reducing valves checked for proper operation and setting.	______	______
3.8.3-4	Circulating system shows acceptable flows, temperature, and pump vibration levels.	______	______

Checked By ______________________ Date ______________________

Recommended Practices for Machinery Installation and Installation Design

Chapter 9—Commissioning

Manufacturing, Distribution and Marketing Department

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CONTENTS

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CHAPTER 9—COMMISSIONING

Section 1—Definitions

1.1 designated machinery representative: The person or organization designated by the ultimate owner of the equipment to speak on his behalf with regard to machinery installation decisions, inspection requirements, and so forth. This representative may be an employee of the owner, a third party inspection company, or an engineering contractor as delegated by the owner.

1.2 engineering designer: The person or organization charged with the project responsibility of supplying installation drawings and procedures for installing machinery in a user facility after machinery has been delivered. In general, but not always, the engineering designer specifies machinery in the user facility.

1.3 equipment user: The organization charged with operation of the rotating equipment. In general, but not always, the equipment user owns and maintains the rotating equipment after the project is complete.

1.4 equipment installer: The person or organization charged with providing engineering services and labor required to install machinery in a user facility after machinery has been delivered. In general, but not always, the installer is the project construction contractor.

1.5 equipment train: Two or more rotating equipment machinery elements consisting of at least one driver and one driven element joined together by a coupling.

1.6 final alignment: The aligning of two adjacent machinery shafts after the measurement of piping-imposed strains on the machinery are verified as being within the specified tolerances.

1.7 isolation block valve: A valve used to isolate a process machine preparatory to maintenance; also known as a *block valve* or *isolation valve.*

1.8 recycle line: A line from the discharge of a pump, blower, or compressor routed back to the suction system. A recycle line will usually include control elements such as meters or valves. The recycle line may connect directly into the suction line or may connect into suction vessels or liquid knockout vessels and may include a cooler; also known as *bypass line, minimum flow bypass,* or *kickback line.*

1.9 suction knockout vessel or liquid dropout vessel: A vessel located in the suction line to a compressor or blower used to separate any entrained liquid from the gas stream. It may contain a demister mat and/or centrifugal separators to aid in this separation. Usually the compressor or blower takes suction from the top of the knockout vessel.

1.10 warm-up line: A line used to purge warm or hot fluid through a process machine. The intention is to heat up or maintain the temperature of a machine to a temperature greater than the surrounding ambient temperature.

Section 2—Machinery Commissioning

2.1 Scope

This Recommended Practice is intended to provide guidelines for the design and installation practices that affect the commissioning of general purpose equipment, and to provide guidelines for the commissioning. Unless otherwise specified by the user, instructions supplied by the machinery vendor should be included.

2.2 Purpose

Note: It is important to have the vendor-required procedures identified as early as possible so that they may be incorporated before the equipment arrives at the installation site.

General purpose equipment includes equipment such as pumps and drivers, and small blowers.

Section 3—Commissioning Design

3.1 Scope

This section is intended to assist the designer so that commissioning and start-up occur smoothly.

3.2 Strainers

Design shall include either permanent strainers or capability to install temporary strainers.

3.3 Bypasses

Any bypasses required for start-up shall be included in the piping design.

3.4 Draining and Purging

All equipment shall have a capability of controlled draining and purging and lockout-tagout.

3.5 Horsepower

Drivers shall be of sufficient horsepower for start-up conditions. These conditions include different temperatures, different specific gravities, and different flow rates from normal conditions. Verify these conditions with the user.

3.6 Instrumentation

Instrumentation shall be specified to cover the range of operation through the start-up conditions. This may require larger range instruments from those required for normal operation.

3.7 Turbine Inlet Piping

Steam turbine inlet piping shall have a start-up bypass around the inlet block valve for turbine solo control.

3.8 Instrument Checkout

Control loops and instrumentation loops shall be designed such that function can be verified without the process in operation.

Section 4—Field Commissioning

4.1 Scope

This section provides guidelines for commissioning and start-up of general purpose equipment.

4.2 Preoperational Checks

4.2.1 Obtain the completed checklists for the foundation, piping, grouting, and alignment activities for the particular equipment train to be started.

