Study Guide for Source Inspection and Quality Surveillance of Rotating Equipment

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Foreword

This guide has been developed to provide information for source inspectors for the purpose of providing a consistent method of Vendor quality surveillance for the oil, petrochemical and gas industries. It is intended as a resource for individuals studying to take the API Source Inspector Certification examination. Other references contained herein and in the published Body of Knowledge (BOK) will also be necessary for individuals to become familiar with in order to pass the examination and to perform satisfactorily in the source inspection job. This study guide is also intended as a draft from which an API Recommended Practice for Source Inspection could eventually be formulated and published utilizing the ANSI standardization process.

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Guide for Source Inspection and Quality Surveillance of Rotating Equipment

1 Scope

This study guide covers the process of providing quality inspection of equipment used in the oil, petrochemical, and gas industry, including upstream, midstream, and downstream segments. This guide may be used as the basis for providing a systematic approach to source inspection to ensure that mechanical rotating equipment purchased meets the requirements specified in project documents and contracts. The activities outlined in this study guide *are not* intended to replace the manufacturer's own quality system.

This study guide focuses primarily on mechanical rotating equipment, including but not limited to pumps, gears, compressors, turbines, etc., and associated appurtenances. This document assumes that vendors have been prequalified by a systematic quality review process of their facilities and quality process to determine if the facility has the ability to meet the requirements of the contractual agreements. That process generally leads to a list of preapproved vendors deemed acceptable to the supply chain management of the purchaser and capable of meeting the requirements of the contract prior to it being placed. Vendors on such a list will normally have an acceptable quality process already in place that meets the requirements of the contract. The purpose of source inspection in such a case is simply to verify that the vendor quality process is working as it should and to verify that certain vital steps in the inspection and test plan (ITP) have been satisfactorily accomplished prior to manufacturing completion and/or shipping.

The primary purpose of this study guide is to assist candidates intending to take the API source inspector examination to become certified source inspectors for mechanical rotating equipment. The study guide outlines the fundamentals of source inspection and may be useful to all personnel conducting such activities to perform their jobs in a competent and ethical manner. For more information on how to apply for the API Source Inspector Rotating Equipment Certification, please visit the API website at www.api.org/icpprograms and select "API SIRE – Source Inspector Rotating Equipment" to find out more.

The Source Inspector (SI) exam contains 100 multiple-choice questions targeting the core knowledge necessary to perform source inspection of mechanical rotating equipment. The focus of the exam is on source inspection issues and activities rather than design or engineering knowledge contained in the reference standards. The exam is closed book and administered via computer-based testing (CBT). The questions address mechanical rotating equipment inspection/surveillance issues that could be encountered by persons who have experience working as source inspectors or persons intending to work as source inspectors and who have studied the material in this study guide and the associated reference materials.

2 References

The following standards or other recommended practices are referenced in this study guide and are the documents from which the Source Inspector (SI) exam has been developed.

API—American Petroleum Institute

Number	Title
API RP 578	Material Verification Program for New and Existing Alloy Piping Systems
API 610	Centrifugal Pumps for Petroleum, Petrochemical and Natural Gas Industries
API 611	General-Purpose Steam Turbines for Petroleum, Chemical, and Gas Industry Services
API 612	Petroleum, Petrochemical and Natural Gas Industries–Steam Turbines–Special-purpose Applications
API 613	Special Purpose Gear Units for Petroleum, Chemical and Gas Industry Services

Number	Title
API 614	Lubrication, Shaft-Sealing and Oil-Control Systems and Auxiliaries
API 616	Gas Turbines
API 617	Axial and Centrifugal Compressors and Expander-Compressors
API 618	Reciprocating Compressors for Petroleum, Chemical, and Gas Industry Services
API 619	Rotary-Type Positive-Displacement Compressors
API 670	Machinery Protection Systems
API 671	Special Purpose Couplings
API 672	Packaged, Integrally Geared Centrifugal Air Compressors
API 674	Positive Displacement Pumps–Reciprocating
API 676	Positive Displacement Pumps–Rotary
API 677	General-Purpose Gear Units for Petroleum, Chemical and Gas Industry Services
API 681	Liquid Ring Vacuum Pumps and Compressors
API 692	Dry Gas Sealing Systems for Axial, Centrifugal, and Rotary Screw Compressors and Expanders

ANSI (American National Standards Institute)

Number	Title
ANSI HI 14.6	Rotodynamic Pumps for Hydraulic Performance Acceptance Tests

ASME (ASME International; formerly known as American Society of Mechanical Engineers)

Number	Title
ASME PTC 6	Steam Turbines
ASME PTC 10	Performance Test Code on Compressors and Exhausters
ASME PTC 22	Gas Turbines

ASME Boiler and Pressure Vessel Code (BPVC)

Number	Title
Section II	Materials (Parts A, B, C, and D)
Section V	Nondestructive Examination
Section VIII	Rules for Construction of Pressure Vessels
Section IX	Welding and Brazing Qualifications

ASNT—American Society of Nondestructive Testing

Number	Title
SNT-TC-1A	Personnel Qualification and Certification in Nondestructive Testing

ASTM—American Standard for Testing Materials

Number	Title
ASTM 703	Standard Specification for Steel Castings, General Requirements, for Pressure-Containing Parts
ASTM A182	Standard Specification for Forged or Rolled Alloy and Stainless Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service

MSS—Manufacturer Standardization Society

Number	Title
MSS-SP-55	Quality Standard for Steel Castings for Valves, Flanges, Fittings and Other Piping Components

SSPC—Society for Protective Coatings

Number	Title
SSPC-PA 2	Procedure for Determining Conformance to Dry Coatings Thickness
SSPC	Surface Preparation Guide.

3 Definitions, Abbreviations, and Acronyms

For the purposes of this study guide, the following definitions, abbreviations and acronyms apply.

Term	Description
Alarm point	Preset value of a parameter that warns of a condition requiring attention.
Allowable operating region	Portion of a pump's hydraulic coverage over which the pump is allowed to operate, based on vibration within the upper limit of the pertinent pump standard or temperature rise or other limitation, specified by the manufacturer.
Amplitude	The magnitude of vibration. Displacement is measured in peak-to-peak. Velocity and acceleration are measured in zero-to-peak or root mean square (rms).
Anchor bolts	Bolts used to attach the mounting plate to the support structure (concrete foundation or steel structure).
Annealing heat treatment	Heating an object to and then holding it at a specified temperature and then cooling at a suitable rate for such purposes as reducing hardness, improving machinability, facilitating cold working, producing a desired microstructure, or obtaining desired mechanical properties.
Austenitic stainless steel	300 Series of stainless steel has austenite as its primary phase (face centered cubic crystal). Stainless steels in the 300 Series contain chromium and nickel, and some molybdenum and manganese.
Axially (horizontal) split	Split with the principal joint parallel to the shaft centerline.
Barrel pump	Horizontal pump of the double-casing type.
Baseplate	A fabricated (or cast) structure, typically metal, used to mount, support, and align machinery and its auxiliary components. Baseplates may be directly grouted to concrete foundations (after proper leveling) or bolted to pre-grouted chock plates.

Term	**Description**
Bearing and lube oil temperature stabilization	This is generally accepted to be not more than an increase of 2 °F (1 °C) over a 10-minute period at maximum continuous speed.
Bellows seal	Type of mechanical seal that uses a flexible metal bellows to provide secondary sealing and spring loading.
Best efficiency point (BEP)	Flow rate at which a pump achieves its highest efficiency at rated impeller diameter. In API 610, speed is not included.
Blades	Rotating air foils for both compressors and turbines, unless modified by an adjective.
Brake horsepower (BHP)	The actual amount of horsepower being consumed by the rotating equipment.
C	The chemical symbol for carbon; may appear on an MTR or in a specification/standard for equipment.
Certification	Documented and signed testimony of qualification. Certification generally refers to the confirmation of certain, specified characteristics of a product or confirmation of a person meeting requirements for a specific qualification.
Calibration	A comparison between measurements—one of known magnitude or correctness (the standard) compared with the measuring device under test in order to establish the accuracy of a measuring device.
Carbon equivalent (CE)	A summation of carbon plus alloying elements contained in steel or alloy steel. The term may be found in specifications/standards and equipment purchase orders.
Cartridge seal	Completely self-contained unit (including seal/rings, mating ring(s), flexible elements, secondary seal, seal gland plate, and sleeve) that is preassembled and preset before installation.
Certified Mill Test Report (CMTR)	Typically used for an additional level of surety that materials in equipment actually contain the elements stated. (see certification)
Circulating oil system Forced lubrication system	A system that pumps oil from a reservoir through filters and an external oil cooler before delivering oil to the bearing(s). NOTE 1 Typically only used with hydrodynamic bearings. NOTE 2 The reservoir may be external or contained within the equipment it serves.
Cladding	A metal integrally bonded onto another metal (e.g. plate), under high pressure and temperature whose properties are better suited to resist damage from the process fluids than the underlying base metal.
Cold working	Plastic deformation (forming, rolling, forging, etc.) of metals below the recrystallization temperature of the metal.
Coast down time	Period required after the driver is tripped for the equipment train to come to a complete stop.
Compressor rated point	The intersection on the 100 % speed curve corresponding to the highest capacity of any specified operating point.
Console	Total system whose components and controls are packaged as a single unit on a continuous or joined baseplate.
Cr	The chemical symbol for chromium, which may appear on an MTR.
Critical service	Typically defined as those applications that are unspared/single-train installations whereby loss of operation would result in significant loss of production, loss of primary process containment, or threat to personnel safety.
Critical speed	Shaft rotational speed at which the rotor-bearing-support system is in a state of resonance.

Term	Description
Cu	The chemical symbol for copper, which may appear on an MTR.
Datum elevation	Elevation to which values of NPSH are referred.
Destructive testing	Various tests that are performed on metals for the purposes of determining mechanical properties and that involve testing (usually breaking) of sample coupons. Examples of such tests include tensile testing, bend testing, and Charpy impact testing. A destructive testing work process involves extracting samples/coupons from components and testing for characteristics that cannot otherwise be determined by nondestructive testing. The work process involves breaking and/or testing coupons/samples to failure, thus usually rendering the component from which the samples were extracted unfit for continued service.
Deviation	A departure from requirements in the contractual agreements or its referenced PO, engineering design, specified codes, standards, or procedures.
Dry film thickness (DFT)	Dry film thickness (of paint and coatings) that is measured by a DFT gauge.
Displacement (refers to vibration)	A vibration measurement that quantifies the amplitude in engineering units of mils (1 mil = 0.001 in.) or micrometers.
Double casing	Type of pump construction in which the pressure casing is separate from the pumping elements contained in the casing.
Drive-train component	Item of the equipment used in series to drive the machine.
Electrical runout	A source of error on the output signal from a noncontacting probe system resulting from nonuniform electrical conductivity properties of the observed material or from the presence of a local magnetic field at a point on the shaft surface.
Elevation	The height of any point on a vessel, structure, or assembly as shown on a drawing, e.g. nozzle, manway, or longitudinal weld, as measured from a base plate or other reference line.
Employer	The corporate, public, or private entity that employs personnel for wages, salaries, fees, or other considerations, e.g. the employer of the source inspector.
Engineered equipment	Equipment that is custom designed and engineered by the client and/or EPC to perform a project-specific function. Engineered equipment will typically require more source inspection than non-engineered equipment.
Engineering procurement construction (EPC)	The type of company hired by an end user to design, purchase, and execute a project.
Equipment train	Two or more rotating equipment machinery elements consisting of at least one driver and one driven element joined together by a coupling.
Examiner	A person who performs specified nondestructive examination (NDT) on components and evaluates the results to the applicable acceptance criteria to assess the quality of the component. Typically, NDT examiners (sometimes called NDT technicians) are qualified to ASNT NDT personnel qualification practices, e.g. SNT-TC-IA or CP-189.
Fe	The chemical symbol for iron, which may appear on an MTR.
Ferrous materials	Alloys that are iron based, including stainless steels.
Gear	Refers to either the pinion or gear wheel.
Gear-rated power	The maximum power specified by the purchaser on the data sheets and stamped on the nameplate.