4.2.2 It is necessary to have clean piping before start-up. Basic cleaning of the piping system shall be performed to remove such items as weld rod, hard hats, and lunch buckets, out of the lines in a new system prior to flanging up to the new equipment. Additional cleaning of the system shall be provided for steam turbine inlet piping and positive displacement compressor piping.

4.2.2.1 Turbine inlet piping shall be free blown clean and verified as clean using a target method. See Appendix A for target procedure.

4.2.2.2 For positive displacement compressor inlet piping, ensure that 100-mesh start-up screens are installed.

4.2.3 Control valves and instrument loops shall be loop functional tested before start-up. Setpoints for controllers, switches, and transmitters shall be obtained from the user, set, and verified.

4.2.4 Verify that all gauges have been calibrated either by the manufacturer when supplied new, or by the installer if existing gauges are used.

4.2.5 Piping and instrument diagrams of the system shall be checked to verify that the unit piping, controls, and instrumentation are built per the design.

4.3 Verification of Requirements

All checklist items should be completed satisfactorily. If any items have not been completed, obtain the proper craft to verify compliance. The turnover punchlist for construction shall be completed and turned over to the designated operations' representative. The designated commissioning personnel shall read and understand all vendor requirements for operation and start-up.

4.3.1 Verify that the user- and/or vendor-required vibration analysis equipment is available and properly calibrated.

4.3.2 Verify that the user-required data to be obtained during commissioning has been defined and that the appropriate data sheets have been prepared.

4.4 Bearing Preparation

Drain all liquids as indicated on the commissioning punchlist from the bearing housing and then refill with clean lubricant. Drain as required until clean lubricant comes out the drain. Verify that proper lubricant has been added to the correct level as indicated on the bearing housing.

4.4.1 Constant level oilers that are installed on the housings shall be used to fill the bearing housing. Verify that the spider in the bottom of the oiler is set to maintain the required oil level as indicated on the bearing housing or machinery drawing.

4.4.2 Bearing housings with a sight level indicator shall be filled to the proper level indicated on the sight glass.

4.4.3 All other rolling-element-type bearing housings without constant lube oilers or sight glasses shall be filled to the center of the bottom ball to provide lubrication. This procedure may involve dimensional transferring from internal bearing housing dimensions to the outside so the commissioning representatives have an indicated required level marking on the outside of the bearing housing for reference.

4.4.4 Verify that the oil rings or slingers are in the proper location and free to rotate.

4.4.5 For sleeve and pressurized thrust pad bearings, the bearing caps shall be removed unless otherwise specified, and a bearing inspection shall be performed to verify no foreign material will enter the bearing area.

4.5 Grease Lubricated Bearings

For grease lubricated bearings, install grease fittings with required extensions for access without removing covers. Remove vent plugs and grease with a compatible grease until new grease comes out the vent. Replace vent after greasing.

Note: Certain manufacturers supply permanently lubricated bearings. Lubrication of these bearings may void the warranty. Do not grease permanently lubricated bearings unless specifically instructed by the user.

4.6 Oil Mist

Oil mist lubricated bearings shall have the reclassifiers installed at the pump bearing housings or manifolds as defined by the user. Verify the orifice sizes stamped on the reclassifiers. Verify all connection points and drains are installed in correct locations.

4.7 Cooling Water

All cooling water piping to the machinery shall be flushed and then connected to the machinery prior to operation.

4.8 Vents and Drains

Unless otherwise specified, all vents and drains not permanently piped shall be plugged with a solid pipe plug of similar material as the material to which the plug is installed.

4.9 Strainers

Permanent or temporary strainers shall be installed prior to start-up.

4.10 Pipe Cleaning

All foreign material shall be removed from the pipe before connecting to the equipment. Foreign material may consist of weld spatter, corrosion products, scale, and dirt.

4.10.1 Inlet lines to steam turbines shall be blown out with nominal steam pressure, typically 690 kilopascals (100 psig). Verify cleanliness by target method.

4.10.2 Auxiliary oil piping (lube oil and seal oil) shall be cleaned in accordance with the lubrication systems section of this recommended practice (see Chapter 8).

4.10.3 For pumps with dual mechanical seals, verify that the overhead reservoir and/or flush oil supply piping are clean prior to filling with fluid.