Term	Description
Gear-service factor	The factor that is applied to the tooth pitting index and the bending stress number, depending upon the characteristics of the driver and the driven equipment, to account for differences in potential overload, shock load, and/or continuous oscillatory torque characteristics.
Gear wheel	The lowest speed rotor in a gearbox.
Gearing	The pinion(s) and gear wheel combination(s). A gear mesh is a pinion and gear wheel that operates together. A gear wheel may mesh with more than one pinion, and therefore be part of more than one gear mesh.
General purpose	Usually spared or in noncritical service.
Heat affected zone (HAZ)	The area of base metal directly adjacent to the weld that has had its metal structure affected by the heat of welding.
Hot working	Plastic deformation (forming, rolling, forging, etc.) of metals at a temperature above the metal recrystallization temperature.
Hunting tooth combination	Exists for mating gears when a tooth on the pinion does not repeat contact with a tooth on the gear until it has contacted all the other gear teeth.
Hydrodynamic bearings	Bearings that use the principles of hydrodynamic lubrication.
Individual Certification Program (ICP)	API program under which this source inspector certification program is administered.
Inlet volume flow	Flow rate expressed in volume flow units at the conditions of pressure, temperature, compressibility, and gas composition, including moisture content, at the compressor inlet flange.
Inspection	The evaluation of a component or equipment for compliance with a specific product specification, code, drawing, and/or standard specified in the contractual requirements, which may include the measuring, testing, or gauging of one or more characteristics specified for the product to determine conformity.
Inspection agency	An entity employed to provide competent, qualified, and certified source inspection personnel for the purpose of performing source inspection. For example, an inspection agency can be an EPC company, an owner-user, or an inspection service company.
Inspection coordinator	Individual who is responsible for the development of the source inspection strategy, coordination of source inspection visits, and implementation of source inspection activities on a project.
Inspection waiver	Permission to proceed with production/shipment without having a purchaser source inspection representative present for a specific activity.
Inspection and test plan (ITP)	A detailed plan (checklist) for source inspection activities that will guide the source inspector in their quality assurance activities at the vendor site with reference to applicable technical information, acceptance criteria, and reporting information. The supplier/vendor should also have their own ITP to guide their fabrication personnel and quality assurance personnel in the necessary quality steps and procedures.
Lamination	A type of discontinuity with separation or weakness generally aligned parallel to the worked surface of a plate material. In a forging, it can rise to the surface or occur internally; it is generally associated with forging at too low of a temperature. In plate material, it may be caused by the tramp elements that have congregated in the center of the plate during rolling.
Leakage rate	Volume or mass of fluid passing through a seal in a given length of time.

Term	Description
Levelness	The position of a surface of a component or structure that is horizontal (within tolerances) with the base plate and at 90 degrees to the vertical plumb line. Nozzle and attachment levelness tolerances are not addressed in ASME *BPVC*, Section VIII, Division 1; however, in the pressure vessel handbook, a ½ tolerance is permissible. To check levelness of a nozzle on a vessel, a level gauge is used. If the bubble is in the middle of the designated lines, the nozzle is level. A level gauge would be used for verification and measurement that the angle of a hillside (tangential) nozzle is properly installed relative to the vessel centerline.
Manufacturer	The organization responsible for the design and manufacture of the equipment.
Martensitic stainless steel	400 Series of stainless steel has martensite as its primary phase (body centered tetragonal microstructure). Stainless steels in the 400 Series contain chromium and manganese, plus phosphorus and silicon in small amounts.
Material test report Mill test report (MTR)	A document that certifies that a metal/material product is in conformance with the requirements (e.g. chemical and mechanical properties)
Maximum allowable continuous rod load	The highest combined rod load at which none of the forces in the running gear (piston, piston rod, crosshead assembly, connecting rod, crankshaft, bearings, etc.) and the compressor frame exceed the values in any component for which the manufacturer's design permits continuous operation.
Maximum allowable speed	Highest speed at which the manufacturer's design permits continuous operation.
Maximum allowable temperature	Maximum continuous temperature for which the manufacturer has designed the pump (or any part to which the term is referred) when pumping the specified liquid at the specified maximum operating pressure.
Maximum allowable working pressure (MAWP)	The maximum continuous pressure for which the manufacturer has designed the rotating equipment (or any part to which the term is referred) when operating on the specified liquid or gas at the specified maximum operating temperature (does not include mechanical seal).
Maximum continuous speed	The speed at least equal to 105 % of the highest speed required by any of the specified operating conditions.
Maximum discharge pressure	Maximum specified suction pressure plus the maximum differential pressure the pump with the furnished impeller is able to develop when operating at rated speed with liquid of the specified normal relative density (specific gravity).
Maximum exhaust casing pressure	The highest exhaust steam pressure that the purchaser requires the casing to contain, with steam supplied at maximum inlet conditions.
Maximum static sealing pressure	Highest pressure, excluding pressures encountered during hydrostatic testing, to which the seals can be subjected while the pump is shut down.
Mechanical runout	An inaccuracy of rotating mechanical systems, specifically indicating that the tool or shaft does not rotate exactly in line with the main axis. Should be measured with a dial indicator, typically on V-blocks.
Mg	The chemical symbol for magnesium, which may appear on an MTR.
Minimum allowable speed	Lowest speed at which the manufacturer's design permits continuous operation.

Term	Description
Minimum allowable suction pressure (compressors only)	The lowest pressure (measured at the inlet flange of the cylinder) below which the combined rod load, gas load, discharge temperature, or crankshaft torque load (whichever is governing) exceeds the maximum allowable value during operation at the set pressure of the discharge relief valve and other specified inlet gas conditions for the stage.
Minimum continuous stable flow (MCSF)	Lowest flow at which the pump can operate without exceeding the vibration limits imposed by the pertinent pump standard.
Minimum exhaust pressure	The lowest exhaust steam pressure at which the turbine is required to operate continuously.
Minimum inlet pressure	The lowest inlet steam pressure and temperature conditions at which the turbine is required to operate continuously.
Misalignment	The degree to which the axes of machine components are non-collinear, either in parallel offset or angularity.
Mn	The chemical symbol for manganese, which may appear on an MTR.
Mo	The chemical symbol for molybdenum, which may appear on an MTR.
Mounting plate	Device used to attach equipment to concrete foundations or steel supports. This is either a baseplate(s), soleplate(s), or chock plate(s).
MT	Magnetic particle testing (examination).
Multistage pump	Pump with two or more stages. Unless they mean BB3/5.
Nb	The chemical symbol for niobium, which may appear on an MTR.
NDT map	A drawing that identifies specific locations where NDT has been conducted on a product/component.
Net pump suction head available (NPSHa)	NPSH determined by the purchaser for the pumping system with the liquid at the rated flow and normal pumping temperature.
Net pump suction head required NPSH3 (per API 610)	NPSH that results in a 3 % loss of head (first-stage head in a multistage pump) determined by the vendor by testing with water.
Ni	The chemical symbol for nickel, which may appear on an MTR.
Nominal pipe size (NPS)	A standard for designating pipe sizes (inches) and associated wall thickness (schedule), e.g. the nominal pipe size for a 4-in. pipe is normally shown as NPS 4.
Nonconformance report (NCR)	A report filled out by the SI detailing an issue that has been discovered to not be in accordance with project contractual agreements, such as the PO, engineering design, specified codes, standards, or procedures.
Nondestructive examination or nondestructive testing	A quality process that involves the examination, testing, and evaluation of materials, components, or assemblies without affecting their functionality, e.g. VT, PT, MT, UT, and RT.
Nonconformance	A departure/deviation from project contractual agreements, such as the PO, engineering design, specified codes, standards, or procedures.
Nonengineered equipment	Equipment that is designed and fabricated by vendors that includes off-the-shelf items such as valves, fittings, some skid units, instruments, pumps, and electrical gear. Such equipment is usually purchased by catalog model numbers, etc. Nonengineered equipment will typically require less source inspection than engineered equipment.
Nonferrous materials	Alloys that are not iron based, e.g. nickel- and copper-based alloys.

Term	Description
Normalizing heat treatment	A heat treating process in which a ferrous material or alloy is heated to a specified temperature above the transformation range of the metal and subsequently cooled in still air at room temperature. Typically, normalizing heat treatments will refine the grain size and improve the impact properties of steels.
Normal operating point	Point at which usual operation is expected and optimum efficiency is desired. This is usually the point at which the vendor certifies the heat rate is within the tolerances stated in this standard.
Normal transmitted power (gears only)	The power at which usual operation is expected and optimum efficiency is desired. The normal transmitted power may be equal to or less than the gear-rated power.
Nozzles	Turbine stationary (nonrotating) airfoils. Inlet, outlet, or pressure casing connections for pumps.
Oil mist lubrication	Lubrication provided by oil mist produced by atomization and transported to the bearing housing(s) by compressed air.
Observed inspection (Observed test)	Inspection or test where the purchaser is notified of the timing of the inspection or test and the inspection or test is performed as scheduled, regardless of whether the purchaser or their representative is present.
Operating region	Portion of a pump's hydraulic coverage over which the pump operates.
Overhung pump	Pump whose impeller is supported by a cantilever shaft from its bearing assembly.
P	The chemical symbol for phosphorus, which may appear on an MTR.
Peak-to-peak value	The difference between positive and negative extreme values of an electronic signal or dynamic motion.
Penetrant testing (PT)	A nondestructive material examination procedure used to check for deficiencies such as cracks by spreading a thin liquid dye onto the material’s surface, followed by the application of a developer.
Pinion	A high-speed rotor or rotors in a gearbox or gearset.
Piston rod drop	A measurement of the position of the piston rod relative to the measurement probe mounting location(s) (typically oriented vertically at the pressure packing on horizontal cylinders).
Piston rod runout	The change in position of the piston rod in either the vertical or horizontal direction as measured at a single point (typically at or near the pressure packing case) while the piston rod is moved through the outbound portion of its stroke.
Potential maximum power	Expected power capability when the gas turbine is operated at maximum allowable firing temperature, rated speed, or under other limiting conditions as defined by the manufacturer and within the range of specified site values.
Predicted capacity limit	The maximum volume flow capacity at the end of curve line that defines the manufacturer’s capability to reasonably predict performance. This may or may not be an actual choke limit.
Preferred operating region	Portion of a pump's hydraulic coverage over which the pump's vibration is within the base limit of the pertinent pump standard.
Pressure casing	Composite of all stationary pressure-containing parts of the pump, including all nozzles, seal glands, seal chambers, and auxiliary connections, but excluding the stationary and rotating members of mechanical seals.
Pressure relief device (PRD)	A devise used to provide a means of venting excess pressure, which could rupture piping or vessel.