4.10.4 Machinery with an external seal oil system shall not be flushed out, steamed out, or operated without the seal oil system in operation at the specified pressure level.

4.10.5 Purging through the machinery shall be held to a minimum period of time to minimize the foreign material in the seal area.

4.10.6 When purging equipment with steam, verify that seals with elastomeric sealing components will not be heated above their allowable temperature limits.

4.11 Driver Prerotation Checks

Driver prerotation checks shall be made to verify that the installation is correct, safe, and that no damage will occur to the equipment on the initial start.

4.12 Mist System

For oil mist systems, the mist system shall be in operation at least 16 hours before starting equipment lubricated by the system.

4.13 Coupling Solo Plate

Verify the coupling design is capable of a driver solo run. Certain coupling types will require an adapter plate in order to solo the driver. If the coupling requires a solo plate, mount it to the driver coupling.

4.13.1 At this point in time the coupling spool is removed and the coupling does not connect the driver to the driven equipment. Verify that the driver solo operation will not cause any contact with the driven equipment.

4.13.2 A second set of coupling bolts may be required after the solo run in order to connect the driver to the driven equipment.

Note: Coupling bolts are typically supplied in matched sets from the coupling supplier. If one bolt assembly from the set needs to be replaced, it is usually good practice to replace all the bolts on that side of the coupling.

4.13.3 If an adapter plate is used for the solo run, torque all coupling bolts to the adapter plate to their required value.

4.14 Coupling Safety Area

Rope off the area around the driver to keep people away from the coupling.

4.15 Shaft Viewing

Verify that the area adjacent to the driver will allow viewing of the coupling during operation in order to verify the direction of rotation.

4.16 Rotation Check

Refer to the driven equipment drawings to ensure the required direction of rotation. Verify that the motor fan will provide cooling if rotation is opposite that required by driven equipment.

4.17 Lockout-Tagout

Verify that all lockout and tagout procedures have been followed so the power system can be energized.

4.18 Motor Solo Run

Motor solo runs are made to determine if any problems exist with the motor operation as soon as possible in order to provide maximum time for correction.

4.18.1 Motor solo requires that the motor and driven equipment not be connected.

4.18.2 Bump the motor start button. This procedure will allow the motor to be energized for a very short period of time in order to verify correct motor rotation. Wait for the motor to come to a stop after the bump. Once the motor is turning with the correct rotation, restart the motor and run for 1/2 hour minimum or until the bearing temperatures and vibration have stabilized, whichever is longer.

4.18.3 Monitor motor bearing temperatures during solo.

4.18.4 Monitor motor vibration during solo.

Note: Major motor problems will show up in a short unloaded run. Other motor problems may not manifest until the motor is loaded and up to temperature. If there is a problem with the motor on the solo run, it is typical that there will be a more serious problem during a loaded run.

4.18.5 Monitor motor amps during solo.

4.18.6 Monitor motor winding temperatures if available during solo.

4.19 Turbine Solo Run

4.19.1 Turbine drive solo should be made as soon as possible after the steam system has been commissioned in order to provide maximum time to correct any turbine problems. Verify that lockout-tagout procedures have been completed.

4.19.2 Verify that piping system is complete and cleaned.

4.19.3 Verify that the vendor instructions are followed properly.

4.19.4 Inlet strainers, either permanent or temporary, shall be installed in the inlet line upstream of the trip and throttle valve.

Note: The integral strainer to the trip and throttle valve is not sufficient as a start-up strainer.

4.19.5 Unless otherwise specified, the exhaust line shall be opened before the inlet line to avoid overpressuring the turbine exhaust casing.

4.19.6 Verify turbine seal leak-off piping is open and that carbon rings (or other sealing system) are installed, if required.

4.19.7 Verify that the turbine cooling water lines are open.

4.19.8 Ensure that required pressure and temperature gauges are installed.

4.19.9 Verify that a working speed indicator system is available to determine the turbine speed. If a handheld unit is to be used, verify access to signal generator.

4.19.10 Exercise the turbine trip and throttle valves prior to admission of steam. Follow user-specified instructions for trip system function verification before start-up.

4.19.11 Follow user-specified instructions for start-up. Verify that proper governor oil level has been achieved for all governor oil systems.

4.19.12 There may be critical speeds on larger turbines that will need to be avoided during start-up. Determine if there are any speed ranges to avoid for each turbine and agree with operations as the ramp speed through these areas.

4.19.13 Turbines with carbon seals need a break-in period where the speed is raised and then reduced to properly wear-in the carbons. Vibration should be monitored during this period. When no jumps in vibration are noticed with increasing speed, then the seals are probably properly seated.

4.19.14 If the turbine speed starts to increase after minimum governor speed is reached and the governor does not control, then investigate the governor control system for problems.

4.19.15 Record vibration data on the data sheet periodically as agreed until the operating conditions have stabilized.

Note: Unloaded turbines will typically require a small amount of steam (relative to a loaded condition) to reach minimum governor speed. Caution shall be exercised so as not to overspeed the turbine accidentally.

4.19.16 Record minimum and maximum governor speed and trip speed.

4.19.17 Check bearing temperatures and bearing vibrations during the coast-down after trip. The turbine should coast smoothly and not come to an abrupt halt.

4.19.18 Adjust trip setpoint per vendor's instructions if trip speed is not acceptable. Turbine trip speed will be given by the turbine manufacturer. Multiple trips within a specified speed range may be required for particular installations.

4.20 Driver to Driven Couple-up

4.20.1 Lockout and tagout equipment as required per plant operating procedures.

4.20.2 Remove any solo plates.

4.20.3 Verify alignment data has been recorded, including any prestretch or compression of the coupling spacer.

4.20.4 Install the coupling spacer to the required shaft end spacing (DBSE). Line up match marks if provided. Verify nonspacer coupling DBSE is correct before bolting coupling flanges. For grease-packed or oil-lubricated couplings, follow coupling vendor instructions for lubrication and bolting.

4.20.5 Torque coupling bolts to the required torque. Typically the torque values are for oil-lubricated bolts. Torque bolts to 50 percent of required torque in a pattern across the diagonal. After all bolts are torqued to 50 percent then torque all bolts in a similar sequence to 100 percent of required torque.

4.20.6 Machinery shall be turned over by hand after coupling to ensure freedom of operation.

4.20.7 On cartridge seal assemblies, verify the locking collars are tight and that the locating cams have been locked out of position so as not to come in contact with the rotating shaft.

4.20.8 Install coupling guard.

4.20.9 Verify all jack screws used for alignment have been loosened so as to eliminate any residual load from the jack screws that might affect alignment.

4.21 Start-up

4.21.1 During initial start-up of the equipment, operating conditions such as inlet and outlet pressures, temperatures, and flow rates shall be recorded.

4.21.2 Vibration signatures shall be obtained for all bearings.

4.21.3 For motor drives, motor current shall be obtained.

4.21.4 All connections shall be inspected for leaks.

4.21.5 Record that proper start-up procedures have been followed.

4.21.6 Piping supports/spring hangers shall be adjusted accordingly when the system is in service at operating temperature (see Chapter 6, Piping, of this recommended practice).

Section 5—Compressors

5.1 Scope

a. Section 5.2 covers activities common to most compressors.

b. Section 5.3 covers activities common to centrifugal compressors.

c. Section 5.4 covers activities common to positive displacement compressors.

5.2 Commissioning of Compressors

This section contains guidelines for the commissioning of compressors.

5.2.1 A vendor service representative may be required onsite to support the commissioning and to protect the warranty.

5.2.2 Obtain the completed checklists to verify installation and cleanout is completed.

5.2.3 Verify all instrumentation has been calibrated and functionally tested.

5.2.4 Verify all control loops have been functionally tested and all control valves work properly.

5.2.5 Verify that all alarm and trip systems have been functionally tested.

5.2.6 Verify that plant operating instructions have been clearly understood and that all valves, controllers, and switches are in their proper positions.

5.2.7 Verify that the lube oil system is in service and that the backup pump is in the auto position.

5.2.8 Verify that the compressor seal system is in service and that all flows and pressures are normal.

5.2.9 Follow plant operating instructions for the following:

a. Instrument air system in service.
b. Buffer gas in service.
c. Inlet and outlet block valves in proper position.
d. All monitoring and data acquisition systems operating properly.
e. Check the permissive start-up indication to verify all prestart-up conditions are satisfied.