Term	Description
Pressure relief valve (PRV)	A type of safety valve used to control or limit the pressure in a system; pressure might otherwise build up and create a process upset, instrument or equipment failure, or fire.
Procedure	A document detailing how a work process is to be performed, e.g. a welding procedure.
Procedure qualification record (PQR)	Per ASME *BPVC*, Section IX, QW 200.2.
Projection	The length from the nozzle or attachment face to the vessel shell centerline.
Protractor	An instrument for measuring angles, typically in the form of a flat semicircle marked with degrees along the curved edge.
Proximity probe	A noncontacting sensor that consists of a tip, a probe body, an integral coaxial or triaxial cable, and a connector, and that is used to translate distance (gap) to voltage when used in conjunction with an oscillator-demodulator.
Quality assurance (QA)	A proactive quality process that aims to prevent defects and refers to a program of planned, systematic, and preventative activities implemented in a quality system that is intended to provide a degree of confidence that a product will consistently meet specifications. It includes systematic measurement, comparison with a standard, monitoring of processes, and an associated feedback loop that is intended to avoid deviations from specification.
Quality control	The specific steps in a QA process that aim to find potential defects in a product before it is released for delivery, e.g. VT, PT, RT, UT, dimensional verification, etc. The QA process will specify the QC steps necessary during manufacture/fabrication of a product.
Qualification	Demonstrated skill, demonstrated knowledge, documented training, and documented experience required for personnel to perform the duties of a specific job, e.g. a certified source inspector.
Quality surveillance	The process of monitoring or observing the inspection activities associated with materials, equipment, and/or components for adherence to the specific procedure, product specification, code, or standard specified in contractual requirements. For the purposes of this guide, quality surveillance and source inspection mean the same thing (see definition for “source inspection”).
Quenching	Rapid cooling of a heated metal for the purpose of affecting mechanical and/or physical properties.
Radially split	Split with the principal joint perpendicular to the shaft centerline.
Rated input speed of gear unit	The specified (or nominal) rated speed of its driver, as designated by the purchaser on the data sheets.
Rated output speed of gear unit	The specified (or nominal) rated speed of its driven equipment, as designated by the purchaser on the data sheets.
Rated operating point	Point at which the vendor certifies that pump performance is within the tolerances stated in API 610. NOTE Normally, the rated operating point is the specified operating point with the highest flow.
Rated power	The greatest turbine power specified and the corresponding speed.
Rated speed/100 % speed	Highest speed (revolutions per minute) of the gas turbine output shaft required of any of the operating conditions for the driven equipment and at which site-rated power is developed.
Root mean square (RMS)	A measure of surface finish on a machined surface.

Term	Description
Rotor	Assembly of all the rotating parts of a pump.
RT	Radiographic testing (examination).
Rust bloom	The term used to describe discoloration that occurs on the surface of steel that has been previously blasted, e.g. near-white or white metal in preparation for coating. When rust bloom is found, the surface should generally be recleaned before coating using the same blast-cleaning process.
S	The chemical symbol for sulfur, which may appear on an MTR.
Seal buffer gas	Clean gas supplied to the high-pressure side of a seal.
Seal chamber (stuffing box)	Region between the shaft and casing into which the seal is installed.
Seal flush	Fluid that is introduced into the seal chamber on the process fluid side in close proximity to the seal faces; typically used for cooling and lubricating the seal faces and/or to keep them clean.
Seal gas	Dry, filtered gas supplied to the high-pressure side of a self-acting gas seal.
Seal leakage	Fluid that flows from the high-pressure side of the seal to the low-pressure side of the seal.
Shutdown set point	Preset value of a measured parameter at which automatic or manual shutdown of the system or equipment occurs.
Soleplate	A plate (grouted or ungrouted), installed under motors, bearing pedestals, gearboxes, turbine feet, cylinder supports, crosshead pedestals, and compressor frames. Plate attached to the foundation, with a mounting surface for equipment or for a baseplate.
Solution anneal heat treatment	Heating an alloy to a specified temperature, holding at the temperature long enough for one or more elements to reenter into solid solution, then cooling rapidly enough to hold those elements in solid solution.
Subject matter expert (SME)	A person who is an authority in a particular area or topic.
Supplier observation reports	Documents filled out by the SI indicating concerns or other factual descriptions of what was noticed during product surveillance, but not necessarily issues that may be considered defects or require NCRs.
Source inspection	The process of providing quality surveillance of materials, fabrications, and equipment being supplied by a vendor or manufacturer/fabricator for use in the oil, petrochemical, and gas industry, including upstream, midstream, and downstream segments. Source inspection largely consists of verifying that the vendor's own quality assurance process is functioning as it should to produce quality products that meet contractual agreements.
Source inspector	Individual responsible for performing the actual source inspection activities at the vendor's facilities in accordance with the applicable inspection and test plan (ITP).
Specification	A document that contains the requirements for the manufacturing and fabrication of specific types of equipment and components.
Special purpose application	Application for which the equipment is designed for uninterrupted, continuous operation in critical service and for which there is usually no spare equipment.
Standby service	Normally idle piece of equipment that is capable of immediate automatic or manual startup and continuous operation.
Stage	One impeller and associated diffuser or volute and return channel, if required.

Term	Description
Surge	The volume flow capacity below which a centrifugal compressor becomes aerodynamically unstable.
Tubular Exchanger Manufacturers Association (TEMA)	A trade association of leading manufacturers of shell and tube heat exchangers.
Tempering	Reheating a hardened metal to a temperature below the transformation range to improve toughness.
Thermocouple	A temperature sensor consisting of two dissimilar metals so joined to produce different voltages when their junction is at different temperatures.
Ti	The chemical symbol for titanium, which may appear on an MTR.
Tolerance	The limit(s) of specified dimensions, physical properties, or other measured values of a component.
Total indicator reading (TIR)	Difference between the maximum and minimum readings of a dial indicator or similar device, monitoring a face or cylindrical surface, during one complete revolution of the monitored surface.
Training	An organized program developed to impart the skills and knowledge necessary for qualification as a source inspector.
Trip speed	The speed at which the independent emergency overspeed device operates to shut down the turbine.
Turndown	The percentage of change in capacity (referred to rated capacity) between the rated and the surge point at the rated head.
Ultrasonic testing (UT)	Generally used to inspect a component for flaws or for measuring thicknesses.
Unbalance	A rotor condition where the mass centerline (principal axis of inertia) does not coincide with the geometric centerline, expressed in units of gram-inches, gram-centimeters, or ounce-inches.
Vanes	Compressor stationary (nonrotating) airfoils. Also, vanes are the motive elements of pump impellers.
Velocity	The time rate of change of displacement. Units for velocity are inches per second or millimeters per second.
Vendor	The entity that is responsible for the actual manufacturing and fabrication (M&F) of the material, equipment, or components, and that is responsible for meeting contractual requirements.
Verification	A check of an instrument to determine if it is performing or reading accurately. This action may lead to a calibration.
Vertical inline pump	Vertical-axis, single-stage, overhung pump whose suction and discharge connections have a common centerline that intersects the shaft axis.
Vertically suspended pump	Vertical-axis pump, of one or more stages, whose liquid end is suspended from a column and mounting plate.
Visual testing (VT)	Performing visual examination of a component or machine.
Welding performance qualification (WPQ)	Welding performance qualification record per ASME *BPVC*, Section IX, QW 301.4.
Welding procedure specification (WPS)	Welding procedure specification per ASME *BPVC*, Section IX, QW 200.1.
Witnessed test	Inspection or test for which the purchaser is notified of the timing of the inspection or test and a hold is placed on the inspection or test until the purchaser or its representative is in attendance.

3.1 Websites Useful to the Source Inspector

API	American Petroleum Institute	http://www.api.org
ASM	American Society for Metals	http://www.asminternational.org/portal/site/www
ASME International	Formerly known as American Society for Mechanical Engineers	http://www.asme.org
ASNT	American Society for Nondestructive Testing	http://www.asnt.org
ASTM International	Formerly known as American Society for Testing and Materials	http://www.astm.org
AWS	American Welding Society	http://www.aws.org
ISA	Instrument Society of America	http://www.isa.org
ISO	International Organization for Standardization	http://www.iso.org/iso/home.html
MSS	Manufacturers Standardization Society	http://mss-hq.org/Store/index.cfm
NDT Resource Center	Nondestructive Testing Resource Center	http://www.ndt-ed.org
NFPA	National Fire Protection Association	http://www.nfpa.org
NEC	National Electrical Code	http://www.nfpa.org/NEC
SSPC	The Society for Protective Coatings	http://www.sspc.org/
Worldsteel	Worldsteel Association	http://www.steeluniversity.org

4 Training and Certification

4.1 General

Training and certification for vendor/source inspection is unique to each organization. This study guide and supporting examination is designed to provide a recommended level of competency for a source inspector of mechanical rotating equipment.

5 Source Inspection Management Program

5.1 Employers or Inspection Agencies

Employers tasked with the responsibility of performing source inspection coordination and/or source inspection activities should develop a management program in order to provide the individuals performing the specific source inspection functions the necessary information to accomplish their duties. These programs are generic in that they provide requirements and guidance on all types of projects that will require source inspection. See Section 7 for the types of source inspection plans that are needed for each specific project.

5.2 Source Inspection Management Programs

Source inspection management programs should cover most of the generic activities identified in this study guide, but also include the following company-specific information:

— what activities need to be accomplished;

— who is responsible for accomplishing each of the activities, i.e. personnel titles;

— the training and competencies required for source inspectors;

— schedule and/or frequency for each of the training activities to be accomplished;

— how each of the activities will be accomplished, i.e. specific work procedures;

— application of acceptance criteria and industry standards;

— hands-on training.

5.3 What These Management Programs May Reference

These management programs may reference many other company-specific source inspection procedures, practices, and policies, with more details needed for specific types of source inspection activities. For example:

— how to prepare a source inspection plan for an entire project and an inspection and test plan for each equipment item;

— guidance on the criteria to use for selecting source inspectors to match their skills and training with different types of equipment with different risk levels;

— guidance on scheduling and conducting significant source inspection events, such as the pre-inspection (fabrication kick-off) meeting, the vendor quality coordination meeting, final acceptance testing, etc.;

— guidance on SI safety at vendor shops;

— how to review welding procedures and welder qualification documents;

— how to review a vendor's inspection/examination records;

— what inspections should be repeated by the source inspector to verify the results of vendor examinations and tests;

— how to handle deviations and nonconformances;

— how to complete specific inspection forms;

— what steps to take before approving product acceptance;

— interfacing with the jurisdictional authorized inspector.

6 Project-specific Source Inspection Planning Activities

6.1 General

From the Source Inspection Management Program documents, a project-specific inspection plan should be developed by the end user/EPC inspection coordinator.

6.2 Coordination of Inspection Events

End users or EPCs should identify dates for source inspection scheduled work process events, such as the pre-inspection meeting (manufacturing kickoff), key inspection events (factory acceptance, performance testing, and final inspection), and anticipated shipping date to allow coordination with other project members involved in the activity.

6.3 Report Review

Source inspection reports are important deliverables from the source inspector to the end user, EPC, or other client. The amount and type should be specified in the ITP. Each inspection report should be reviewed for content, completeness, and technical clarity prior to distribution.

7 Source Inspection Performance

7.1 Inspector Conduct and Safety

a) Individuals tasked with the responsibility of performing source inspection activities should conduct themselves professionally while visiting a vendor facility as a representative of their employer and/or purchaser. If any conflict should arise during the inspection activity, the source inspector should notify their supervisor/purchaser for resolution as soon as possible. It is important that the source inspector not be confrontational or argumentative regardless of the importance of the issue at hand; but rather simply indicate in objective terms how the vendor intends to proceed to resolve the issue.

b) Safety of the individual performing source inspection is one of the most important aspects of their work. A safety program should be provided by the EPC/user that identifies specific safety hazards associated with the job. Source inspectors should be adequately trained and knowledgeable in these safety programs in order to minimize the possibility of injury. The safety program should include:

   1) potential travel safety issues specific to the job;

   2) potential shop safety issues and hazard recognition;

   3) how to handle the observation of unsafe acts in the shop.

      — The source inspector must observe the safety procedures and policies of the vendor while on their premises or, if more stringent, their own company safety requirements.

7.2 Review of Project Documents

7.2.1 General

7.2.2 Typical project documents include, but are not limited to, contractual agreements (purchase orders and/or subcontracts), source ITP, project specifications, engineering or fabrication drawings, data sheets, applicable codes, references, or standards.

7.2.2.1 Source inspectors should familiarize themselves with all project documents applicable to the assigned scope of work and ensure that they have access to the specific edition/version of those documents specified in the contractual agreement at all times during their inspection visits.

Prior to beginning the quality surveillance specified in the ITP, the source inspector should confirm that the vendor has the most current approved documents, drawings, etc. specified in the engineering design. Later editions of industry codes and standards do not apply if the engineering design has specified an earlier edition of a specific standard.

Additionally, the source inspector should confirm that all the project documents that are required to be submitted have been reviewed/approved by the purchaser.

7.2.3 Contractual Agreements

Contractual agreements, including the purchase order, all specified engineering design documents, specified company standards, and specified industry standards, form the basis for the requirements for source inspection of the purchased products.

7.2.4 Engineering Design Documents

For engineered equipment, the source inspector must be familiar with the engineering design documents and drawings that are vital to quality of the purchased products.

7.2.5 Company and Client Standards

The source inspector must be familiar with all company and client standards that are specified in the contractual agreements. These standards typically augment or supplement industry standards for issues not sufficiently well covered in industry standards. All mandatory requirements, i.e. “shall” statements, included in the company specifications shall be met. They should be handled in accordance with standard purchaser management NCR systems requirements.

Other clauses contained in the specified standards, such as those suggested or recommended (i.e. “should” statements), are expectations of the vendor, but not necessarily requirements. These may become an issue to be reported in supplier observation reports, and handled in accordance with standard purchaser management systems. Company and client standards may cover engineered and nonengineered equipment.

7.2.6 Industry Codes and Standards

7.2.6.1 General

The source inspector needs to be familiar with industry codes and standards as specified by the user or EPC in the contractual agreements, such as those in the following subsections.

7.2.6.2 Standards

There are many standards that may be included in contractual agreements to specify and control the quality of products. A few of the standards that the source inspector may need to be familiar with are shown in the following subsections, but this list is not all inclusive. Other standards that are specified in the contractual agreements may be equally important to the quality of the delivered product. The information contained in the following industry standards is generic to a wide variety of products, and therefore should be general knowledge to the experienced source inspector.

API 610, *Centrifugal Pumps for Petroleum, Petrochemical, and Natural Gas Industries*

API 610 specifies requirements for centrifugal pumps, including pumps running in reverse as hydraulic power recovery turbines, for use in petroleum, petrochemical, and gas industry process services. API 610 is applicable to overhung pumps, between bearing pumps, and vertically suspended pumps. Clause 9 provides requirements applicable to specific types of pumps. All other clauses of API 610 apply to all pump types. Illustrations of the various specific pump types are provided, as are the designations assigned to each specific pump type. It does not cover sealless pumps.

NOTE For sealless pumps, reference can be made to API 685. For heavy-duty pump applications in industries other than petroleum, petrochemical, and gas processing, reference can be made to ISO 9905.

Relevant industry experience suggests pumps produced to this international standard are cost-effective when pumping liquids at conditions exceeding any one of the following:

discharge pressure (gauge)	1900 kPa (275 psi; 19.0 bar)
suction pressure (gauge)	500 kPa (75 psi; 5.0 bar)
pumping temperature	150 °C (300 °F)
rotative speed	3600 r/min
rated total head	120 m (400 ft)
impeller diameter, overhung pumps	330 mm (13 in.)

API 611, *General-Purpose Steam Turbines for Petroleum, Chemical, and Gas Industry Services*

API 611 specifies the minimum requirements for general-purpose steam turbines, including basic design, materials, related lubrication systems, controls, auxiliary systems, and accessories. General-purpose turbines are horizontal or vertical turbines used to drive equipment that is usually spared, is relatively small in size (power), or is in noncritical service. They are generally used where steam conditions will not exceed a pressure of 700 psig (48 bar) and a temperature of 750 °F (400 ˚C) or where speed will not exceed 6000 rpm.

API 612, *Special Purpose Steam Turbines*

API 612 specifies the minimum requirements for special-purpose steam turbines, including basic design, materials, related lubrication systems, controls, auxiliary systems, and accessories. It also covers the related lube oil systems, instrumentation, control systems, and auxiliary equipment.

API 613, *Special Purpose Gears*

API 614, *Lubrication, Shaft-Sealing and Oil-Control Systems and Auxiliaries*

API 614 specifies the general requirements for lubrication systems, oil type shaft-sealing systems, dry-gas face-type shaft-sealing systems, and control-oil systems for general- or special-purpose applications for equipment such as compressors, gears pumps, and drivers. General-purpose applications are limited to lubrication systems.

This edition of API 614 is the adaptation of ISO 10438:2007, *Petroleum, petrochemical and natural gas industries – Lubrication, shaft-sealing and oil-control systems and auxiliaries*.

API 616, *Gas Turbines*

API 616 specifies the minimum requirements for open, simple, and regenerative-cycle combustion gas turbine units for services of mechanical drive, generator drive, or process gas generation. All auxiliary equipment required for operating, starting, controlling, and protecting gas turbine units are either discussed directly in this standard or referred to in this standard through references to other publications. Specifically, gas turbine units that are capable of firing gas or liquid or both are covered by this standard. This standard covers both industrial and aeroderivative gas turbines.

API 617, *Axial and Centrifugal Compressors and Expander-Compressors for Petroleum, Chemical and Gas Industry Services*

API 617 specifies the minimum requirements for axial compressors, single-shaft and integrally geared process centrifugal compressors, and expander-compressors. This standard does not apply to fans or blowers that develop less than a 5-psi rise above atmospheric pressure. This standard also does not apply to packaged, integrally-geared centrifugal plant and instrument air compressors. Hot gas expanders over 500 ˚F are not covered in this standard.

API Std 618, *Reciprocating Compressors for Petroleum, Chemical, and Gas Industry Services*

API Std 618 specifies the minimum requirements for reciprocating compressors and their drivers for handling process air or gas with either lubricated or nonlubricated cylinders. Compressors covered by this standard are low- to moderate-speed machines. Also included in this standard are related lubrication systems, controls, instrumentation, intercoolers, aftercoolers, pulsation suppression devices, and other auxiliary systems. This standard does not cover integral gas engines, compressors with single-acting trunk-type pistons that also serve as crossheads, and plant or instrument-air compressors that discharge at or below 125 psig.

API 670, *Machinery Protection Systems*

API 671, *Special Purpose Couplings*

API 672, *Packaged Centrifugal Air Compressors*

API 673, *Fans*

API 674, *Positive Displacement Pumps—Reciprocating*

API 676, *Positive Displacement Pumps—Rotary*

API 677, *General-Purpose Gear Units for Petroleum, Chemical and Gas Industry Services*

API 677 covers the minimum requirements for general-purpose, enclosed single- and multistage gear units incorporating parallel shaft helical and right angle spiral bevel gears for the petroleum, chemical, and gas industries. Gears manufactured according to this standard shall be limited to the following pitch-line velocities. Helical gears should not exceed 60 m/s (12,000 ft/min), and spiral bevels shall not exceed 40 m/s (8000 ft/min). Spiral bevel gearsets shall be considered matched sets. This standard is not intended to apply to gears in special-purpose service, which are covered in API 613; to gears integral with other equipment; to epicyclic gear assemblies; or to gears with non-involute tooth forms.

API 681, *Liquid Ring Vacuum Pumps*

API 682, *Pumps—Shaft Sealing Systems for Centrifugal and Rotary Pumps*

API 682 specifies requirements and gives recommendations for sealing systems for centrifugal and rotary pumps used in the petroleum, natural gas, and chemical industries. It is applicable mainly for hazardous, flammable, and/or toxic services where a greater degree of reliability is required for the improvement of equipment availability and the reduction of both emissions to the atmosphere and life-cycle sealing costs. It covers seals for pump shaft diameters from 20 mm (0,75 in) to 110 mm (4,3 in).

Hydraulic Institute

HI 14.6, *Centrifugal Tests*

HI 14.6 is for centrifugal, sealless centrifugal, and regenerative turbine pumps of all industrial types, except vertical multistage diffuser. It includes detailed procedures on the setup and conduct of hydrostatic and performance tests of such pumps.

7.2.6.3 ASME Codes and Standards

There is a wide variety of ASME codes and standards that may be included in the contractual agreements to specify equipment fabrication methods and control the quality of products for the energy industry. A few of those that the source inspector should be familiar with and apply when specified are shown in the following subsections, but this list is not all inclusive. Occasionally, there may be other sections of the ASME *BPVC* that will be specified on different projects in which the source inspector will be involved.

ASME *BPVC* Section II—*Materials*

This section of the *BPVC* is divided into four parts covering materials for the construction of piping and pressure vessels.

ASME *BPVC* Section V—Nondestructive Examination

This section of the *BPVC* contains requirements and methods for NDT techniques that are specified by other sections of the ASME *BPVC* and/or contractual agreements. Most of the common methods of NDT are covered in Section V, including RT, UT, MT, PT, VT, and LT. Appendix A of Section V presents a listing of common imperfections and damage mechanisms and the NDT methods that are generally capable of detecting them. Section V also provides guidance on methods of evaluating NDT results. The source inspector should be thoroughly familiar with the contents of Section V for whichever NDT method is specified in contractual agreements and/or ITP. For the purposes of source inspector examination, some of the content covered in ASME *BPVC* Section V that applicants should focus on includes:

— all definitions in Subsection A, Article 1, Appendix 1, and Subsection B, Article 30, SE-1316;

— Article 1 on General Requirements for NDT;

— Article 2 on Radiographic Examination;

— Article 4 on Ultrasonic Examination Methods of Welds;

— Article 5 on Ultrasonic Examination Methods for Materials;

— Article 6 on Liquid Penetrant Examination;

— Article 7 on Magnetic Particle Examination;

— Article 9 on Visual Examination;

— Article 10 on Leak Testing;

— Article 23, Section 797 on UT Thickness Testing;

— all definitions in Appendix 3.

ASME Section VIII, Division 1, *Boiler Pressure Vessel Code*

— Appendix 7, Examination of Steel Casting

ASME *BPVC* Section IX—Qualification Standard for Welding and Brazing Procedures, Welders, Brazers, and Welding and Brazing Operators

Section IX of ASME *BPVC* Part QW covers the qualifications of welders, welding operators, and the procedures that will be employed during fabrication. The primary subjects covered include welding general requirements, welding procedure specifications and qualification, and welder performance qualification. Section IX does not cover acceptance criteria for production welds.

Section IX also covers fabrication by brazing (Part QB); the source inspector should be aware of that section, but will not need to be familiar with it until and unless assigned to a project that specifies brazed construction. The source inspector should be thoroughly familiar with the contents of Section IX Part QW with regard to the WPS, PQR, and WPQ that are specified in contractual agreements and/or ITP. For the purposes of source inspector examination, the applicants need to focus their attention on the following sections of ASME *BPVC* Section IX:

— Welding General Requirements QW 100 to 190;

— Welding Procedure Qualifications QW 200 to 290;

— Welding Performance Qualifications QW 300 to 380;

— Welding Data QW 400 to 490;

— Standard Welding Procedure Specifications QW 500 to 540.

7.2.6.4 ASNT Standards

ASNT SNT-TC-1A

This recommended practice establishes a general framework for a qualification and certification program for NDT technicians. In addition, it provides recommended education requirements and training requirements for different test methods. The source inspector should be familiar with this standard, including the duties and responsibilities for each of the three levels of NDT qualified technician.

7.2.6.5 SSPC Standards

SSPC-PA 2 Coating Applications Standard No. 2, *Procedure for Determining Conformance to Dry Coating Thickness Requirements*

This standard describes a procedure for determining conformance to a specified dry film thickness (DFT) range on metal substrates using NDT thickness gauges. The source inspector should be familiar with Sections 1 to 8 of this standard.

SSPC Surface Preparation Guide

This guideline briefly describes the scope of the seven SSPC and NACE surface-preparation standards with application to source inspection. The source inspector should be familiar with the scope of the standards listed below that are included in this guide, but need not be familiar with the details in the specific standards for examination purposes.