5.3 Start-up Centrifugal Compressors

For centrifugal compressors, follow user's specified procedures for start-up. These procedures shall include but not be limited to the following:

a. Inlet control valve setting for start-up. Typical motor drives require inlet valve position to be as closed as possible to minimize acceleration time.
b. Seal system operation including any remote seal pots and degassing systems.
c. Surge control system operation. Typical surge systems are placed in automatic for start-up.

5.3.1 Once the compressor is started, the inlet control valve and the surge control valve shall be adjusted to achieve smooth operation of the compressor.

Note: Closing the throttle valve too far results in surging the compressor. Violent surging is detected by an audible thumping from the compressor, vibrations, large fluctuations in discharge pressure and axial position of the rotor, and checkvalve banging. Violent surging may cause the thrust bearing to fail, as well as other potential damage.

On constant speed compressors, surge can be stopped by increasing the flow through the compressor, and/or reducing the pressure ratio across the compressor. Follow user's and manufacturer's guidelines.

5.3.2 Record compressor operating data on data sheet.

5.3.3 Verify compressor operation is satisfactory and that all auxiliary systems are working properly.

5.4 Start-up Positive Displacement Compressors

For reciprocating compressors, follow the user's specified procedures for start-up. These procedures shall include, but not be limited to the following.

5.4.1 For reciprocating compressors an atmospheric run is typically made in order to verify mechanical integrity. This run is a nonpressurized operation of the compressor. To make a nonpressurized run, do the following:

a. Remove suction or discharge valves from each compression end of the cylinder.

b. Install valve covers on the valve ports without the valves with double nuts between the cylinder and valve cover. This will allow air flow in and out of the cylinder during operation, while minimizing the opportunity of introducing objects into the cylinder during operation. Secure the valve covers by putting nuts on the top of the valve cover at the two long studs provided.

c. Start cylinder lubricator system (if applicable). For lubricated cylinders the lubricators are typically started several minutes before the compressor is first operated in order to ensure oil is in the cylinder.

d. Rotate the compressor using the pneumatic or manual barring device. This will distribute the cylinder oil and verify that there are no mechanical tight spots during the revolution. If the machine will not manually bar over, then check for mechanical interference in the running gear or in the cylinders. **Do not operate the compressor until it is free to rotate.**

e. Operate the compressor for a short period of time, and then shut down and inspect for problems. Typical break-in period for atmospheric operation is as follows:

1. After operating for 5–10 minutes, shut down and check crosshead and crank case for high temperatures or metal wear.
2. If first run is acceptable, operate for 30–45 minutes and recheck.
3. If the first two runs show no problems, then run for 4 hours or until bearing temperatures stabilize. Inspect and, if acceptable, install valves and make ready for operation.