— SSPC-SP1, *Solvent Cleaning*;

— SSPC-SP3, *Power Tool Cleaning*;

— SSPC-SP5 or NACE 1, *White Metal Blast Cleaning*;

— SSPC-SP6 or NACE 3, *Commercial Blast Cleaning*;

— SSPC-SP7 or NACE 4, *Brush-Off Blast Cleaning*;

— SSPC-SP10 or NACE 2, *Near-White Blast Cleaning*;

— SSPC-SP11, *Power Tool Cleaning to Bare Metal*.

7.2.7 Welding Procedures and Qualifications

Welding procedure qualifications are the responsibility of the vendor, while it is the responsibility of the source inspector that they be verified as the ones approved by the purchaser. Prior to verifying welding inspection documents provided by the vendor, the source inspector should confirm that the version of the WPS that was used was the one approved by the responsible person, e.g. engineer/WPS/PQR SME for both the purchaser and vendor. ASME *BPVC* Section IX is the appropriate reference for knowledge and understanding of WPS/PQRs.

— welding procedure;

— qualifications of the welder;

— inspection report.

7.2.8 NDT Procedures

Development of NDT procedures are the responsibility of the vendor, while it is the responsibility of the source inspector that they be verified as the ones approved for use. Prior to witnessing NDT, the source inspector should confirm that the version of the NDT procedure has been reviewed and approved by the responsible person, e.g. engineer/NDT SME.

NOTE The *AWS Welding Inspection Handbook*, ASME *BPVC* Section V, AWS D1.1, and ASNT SNT-TC-1A are the appropriate references for knowledge and understanding of NDT procedures and required training and certification of NDT technicians.

7.2.9 Project Schedules

While the responsibility of establishing and monitoring the delivery is not generally in the purview of the source inspector, and the responsibility of meeting the schedule remains with the vendor, the source inspector may be requested to report on fabrication status or slippage of milestone progress. The source inspector should notify the inspection coordinator if they believe that product quality may be compromised by schedule pressures.

7.3 Performing the Source Inspection

Individuals assigned to perform the source inspection activity shall follow the approved ITP. Visual inspection, welding inspection, dimensional inspections, observing NDT, and all other examinations and tests shall be performed in accordance with the source ITP, project specification, and applicable code and standards, and meet the applicable acceptance criteria. See Section 9 (Examination Methods, Tools, and Equipment).

One important step in the source inspection work process is to verify evidence that the vendor personnel conducting the fabrication and quality control steps during fabrication are qualified and certified, as specified in the ITP or other contractual documents.

During the course of manufacturing and fabrication, the vendor may propose contract deviations that could impact cost, schedule, and/or quality. In such cases, the source inspector should request that the vendor propose such changes in writing for review and approval by the purchaser of the equipment.

7.4 Source Inspection Work Process Scheduled Planning Events

7.4.1 General

Typical source inspection scheduled work process events include the following:

Pre-inspection Meeting/Kickoff meeting (Prior to Start of Manufacturing)

The source inspector assigned to the vendor facility should participate in the pre-inspection/KOM meeting. The purpose of this meeting is to ensure that everyone who will be involved in manufacturing, fabrication, and monitoring the quality of the equipment fully understands specific requirements and details of the job, especially those requirements that may be non-routine or different relative to normal vendor quality surveillance. These source inspection work process events may also be observed or handled by others besides the source inspector. Advance preparation by the source inspector is important to ensure the meeting covers all necessary requirements as outlined in the purchaser and vendor meeting outline. Those requirements may include review of:

a) PO and contractual agreements;

b) engineering, technical, and material requirements and status;

c) fabrication schedules;

d) critical path and long-lead equipment/materials;

e) quality requirements, e.g. ITP, NCR, inspection frequency, etc.;

f) sub-suppliers and their quality requirements;

g) special requirements, e.g. performance or functional testing requirements;

h) painting, preservation, and tagging;

i) communication requirements, e.g. inspection point notification, report distribution, proposed changes, hold points, schedule impacts, etc.;

j) shipping and release plan;

k) final documentation requirements;

l) recording and reporting any observations, exceptions, or deviations.

Report Writing

a) A key deliverable of source inspection is the progressive inspection report detailing items of the inspection.

b) The source inspector should reference the following minimum information in each report or approved report format:

    1) date of visit;

    2) appropriate contract number and key information;

    3) purpose of visit;

    4) action items or areas of concern;

    5) results of inspection/surveillance;

    6) reference drawings/data used (including drawing numbers) to perform inspection/surveillance;

    7) revisions of referenced drawings/data;

    8) reference to the applicable requirement in the ITP;

    9) identification of nonconforming or deviating items/issues.

c) Sufficient photos should be taken to document daily inspections. The source inspector should request permission from the vendor prior to taking any photographs. Wide-angle and close-up photos should be sufficient to document activity and results. Photos should be dated and labeled.

d) Reports should be submitted to the inspection coordinator for review of content and technical clarity before they are distributed to the purchaser, unless otherwise instructed.

7.5 Nonconformance/Deviations

a) Deviations to the contractual agreement should be identified as nonconformance and should be reported to the purchaser.

b) Nonconformance reports: The source inspector should reference the following minimum information in each report or approved report format:

   1) date of inspection;

   2) contract number, serial number, and information;

   3) description of nonconforming item and issue;

   4) photo of discrepancy (if possible);

   5) specifications, drawings, codes, or standards involved;

   6) impact on the product/schedule;

   7) vendor-recommended disposition of the nonconformance.

c) The source inspector should issue the nonconformance report to the inspection coordinator/purchaser for review and distribution, unless instructed otherwise.

d) In general, deviations from specifications should be approved by the responsible engineer/purchaser.

e) Acceptable disposition of a nonconformance (as approved by the responsible engineer/purchaser) may include:

   1) Use as is (with purchaser accepting the nonconformance).

   2) Rework/repair per purchaser agreed approved repair procedure.

   3) Scrap the equipment/component involved.

f) It is the source inspector's responsibility to verify that NCR disposition has been properly implemented.

8 Examination Methods, Tools, and Equipment

8.1 General

This section describes the typical examination methods, tools, and equipment with which source inspectors should be familiar during the course of their surveillance at a vendor. Requirements for examinations from the purchaser or references in the contract agreement that may be more stringent than industry codes/standards or the vendor's normal procedures should be included in the ITP.

8.2 Review and Confirmation of Materials of Construction

a) Ensuring that the vendor is using the correct material during the manufacturing of equipment is a critical element of quality surveillance. Typical reviews should consist of the following:

- Material test reports (MTRs): The information necessary for the source inspector to know and understand about MTRs is covered in ASME *BPVC* Section II, SA-370, and EN10204.
- Any reports, e.g. MTRs, that have been modified, corrected, or obliterated should be cause for further investigation, as these could indicate the potential that the material or component is counterfeit material. All MTRs shall be legible.
- Confirming that the construction materials proposed are the actual materials used during construction is a typical source inspection activity. The source inspector should:
  - Confirm the correct material type and grade.
  - Confirm the origin of the material.
  - Check material size and/or thickness.
  - Verify traceability of the material to a certifying document.
  - Verify that the material complies with specific chemical and/or mechanical properties as specified in the contractual documents.
  - Verify compliance to NACE MR0175/ISO 15156 for equipment in sour service. Verify heat treat and hardness. Maximum hardness requirements for P-Numbered alloy steels are given in NACE MR0103, Table 2. Other alloy steels shall have a maximum hardness of 22 HRC (237 HBW) (NACE MR0103, 2.1.6). Ferrous materials not covered by NACE MR 0103-2007 or NACE MR 0175-2008 shall have a maximum yield strength of 620 N/mm2 (90,000 psi) and a maximum Rockwell hardness of HRC 22.
  - Check for evidence of specified heat treatment.
  - This is typically done by verifying that material grade, type, and serial number match the material certifying document. Some vendor quality programs, as well as purchasers' programs, have various methods for ensuring that the correct material is used in manufacturing with the use of positive material identification (PMI). The source inspector should be familiar with those methods and ensure compliance. API RP 578 is a good reference document for material verification and positive material identification.

b) The source inspector should be aware of the potential for counterfeit materials/documents. Key issues to watch for include, but are not limited to:

- generic documentation that is not product-specific;
- material or equipment containing minimal or no documentation;
- markings or logos that are questionable or obliterated;
- items that have inconsistent appearance;
- documents that have been altered;
- items that lack material traceability or product certification;

— ASME or ASTM stampings that may have been counterfeited.

8.3 Dimensional Inspections and Measurement Devices

a) The source inspector should be proficient in understanding and performing dimensional inspections. Equipment such as dial indicators, calipers, micrometers, vibration instruments, temperature gauges, pressure gauges, and levels are all typical tools that are used for inspection.

The source inspector should be familiar with the proper usage and application of these tools, along with calibration requirements. Tools used for precision measurement are typically calibrated in accordance with a vendor's written calibration procedure per NIST, ISO Guide 99, or other industry standards.

b) The main objective for performing calibration is to verify the accuracy and provide traceability of the instrument. The accuracy of a measuring device can become suspect for various reasons. Some of the common causes of the loss of accuracy are:

— normal wear during usage;

— misuse of the instrument either in application or mishandling (i.e. dropping, incorrect storage, etc.);

— environmental issues, such as temperature changes, and hazardous or corrosive conditions.

c) The vendor should have a calibration procedure that, at a minimum, addresses:

— intervals;

— environment;

— tolerances;

— certification of standards;

— traceability;

— records;

— adjustments;

— removal from service.

d) Most companies establish a calibration interval based on multiple variables, including manufacturer's recommendations, amount and type of usage, conditions of the unit, accuracy requirements, and established history of previous calibrations. The shorter the interval or more frequent the calibration, the lower the risk concerning use of a device that does not comply with the calibration requirements and potential for unacceptable material to be inadvertently accepted. However, calibration can be an expensive process, with serious ramifications for acceptance of product later found to be nonconforming. Therefore, the vendor is required to take all potential parameters into consideration when establishing a calibration interval. Vendors that do not perform a lot of detailed precision measurement may elect to establish a requirement for the measurement device to be calibrated prior to each use.

e) The vendor should maintain adequate records addressing the method of controlling precision measuring devices that require calibration. The records should include storage and handling requirements, calibration due dates, prevention of usage of devices past calibration due dates, means to identify product verified using a specific measuring device, and determination of optimal calibration interval based on an established history. Maintaining accurate calibration records will also provide the vendor with an indicator that a measuring device has reached the end of its lifetime in relation to ability to hold calibration, or the extent of recalibration required each time it is subjected to calibration.

f) The vendor should include in the calibration procedure a method to recall material checked with a device that was later found to not be in calibration. Finding that a device fails calibration at the established calibration interval will normally require the issuance of a nonconformance in the vendor's quality system. When a device is found to be out of calibration, any measurements made since the last known calibration are suspect. As part of the nonconformance resolution, the vendor shall determine the extent of the calibration error, the criticality of product verified with the device, and the ability to identify all potentially unacceptable product, either in-house or shipped. Depending on the level of error and criticality of the product, the vendor may be able to re-measure or rework product that is still in-house. The vendor may also need to contact customers that have received product to issue a recall or advise of the need for service to bring the product into specification requirements.

g) When performing dimensional inspections, the source inspector should have access to the dimensional requirements and the allowable tolerances on the manufacturer's drawings. Actual dimensions should be recorded in the inspection reference drawing. Dimensions that exceed the tolerances should be reported as a nonconformance or deviation.

8.4 Visual Inspections

a) Adequate lighting is essential when performing visual inspection. The source inspector should be familiar with the minimum lighting requirements defined by the applicable code, standard, or specification. If there is inadequate lighting available during the visual inspection—which is not uncommon in some shops—the source inspector should address these concerns with the vendor and inspection coordinator to resolve. Portable lighting instruments, such as pen lights, high-power flashlights, etc., are common tools that the source inspector may need in order to perform adequate visual inspection.

b) Source inspectors who are performing visual inspections of welding, coatings, surface finish, cleanliness, etc., should be appropriately trained and qualified to perform those activities in accordance with the applicable codes or standards, including visual acuity requirements.

8.5 Nondestructive Testing (NDT) Techniques

8.5.1 General

8.5.1.1 The primary source for the specific NDT techniques to be applied during manufacturing and fabrication by the vendor is included in the applicable project specifications. Those documents should reference other appropriate codes/standards for NDT methods, such as ASME *BPVC* Section V, and NDT technician qualifications, such as ASNT SNT TC-1A. The source inspector should be familiar with the NDT qualification/certification processes described in ASNT SNT TC-1A, especially what NDT duties/responsibilities can be carried out by Level I, Level II, and Level III NDT technicians.

8.5.1.2 The source inspector should be familiar with NDT terminology contained in ASME *BPVC* Section V, Subsection A, Article 1, Mandatory Appendix 1, and Subsection B, Article 30, SE-1316.

8.5.2 Penetrant Testing (PT)

ASME *BPVC* Section V, Article 6, T-620, covers most of what the source inspector needs to know about PT. Discontinuities revealed during PT are normally recorded on an NDT report.

8.5.3 Magnetic Particle Testing (MT)

ASME *BPVC* Section V, Article 7, T-750, covers most of what the source inspector needs to know about MT. Discontinuities revealed during MT are normally recorded on an NDT report.

8.5.4 Radiographic Testing (RT)

ASME *BPVC* Section V, Article 2, T-220, and E-94 or E1742 cover most of what the source inspector needs to know about RT. Discontinuities revealed during RT are normally recorded on an NDT report.

8.5.5 Ultrasonic Testing (UT)

ASME *BPVC* Section V, Article 4; Article 5, T-530; and E797 cover most of what the source inspector needs to know about UT. Discontinuities revealed during UT are normally recorded on an NDT report.

8.5.6 Positive Material Identification (PMI)

API RP 578 covers most of what the source inspector needs to know about material verification and PMI.

NOTE The API Source Inspection of Rotating Equipment exam does not qualify an individual to perform the NDT tasks described in Section 8.5.

8.6 Destructive Testing

a) Destructive testing is defined as those tests that are performed on metals for the purposes of determining mechanical properties and that involve testing of sample coupons. Examples of such tests include tensile testing, bend testing, and Charpy impact testing.

b) Tensile testing is performed to determine yield strength (point at which elastic deformation becomes plastic/permanent deformation) and ultimate tensile strength of an item.

c) Bend testing is commonly performed on weld coupons to check the ductility and integrity of welds.

d) Charpy impact testing is performed to determine the toughness of metals and welds. It may be specified for a variety of reasons at several different temperatures to show that the vessel or piping system has the ability to deform plastically before failing i.e. avoid catastrophic brittle fracture. For many construction codes, impact testing often becomes a requirement at temperatures below –20 °F, but the engineering specifications may require impact testing at other temperatures, as well.

e) Most of the information necessary for the source inspector to know and understand destructive testing of metals is covered in ASME *BPVC* Section IX.

8.7 Pressure/Leak Testing

8.7.1 General

Pressure/leak testing is normally specified by the applicable codes/standards and contractual agreements.

8.7.2 Pressure/Leak Testing

8.7.2.1 Hydrostatic testing is conducted with liquid for the integrity of the equipment. A gas test is typically performed as a leak test. As the name indicates, pressure testing involves testing with elevated pressures, often above that at which the component will normally operate, so safety is of utmost importance when witnessing a pressure test. Pressure tests shall be conducted in accordance with the construction code or standard to which the item was built, e.g. ASME *BPVC* Section VIII for vessels or ASME B31.3 for process piping. API standards (such as API 610) also address minimum requirements to hydrostatic test pump pressure-containing parts before further testing (such as performance or running tests). These codes generally indicate how to witness such a test safely after the pressure has equalized and stabilized. Whether testing by hydrostatic test, hydro-pneumatic, or pneumatic, the pressure testing equipment should have the means to prevent over-pressuring the equipment under test.

8.7.2.2 Hydrotesting is the most common method of pressure testing and involves the application of pressure using a liquid. It is very important that high-point vents be opened during filling and before the application of pressure to ensure that there is no air left in the system. All connection welding to case should be completed prior to hydrostatic test. Verification that chloride content is less than 50 ppm is to be conducted when hydrotesting austenitic stainless steels; this is a common requirement. The source inspector should be aware of this when austenitic stainless steel is tested. Verification of drying after hydrostatic testing is critical to prevent deposition of chlorides. The vendor should test in a safe area in case a tested part fails. The source inspector should verify a current lab analysis has been performed concerning the water quality in compliance with PO/contractual requirements, including chloride content or other items as specified in these documents.

8.7.2.3 Pneumatic testing is generally conducted with air, though it is sometimes conducted with a combination of air and water. There are significantly greater risks involved in higher-pressure pneumatic testing, so it should never be conducted without the full knowledge and consent of the responsible engineer who has been satisfied that the potential for brittle fracture during test is negligible. The danger comes from pieces of the equipment that fail under pneumatic pressure being propelled with great force for long distances, thereby doing a lot of damage and/or inflicting severe injury.

8.7.2.4 Leak testing is generally the term used to describe low-pressure testing with air or gas just to see if the joints in a piece of equipment, e.g. flanges and threaded connections, are leak tight after assembly. Leak tests are usually done at low pressures that are substantially below equipment design pressures to minimize risk of injury. Specialized leak tests with helium or other gases have to be specified by contractual document, which will detail the leak test procedure and generally reference an industry standard.

8.8 Performance/Functional Testing/Mechanical Run Test

Performance and functional testing is typically required for all rotating equipment. Prior to performance or functional testing, the vendor should provide a detailed functional test procedure that has been submitted for review and comment from the purchaser. The advance notice shall be made in accordance with API 610 or the purchase order, whichever was agreed upon.

The source inspector should be very familiar with the functional/performance test procedures and a detailed report that is expected at the end of the test. The source inspector should also verify that all attributes of the test are accurately reported in the final test report provided by the vendor.

Following is a typical example of this functional testing:

A performance curve is plotted to indicate the variation of the pump differential head against the volumetric flow of a liquid at an indicated rotational speed or velocity, while consuming a specific quantity of horsepower. The performance curve typically consists of the following curves in relation with each other on a common graph. These curves are:

— the head-flow curve. It is called the H-Q curve;

— the efficiency curve;

— the energy curve. It records brake horsepower;

— net positive suction head (NPSH3) curve (if required to be tested).

The purpose of a pump performance test is to ensure that the actual performance of a pump is consistent with the curve shown on the predicted performance and included as part of the contract.

Recorded test data usually consists of the following information:

— test fluid temperature;

— test fluid specific gravity;

— torque (power) reading;

— test RPM;

— frequency of supply voltage;

— flowrates;

— discharge pressure;

— suction pressure;

— elevations corrections;

— vibration levels;

— oil temperature;

— A minimum of five points are taken to cover the flow range from 0 to 120 % of BEP, depending on the test standard. For API 610 pumps, these normally are:

  — shutoff (no vibration data required);

  — minimum continuous stable flow (beginning of allowable operating region);

  — between 95 % and 99 % of rated flow;

  — between rated flow and 105 % of rated flow;

  — approximately the best efficiency flow (if rated flow is not within 5 % of best efficiency flow rate);

  — end of allowable operating region.

  NOTE For ANSI pumps, follow ANSI requirements.

— The number of vibration readings shall be taken in accordance with API-610 for API pumps;

— Once test is completed, all data should be converted into suitable units, plotted on a chart, and compared to the acceptance criteria;

— Acceptance criteria cover tolerances on:

  — head, efficiency, flow rate, vibrations levels, brake horsepower, speed, and bearing or bearing oil temperatures (as required).

If specified, the pump should be run on the test stand at the rated flow until oil temperature/vibration stabilization has been achieved. If specified, the pump should be mechanically run at the rated flow for 4 hours or as agreed upon.

8.9 Equipment Disassembly Inspection Examples

a) If specified, disassembly inspection is may be performed to inspect the rotating equipment internals for contact after testing.

b) Disassembly due to the need to reduce impeller diameter by more than 5 % to meet performance requires a retest.

c) The following may be specified: If a pump has anti-friction (ball or roller) bearings, oil may be drained from bearing housings and inspected on the subject of color change and foreign material inclusion. If a pump has hydrodynamic bearings (sleeve and or thrust), bearings may be removed and inspected after the test if specified.

d) If it is necessary to disturb the mechanical seal assembly following the performance test, or if the test seal faces are replaced with the job seal faces, the final seal assembly may be pneumatic-tested if specified.

8.10 Surface Preparation/Coatings Inspections

a) Performance of coating systems typically depends on the how well the substrate or surface is prepared for coating applications. Typically, on rotating equipment, visual inspection of surface preparation is recommended or required if specified. Inspections typically consist of:

- — surface profile measurement;
- — visual surface comparison;
- — verification of blasting medium.

b) Coating systems are usually specified in the contractual and engineering documents, and likely will involve single or multiple coating applications. The method of inspection of these coating systems is by the use of a dry film thickness gauge (DFT) per SSPC-PA 2, which the source inspector should be familiar with.

c) The source inspector should also be aware of specific coating requirements, such as stripe coating of welds, edges, corners, etc., that are performed to ensure coating performance on rough or uneven surfaces.

d) In addition to purchase-order requirements and company standards, a coating manufacturer's recommendations will provide the details for correct application to be followed.

e) Prior to releasing the rotating equipment for shipment, the source inspector should inspect the external coated or lined surfaces for the following items: raised areas, pinholes, soft spots, disbondment, delaminations, blisters, holidays, bubbling, fish-eyes, runs and sags, uniformity, mechanical damage, orange peel, adhesion, mud flat cracking, and proper color or shade. For internal or spare coating, the inspector should check for anti-fouling testing prior to balance or testing.

f) Any areas found in need of coating repairs should be properly identified and documented with an NCR by the vendor and approved by the source inspector, as should any testing and re-inspection performed after repairs have been made.

9 Final Acceptance

9.1 Prior to Final Acceptance of Rotating Equipment

Prior to final acceptance of rotating equipment, the source inspector should determine the following:

- — All work specified in the contractual agreements is completed by the vendor.
- — As-built drawings and datasheet updates have been completed and submitted to the purchaser.
- — All NCRs have been resolved and closed out by the vendor QC representative and owner's QA representative.
- — All punch-list items have been completed.
- — All inspection-related activities have been completed and documented.

— All vendor work has been deemed acceptable by the owner's QA representative in accordance with the requirements of codes, standards, and project specifications.

9.2 Shipping Preparations

Shipping preparations may also be specified in the contractual and engineering documents. It is important that the source inspector confirm that all bracing, strapping, mounting, covering, packaging, marking, and protection from the weather, etc., is effectively completed before the equipment is released for shipment. These are typically defined in the purchase agreement or attached as a requirement, which may be different from project to project.

9.3 Reviewing Final Vendor Data

a) It is typical for the source inspector to perform a final review of the contractually required vendor data (should consult vendor documentation and data report [VDDR]) upon the completion of the manufacturing prior to shipment of the materials or equipment.

b) This review is to determine that all documents are complete, with the as-built information with all supporting documents as identified in the contractual agreement. Such documentation may include, but is not limited to:

- final drawings/data sheets;
- MTRs;
- performance test documentation;
- NDT results;
- product-specific QC checks;
- NCR closeouts;
- certification documents;
- code compliance documentation as applicable.