5.4.2 Pressurize the compressor with nitrogen and check for leaks.

5.4.3 Follow plant instructions for venting and introducing process gas to the compressor.

5.4.4 Operate all capacity controls before start-up and verify action.

5.4.5 Start compressor at zero percent capacity step.

5.4.6 Load compressor to user's required capacity.

5.4.7 Record compressor operating data on data sheet.

5.4.8 Verify compressor operation is satisfactory and that all auxiliary systems are working properly.

SECTION 6—MACHINERY COMMISSIONING CHECKLIST

Processing Unit_____

Equipment Tag No.______

		Initials	Date
4.2	**Preoperational Checks**		
4.2.1	Receiving, storage, foundation, grouting, piping, and alignment data sheets complete and attached.	_______	_______
4.2.2	Piping clean/free blown.	_______	_______
4.2.2.1	Steam line free blow required? _________ (yes/no)	_______	_______
4.2.2.2	Positive displacement compressor 100-mesh screen installed.	_______	_______
4.2.3	Piping clean, control loops functionally tested and correct, all setpoints set and verified.	_______	_______
4.2.4	New or calibrated gauges supplied.	_______	_______
4.2.5	System piping and instrumentation drawings verified.	_______	_______
4.3	All vendor and plant requirements read and understood.	_______	_______
4.4	Bearing housings prepared.	_______	_______
4.4.1	Constant level oilers set to proper level.	_______	_______
4.4.2	Sight glasses at proper level.	_______	_______
4.4.3	All oil levels set to proper level.	_______	_______
4.4.4	Oil rings in proper location.	_______	_______
4.4.5	Thrust pad and/or journal inspection indicates clean.	_______	_______
4.5	Grease bearings greased with __________ grease.	_______	_______
4.6	Oil mist reclassifiers installed. IB bearing reclassifier size __________.		
	OB bearing reclassifier size _________.	_______	_______
	Other reclassifiers: location _________ size ______		
	location _________ size ______		
4.7	Cooling water piping flushed and connected.	_______	_______
4.8	Pipe plugs installed. Material of plugs ______.	_______	_______
4.9	Strainers installed properly. Finest mesh size _________.	_______	_______
4.10	Piping to equipment clean (no hard hats, rags, flashlights, etc.).	_______	_______
4.10.1	Piping connected to blow out stream and vented to safe area.	_______	_______
	Blowout medium used ______________.		
	Target method used ____________.		
4.10.2	Auxiliary oil flushes	_______	_______
	Lube oil flush start _________ finish _________		
	Seal oil flush start _________ finish _________		
4.10.3	Overhead seal pots and piping flushed and cleaned.	_______	_______

SECTION 6—MACHINERY COMMISSIONING CHECKLIST (CONTINUED)

		Initials	Date
4.10.4	Was machinery flushed through? __________ (yes/no)	________	________
4.10.6	Record purge medium and temperature. ______ ______ °F	________	________

4.11 Driver Prerotation Checks

		Initials	Date
4.12	Oil mist system start date/time _____________	________	________
4.13	Adapter plate for solo run required? ________ (yes/no)	________	________
4.13.1	Solo run will not contact adjacent areas.	________	________
4.13.2	Adapter plate bolt torque values _______________ lb-in.	________	________
4.14	Coupling area roped off and safe.	________	________
4.15	Shaft visible.	________	________
4.16	Required direction of rotation looking at driver shaft coupling face from driven equipment. Circle one: CW CCW.	________	________
4.17	All lockout and tagout procedures have been followed.		

4.18 Motor Solo Run

		Initials	Date
4.18.1	Follow section 1.18 if driver is motor.	________	________
4.18.2	Motor power bump rotation is correct then run. If not, switch leads and run motor.	________	________
4.18.3	Motor bearing temperature: IB ___________ Motor bearing temperature: OB ___________ Temperatures taken ___________ minutes after start-up. Temperatures after 30 minute run: IB _______ OB ______	________	________
4.18.4	Vibration signature taken _______ minutes after start-up.	________	________
4.18.5	Motor amps ___________.	________	________
4.18.6	Motor winding temperatures A ______°F B _______°F C_______°F	________	________

4.19 Turbine Solo Run

		Initials	Date
4.19.1	Follow section 1.19 for turbine drivers.	________	________
4.19.1	Lockout-tagout procedures complete.	________	________
4.19.2	Verify piping system complete and cleaned.	________	________
4.19.3	Vendor instructions understood.	________	________
4.19.4	Inlet strainers installed.	________	________
4.19.5	Exhaust line open.	________	________
4.19.6	Carbon rings installed, and leak-off piping open.	________	________
4.19.7	Cooling water on.	________	________
4.19.8	Gauges installed.	________	________
4.19.9	Speed indicator working properly.	________	________

SECTION 6—MACHINERY COMMISSIONING CHECKLIST (CONTINUED)

		Initials	Date
4.19.10	Trip system functional.	______	______
4.19.11	User's instructions understood.	______	______
4.19.12	Turbine critical speeds: __________	______	______
4.19.15	Turbine vibration data at minimum governor. Get signature.	______	______
4.19.15	Turbine vibration data at maximum governor speed.	______	______
4.19.16	Turbine minimum governor speed: _____ rpm Turbine maximum governor speed: _____ rpm Turbine trip speed: _____ rpm	______	______
4.19.17	IB bearing temp ______ OB bearing temp _____	______	______