10 Manufacturing and Fabrication Processes

10.1 General

a) The vendor is responsible for the quality of all their products, which includes not only good workmanship, but also compliance with all codes, standards, and specifications contained in the contractual agreements. The source inspector is responsible, as defined in the inspection and test plan (ITP), for performing the source quality surveillance activities at the vendor's facilities in accordance with the applicable ITP.

b) Specific processes that are commonly used include welding, heat treatment, casting, forming, forging, machining, assembly, etc. The source inspector needs to be familiar with those processes to confirm compliance with codes, standards, and project document requirements. For all processes including rework and repair, the following information should be consistent and confirmed:

- The manufacturing and fabrication process has a documented method that describes how to perform the work.
- Proof of training and qualifications, especially for weld repairs, is available if requested.

— Individuals performing the work have on-demand, on-site access to the relevant procedures.

— There are acceptance criteria documented to determine if the process's results are acceptable.

— The results of all processes are documented.

c) Rework and repair should be approved by the purchaser and verified by the source inspector.

10.2 Welding Processes and Welding Defects

Different welding processes are susceptible to different types of welding defects. Therefore, it's important for the source inspector to know which welding processes will be applied during manufacturing/fabrication and to be familiar with the typical defects that can occur. The source inspector should revert to the purchase agreement and vendor welding procedures as applicable.

10.3 Casting

a) Typical defects associated with the casting process that the source inspector should be aware of include:

— shrinkage voids;

— gas porosity;

— trapped inclusions.

b) Castings are susceptible to the creation of voids during the casting process that could result in through-wall leaks. ASTM grades of castings typically used in the petrochemical industry for pump casings are referenced in ASTM A703, *Standard Specification for Steel Castings, General Requirements, for Pressure-Containing Parts*. This standard prohibits peening, plugging, and impregnating defects in castings to stop leaks, as opposed to making more permanent welding repairs. The source inspector should ensure that any casting repairs needed are brought to their attention so that adequate repair procedures can be provided, approved by the purchaser, and implemented.

c) ASTM A703 also provides casting grade symbols that identify the type of material in the casting. Grade symbols are required on castings (e.g. WCB, WC9, CF8M, and so forth) in order to indicate the type of casting material. The source inspector should verify that the casting grade symbol on all parts matches the specified grade in the contractual documents.

d) MSS-SP-55, *Quality Standard for Steel Castings for Valves, Flanges and Fittings and Other Piping Components—Visual Method for Evaluation of Surface Irregularities*, is the standard that is generally used to perform visual evaluation of surface irregularities that may have occurred during the casting process. The source inspector accepting castings should be aware of this standard.

10.4 Forging

a) Forging consists of a number of processes that are characterized by the use of localized compressive forces that are applied via hammers, presses, dies, or other forging equipment to induce plastic/permanent deformation. While forging may be performed in all temperature ranges, most forging is done above the recrystallization temperature of metal.

b) ASTM A788, *Standard Specification for Steel Forgings, General Requirements* covers a group of common requirements that may be applied to steel forgings for general use. Key elements of ASTM A788 include the following:

— The purchaser may specify additional requirements.

— Tension and hardness tests should be conducted to evaluate mechanical properties.

— Repair welding is not allowed unless permitted by the product specification, and if approved by the purchaser.

— Supplementary general requirements performed by agreement between the supplier and the purchaser are designated by an “S” followed by a number (e.g. S5).

10.5 Machining

a) The principal machining processes are turning, drilling, grinding, and milling. Other machining operations include shaping, planing, boring, broaching, and sawing.

Turning operations are operations that rotate the workpiece as the primary method of moving metal against the cutting tool. Lathes are the principal machine tool used in turning.

Milling operations are operations in which the cutting tool rotates to bring cutting edges to bear against the workpiece. A milling machine is the principal machine tool used in milling.

Drilling operations are operations in which holes are produced or refined by bringing a rotating cutter with cutting edges at the lower extremity into contact with the workpiece. Drilling operations are done primarily in drill presses, but sometimes are done on lathes or mills.

Grinding provides additional accuracy that typically will allow the finished part or surface to have a tolerance of 0.0002 in. or better.

— Burnishing is used if exceptional surface finish is needed for proximity probes, for example.

— Grinding may be used for rotor balancing corrections, but the level of precision is not as stringent.

b) Machining requires attention to many details for a workpiece to meet the specifications set out in the engineering drawings or blueprints. Besides the obvious problems related to correct dimensions, there is the problem of achieving the correct finish or surface smoothness on the workpiece, such as parting flange finish or nozzle finishes. Typically, there is no in-process inspection by the source inspector for the machining operation; however, the source inspector may be required to check dimensional aspects and tolerances of machined components.

10.6 Rotating Equipment Assembly

Although assembly also incorporates instrumentation, control systems, and electrical gear prior to shipment (see 10.8), the source inspector is concerned with assembly of the rotating and stationary parts. The inspections that are important to assembly may be:

a) mounting clearances, mounting, and straightness;

b) assembled rotor TIR;

c) surface finish at journal areas;

d) surface finish of nozzles and parting flange(s);

e) concentricity of the pressure casing bores;

f) perpendicularity of the seal mounting faces;

g) bearing journal concentricity and journal to bearing contact;

h) axial movement of the rotor in the pressure casing (typically with respect to the thrust bearing);

i) checking final torqueing and torque sequence for:

— all pressure casing bolts and studs;

— bearing housing and other auxiliary bolting and studs.

10.7 Metallurgy Issues Associated with Manufacturing and Fabrication Processes

10.7.1 Physical and Mechanical Properties of Metals

The physical properties of a metal or alloy are those that are relatively insensitive to structure and can be measured without the application of force. Examples of physical properties of a metal are chemical composition, melting temperature, thermal conductivity, electrical conductivity, coefficient of thermal expansion, and density.

Chemical composition and heat treatments often change hardness, weldability, tensile strength, etc. Sometimes, alloying elements can add benefit in one area and detract in another. It is important for the source inspector to be aware of elements in the MTR. It is also important to know what elements should or should not be present. Also important is the summary of mechanical attributes, such as SMYS and UTS, amongst others.

Materials of construction are selected to provide adequate strength and toughness for the maximum and minimum temperatures and pressures on the datasheet. For the inspector, verification that mechanical properties meet the requirements specified by the component definition, is essential. Inspectors should understand the underlying principles of mechanical properties and the nature of tests conducted to verify the value of those properties.

10.7.2 Hardness and Hardenability of Metals

Hardenability is defined as that property of a ferrous alloy that determines the depth and distribution of hardness induced by quenching. It is important to note that there is not a close relationship between hardenability and hardness, which is the resistance to indentation. Hardness depends primarily on the carbon content of the material, whereas hardenability is strongly affected by the presence of alloying elements, such as chromium, molybdenum, and vanadium, and to a lesser extent, by carbon content and alloying elements such as nickel, copper, and silicon.

NOTE API 5L pipe (with a weld seam) disallows both vanadium and boron above API 5L pipe for any diameter and wall thickness ≤1 in. (25 mm) because of cracking issues. If a pipe is attached to a nozzle on the pressure casing, welding is required. Therefore, it seems logical to *not* mention vanadium in this paragraph

10.7.3 Weldability of Metals

The American Welding Society defines weldability as “the capacity of a metal to be welded under the fabrication conditions imposed, into a specific, suitably designed structure, and to perform satisfactorily in the intended service.”

10.7.4 Preheating and Postweld Heat Treatment

10.7.4.1 Preheating

Preheating is defined as heating of the weld area and surrounding base metal to a predetermined temperature prior to the start of welding. The primary purpose for preheating steels is to reduce the tendency for delayed hydrogen-induced cracking. The higher temperature at the weld site allows better hydrogen diffusion from the weld, which helps prevent the formation of martensite (a more crack-prone microstructure) in the weld and base metal HAZ. According to ASME B31.3, the pre-heat zone for welding of new process piping should extend at least one inch beyond the edge of the weld for piping. Pre-weld preheat shall be done evenly at the prescribed rate to ensure proper temperature distribution. Thermocouples, IR sensor guns, or heat sticks can be employed to determine if desired temperature is attained.

a) Postweld heat treatment (PWHT)

Postweld heat treatment (PWHT) produces both mechanical and metallurgical effects in carbon and low-alloy steels that will vary widely depending on the composition of the steel, its past thermal history, the temperature and duration of the PWHT, and heating and cooling rates employed during the PWHT. The type of PWHT is dependent on many factors, including chemistry of the metal, thickness of the parts being joined, joint design, welding processes, and the equipment operating environment. The temperature of PWHT is selected by considering the changes being sought in the equipment or structure. PWHT is the most common form of fabrication heat treatment applied to fixed equipment. When PWHT is required by code or the vendor, the source inspector needs to coordinate with the user and vendor to ensure temperature, ramp-up, hold, and ramp-down rates are adhered to. Thermocouples shall be located in order to verify even distribution of temperature on components and to ensure that no component is over- or underheated during PWHT. Most of the information necessary for the source inspector to know and understand about PWHT is covered in ASME *BPVC* Section VIII, Division 1.

b) Other heat treatments

Other heat treatments include annealing, normalizing, solution annealing, and tempering. See Section 3 for definitions of those heat treatments.

10.8 Assembly Inspection of the Equipment Train on the Baseplate

a) Prior to shipment, most purchasers expect to have all the primary and auxiliary equipment properly mounted on the baseplate and inspected. The inspections can cover the following, for example:

- installation of the driven equipment on the baseplate;
- installation of the driver on the baseplate;
- installation of a gearbox (if included in the equipment purchase);
- removing soft foot and rough alignment:
    - bolts and/or provision for vertical and horizontal positioning are present;
    - spacers, shims, and shim amounts are in accordance with the appropriate API standard or recommended practice;
- vent and drain piping or tubing;
- auxiliary systems, such as fuel, lubrication, seal support, and cooling;
- installation of panelboards, terminal strip boxes, or pull-boxes for SCADA gear or control wiring;
- disassembly, tagging, and packaging of auxiliary piping and tubing for shipment;
- removal of the rotating equipment from the baseplate prior to shipment, as agreed by the purchaser and vendor.

11 Centrifugal Pumps

11.1 General

Material of construction of the pump is specified on the pump data sheet. API 610, Annex H, shows material classes and acceptable materials that are appropriate for various services. API 610, Section 8 (Inspection, Testing, and Preparation for Shipment), is the industry guideline for all inspection and testing activities required for API 610 pumps.

The source inspector should be familiar with all requirements in this section of API 610. The inspection and test plan (ITP) specifies what level of inspection and document review is required. Documents that are required to be submitted for review and approval are listed in the VDDR (see API 610). The ITP and VDDR are mutually agreed between the pump purchaser and the vendor.

Following is a list of documents typically required for purchase of centrifugal pumps:

a) API 610 pump data sheet

   — This data sheet is a part of the purchase documents package and is issued by the purchaser, reviewed by and updated by the vendor, and mutually agreed. It provides a general reference to material of construction, material certification, and PMI requirements. The data sheet has three stages:

      — As issued for PO (purchase): part of PO package submitted by the purchaser and accepted by vendor.

      — As sold: submitted by vendor as one of the documents with vendor's bid.