4.20 Driver to Driven Couple-up

4.20.1	Lockout-tagout procedures followed.	______	______
4.20.3	Alignment data recorded.	______	______
4.20.4	Coupling spacer installed. DBSE dimension verified as _______ inches.	______	______
4.20.5	Coupling bolts torqued to _________.	______	______
4.20.6	Machinery turns freely.	______	______
4.20.7	All seal cartridges have locking collar tight and locating cams rolled out and secured away from rotating elements.	______	______
4.20.8	Coupling guard installed.	______	______
4.20.9	All jack screws not in contact with equipment feet.	______	______

4.21 Start-up Data

4.21.1	Obtain the following information: Inlet pressure P1______ Outlet pressure P2 ________ Inlet temperature T1 ______ Outlet temperature T2 ______ Flow rate ____________ Motor amps _________	______	______
4.21.2	Obtain vibration signatures for all bearings. Overall vibration should be 0.15 inches per seconds true peak or less for each bearing. Driver bearings IB_________ OB___________ Driven bearings IB_________ OB___________	______	______
4.21.5	Proper procedures followed.	______	______

Section 5 Compressors

5.2.1	Vendor service representative called for start-up.	______	______
5.2.2	Completed installation checksheets verified.	______	______
5.2.3	Instrumentation functionally tested.	______	______

SECTION 6—MACHINERY COMMISSIONING CHECKLIST (CONTINUED)

		Initials	Date
5.2.4	Control loops functionally tested.	______	______
5.2.5	Trips functionally tested.	______	______
5.2.6	User's instructions understood.	______	______
5.2.7	Lube oil system in service with backup pump in auto.	______	______
5.2.8	Follow operating instructions.	______	______
5.3	Follow start-up instructions for centrifugal compressor	______	______
5.3.2	Record centrifugal compressor data.	______	______
5.4	Follow start-up instructions for positive displacement compressor.	______	______
5.4.1	Record atmospheric run data.	______	______
5.4.2	Compressor leaked checked.	______	______
5.4.3	Capacity controls operate properly, all steps.	______	______
5.4.7	Record positive displacement compressor operating data on data sheets.	______	______
5.4.8	Compressor system operating properly.	______	______

APPENDIX A—STEAM BLOWING PROCEDURE

The purpose of steam blowing is to remove the foreign material from the steam piping. Particles carried by the steam into the turbine will damage the governor valve, nozzle block, and turbine wheel blading.

A.1.1 Remove the piping spool between the turbine trip valve and the isolation block for the turbine inlet. If there is a steam strainer downstream of the block valve, the strainer must be removed.

A.1.2 Support inlet piping to withstand the reactive force from the steam blow.

A.1.3 Place a covering over the turbine inlet flange. The cover protects the turbine from particles entering during the steam blow, and acts as a device to hold the target. Typically a blind flange can be used with brackets on the outside to hold the target plate. Certain applications will require a redirectional spool be installed in order to direct the steam in a safe direction.

A.1.4 Target mounting methods must ensure that the targets will remain safely attached during the steam blowing process. Actual target material shall be polished 304 or 316 stainless steel. At least two targets shall be supplied for the test.

A.2.1 Close the inlet valve at the header and open the inlet valve at the turbine.

A.2.2 Blow steam through the system without any backpressure at flows as close to maximum as possible until no particles can be observed from the line. Several cycles of blowing may be required to remove the particles. Sometimes a cooling process followed by a rapid heating can assist the process.

Note: Steam blowing allows hot steam to be discharged around the turbine area. Particles will be discharged from the open valve at high velocities, requiring the area to be clear. Steam blowing generally causes an increase in the local noise levels and proper instruction for noise hearing protection should be provided.

A.3.1 Close the header valve once no particles are seen, and securely attach the polished target on the target support.

A.3.2 Open the steam header valve and blow for at least 15 minutes. Close the header valve and inspect the target.

A.4.1 Acceptance criteria for piping cleanliness is based on the following:

a. An acceptance target will have no raised pits.

b. An acceptable target will have less than three pits in any square centimeter of the target, and no pit shall be larger than 1 millimeter.

A.4.2 Steam blowing shall be repeated until the acceptance criteria have been met.

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