      — As built: submitted by vendor after final pump test and before final inspection.

b) Inspection requirements form Issued by the purchaser with PO

   — An inspection requirements form may be included in the purchase package. This form is issued by the purchaser during the procurement process. It contains requirements for inspection and actions that are to be conducted between the date of PO acceptance by the supplier and the date of final inspection and shipment of the equipment.

c) Supplier's quality plan (ITP)

   — One of the first documents from the supplier is an inspection and test plan (ITP). The vendor ITP should address all activities required for manufacturing, inspection, assembly, test, and shipment. The vendor develops this plan based on job requirements specified in data sheets, the inspection requirement form, technical notes, specifications, and applicable industry standards, such as API 610 or ASME. The ITP is a purchaser-approved document. The ITP should be developed for each major component, subassembly, and final package. ITPs usually feature a matrix, including for each activity:

      — inspection and test requirements for this activity;

      — standard or other code reference on which this activity is based;

      — specific area, place, or characteristic of the part or stage in production where this activity takes place;

      — supplemental documents that are required for this activity;

  - — level of client involvement in this activity (review documents, surveillance, verify, witness, approve of activity, hold point).

d) Pump cross section with BOM (bill of materials)

- — The BOM should list the part name, quantity, identification number, part number, and material of construction with ASTM codes for all major parts. Materials should be identified by reference to applicable international standards, such as ASTM, AFNOR, BS, DIN, EN, JIS, etc., including the material grade (for example, Tables H.2 and H.3 of API 610 may be used for guidance). The pump cross section and BOM are reviewed and approved for construction by purchaser RE.

e) NDT procedures, weld maps, hydro and performance test procedure

- — The vendor should submit for client approval NDT procedures, weld procedures, weld maps, PMI test procedure, hydro and performance test procedure according to an approved VDDR. If weld repair is needed, the vendor should submit a weld repair procedure for purchaser approval. For casting repairs made in the vendor shop, repair procedures, including weld maps, should be submitted for the purchaser's approval. The purchaser should specify if approval is required before proceeding with repair. Repairs made at the foundry level should be controlled by the casting material specification (producing specification Ⅱ).

f) Vendor unpriced quotes and buyouts for major parts

- — Usually, quotes and buyouts are not required documents for review and approval by the purchaser. However, they should be reviewed by the source inspector and must be included in ITP as a "review" action. Such parts include, but are not limited to, pump pressure casing, impellers, diffusers, shafts, wear rings, sleeves, bushings, weld fabrication, pressure bolting and gaskets. The source inspector typically verifies that quotes and buyouts have correct quantity, material, level of inspection, and NDT based on the requirements of PO and ITP. Depending on the vendor's manufacturing structure and philosophy, buyouts can be for materials such as bars, sheets, pipes, casting, weld fabrication, forging, rough machined parts, or final machined parts with all the required NDT and hydro testing completed at sub-vendor shops.

g) Material certificates

- — The vendor should furnish material certificates that include chemical analysis and mechanical properties for the heats from which the material is supplied for pressure-containing castings and forgings, impellers, and shafts. Unless otherwise specified, piping nipples, auxiliary piping components, and bolting are excluded from this requirement. Material certificates should list part number, part name, and reference to pump cross section number for easy identification. In many cases, parts such as castings, forgings, and loose items for fabrication have different part numbers listed on material certificates than those listed on a pump cross section. The source inspector should always request that the final part number and assembly number are added to the material certificate. Material certificates should be easily legible.

h) PMI and NDT procedures

- — If specified by the ITP, the vendor should submit all PMI, NDT, and other material tests procedure for the purchaser's review and/or approval for use. These procedures should be listed on the purchaser's VDDR and should be reviewed and approved by the purchaser prior to the start of manufacturing.

- — Acceptance criteria for various NDEs can be found in ASME Section VIII, as follows:

  - — Mandatory Appendix 4, "Rounded Indications Charts Acceptance Standard for Radiographically Determined Rounded Indications In Welds"

  - — Mandatory Appendix 6, "Methods for Magnetic Particle Examination (MT)"

— Mandatory Appendix 8, “Methods for Liquid Penetrant Examination (PT)”

— Mandatory Appendix 12, “Ultrasonic Examination of Welds (UT)”

i) PMI and NDT reports

The source inspector should verify if PMI and NDT test reports require submittal for the purchaser’s review and comment. PMI and NDT test reports should be easily traceable to the components to which they apply. Tools, instruments, and other equipment used for tests need to be listed and calibration records provided.

If the source inspector observes PMI or NDT testing, pictures should be taken and attached to the source inspection report.

11.2 Design and Construction Standards

API 610, Section 4.2.2 (Pump Designations and Descriptions), specifies various types of pumps. Pumps require two major assemblies:

— Stationary: includes pressure casing and bearing housings;

— Rotating: includes impeller(s) and shaft.

Pressure casing is subject to hydrostatic testing.

All rotating elements are subject to balancing. Generally, impellers are balanced individually. Rotors are balanced as assemblies with shaft, sleeves, and impellers mounted. For more information on balancing requirements, refer to API 610, Section 6.9.4 (Balancing). The pump data sheet specifies the extent of balancing required.

All horizontal pumps and in-line pumps have anti-friction or hydrodynamic bearings, or a combination of both. Vertical pumps may have thrust bearings unless thrust bearings are provided in the pump driver. The following types of bearing lubrication are typically utilized: Oil sump with ring or flinger; oil mist; forced oil lubrication (API 614), or grease. Sometimes, two of these are combined.

Pump units are supplied with mechanical seal(s) (see API 682), drivers, couplings, shaft guards, auxiliary piping, and instrumentation. All equipment is usually installed on a single baseplate. Vertically suspended pumps are typically supplied with a sole plate.

11.3 Materials of Construction/Pump Components

Major pump parts and assemblies that require source inspector activity, if specified on ITP, are:

11.3.1 Pressure Casing

Pressure casing parts may be subject to surface and subsurface examinations. Pressure casing material inspection requirements can be found in API 610. Inspection class 1 specifies minimum requirements for pressure casing inspection. Job-specific requirements often involve MP or LP inspections as per class 2. Material inspection standards are also listed in API 610. These standards establish minimum acceptance criteria for casings. Job-specific purchaser requirements or supplier inspection procedures may exceed these requirements. The additional requirements are found in the ITP.

Listed below are the manufacturing methods of producing a pressure casing: casting, forging, weld fabrication, or a combination of any of the three. Each of these methods involves certain inspections and tests as specified on data sheets, and a quality plan.

Casting

Figure 1—Single Stage Pump

11.3.2 Cast Casing—Single Stage Overhung Pump

Casting quality can be affected by considerable variations in material processing. Castings can be subject to areas of shrinkage, gas porosity, hot tears, sand inclusions, improper weld repairs, etc. Some materials are also prone to grain boundary tears or cracks that can propagate under in-service stresses caused by temperature, pressure, vibration, and pipe strain.

Industry accepted practices of casting examination are contained in ASME Section VIII, Mandatory Appendix 7 (Examination of Steel Castings). NDT methods such as magnetic-particle, liquid-penetrant, radiographic, and ultrasonic examinations are the most frequently performed at the casting foundry.

Casting should be heat treated in accordance with the material specification before rough machining and hydrostatic testing. Final machine surfaces are subject to the examination. Nondestructive examinations are performed to ensure that casting is free from porosity, cavities, and other surface or internal defects, and ready for final machining. Any defects that are found at a foundry may either be fixed by approved weld repairs or the casting scrapped and re-cast if weld repair is not possible.

11.3.3 Centrifugal Casting

Centrifugal casting is considered the preferable way for casting round shapes such as multistage pump casings, casing covers, nozzles, and bearing brackets. This method uses centrifugal force to force voids and gases out of the molten metal.

Forging

Figure 2—Multi-stage Pump with Forged Barrel, Cover, Suction, and Discharge Nozzles

Forging is a manufacturing process involving shaping of the metal using localized compressive forces. Forging inspection involves the same NDT methods as casting; however, the type of defects in a forged part is different than normally observed in cast parts. Because the forging process involves a hot metal working, forging rarely produces such defects as porosities, blow holes, and gas holes. Due to a possibility of uneven cooling, forging may produce surface cracking and or laminations; therefore, such NDT methods as ultrasonic, magnetic-particle, and liquid-penetrant are the most common tests used for the forged parts.

11.3.4 Fabrication

Pump casing almost always has parts attached by welding, such as pipe attachments of casing connections. Multistage and vertical can pumps have pressure casing manufactured by fabrication. Forged or cast sections may be welded with forged or cast suction and discharge nozzles, as shown in Figure 2. An RT or UT test is typically required for the nozzle weld attachments before a part can be sent for rough machining. After the rough machining process, MT or LP inspections should to be done on the machined surfaces. The next operation is a weld attachment of auxiliary connections, such as drains and vents. Connection welds are subject to an RT, MP, or LP test before the part can be sent for heat treatment and final machining. Suction can pumps have a barrel that is generally fabricated from standard pipes and plates. Major NDT inspections for vertical can pump barrels and covers include weldment inspection. RT, MT, or LP are the most common NDT methods for weldments. If the RT method is utilized, see ASME Section VIII. Top covers will be dimensionally inspected for flatness and hydro-testing of the can will be performed after all welding inspection has been completed.

The pattern tooling, casting process, and cleaning process should be capable of producing the surface finishes specified on the engineering drawing or on the purchase order. Most foundries follow the American Foundry Society surface standard (see Figure 3).

Figure 3—American Foundry Society's C-9 Microfinish Comparator (shows surface finishes from 20 RMS to 900 RMS)

Casting should not show discontinuities that exceed the limits as established in ASME Section VIII, Mandatory Appendix 7, in job-specific requirements, or both.

Figure 4—Pressure Casing Hydro Test

11.3.5 Hydrotest Pump Test Pac

Pump pressure casing hydrotests are performed per API 610, Section 8.3.2. The intent of a hydrostatic test of a centrifugal pump casing is to ensure that the pump pressure-containing components and joints are leak-free from ambient to the maximum operation conditions as defined on the data sheet.

The source inspector should verify the part numbers of the items that are subject to the hydrotests. Casing part numbers need to be stamped on the outside surface. Some pressure casing may be rated for dual-rated (suction and discharge) pressure.

In some cases, testing water should contain a wetting agent to reduce surface tension (see API 610, Section 8). This requirement is typically listed in the vendor's hydrostatic test procedure. Some hydrostatic test procedures also include a requirement that chloride content of liquids used to test should not exceed 50 mg/kg (50 ppm) for austenitic stainless steel.

Pressure gauges used in the test should have current calibration dates shown on the permanently attached tags or located on a dial. The hydrostatic test should be considered satisfactory if neither leaks nor seepage through the pressure-containing parts and joints occurs within 30 minutes or as defined by the approved hydrotest procedure.

NOTE Pipeline pumps normally require a four-hour test.

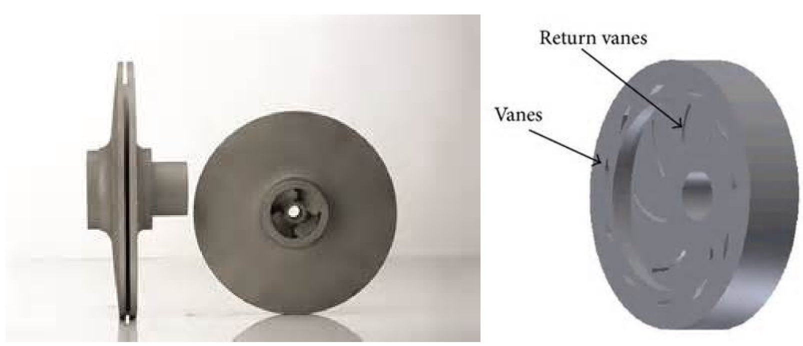


Figure 5—Impellers and Diffusers

11.3.6 Impellers and Diffusers

Impellers and diffusers are typically castings. Investment casting produces better dimensional and surface quality but is more expensive than sand casting. Impellers and diffusers undergo the same type of basic NDT as pressure casing. Per API 610, the minimum inspection of an impeller is visual; further inspection can be required by the purchaser or noted in the ITP. RT or UT are not standard examination methods for these parts. MT, PT, and visual inspections are first done at the foundry level. Then, MT or PT examinations are performed on the final machined surfaces. In addition, impellers are balanced to the level specified on the pump data sheets, technical notes, job specifications, or, at a minimum, as required per API 610. Impellers, balancing drums, and similar major rotating components are typically dynamically balanced to ISO 1940-1, grade G2.5, or as approved by the purchaser in the ITP.

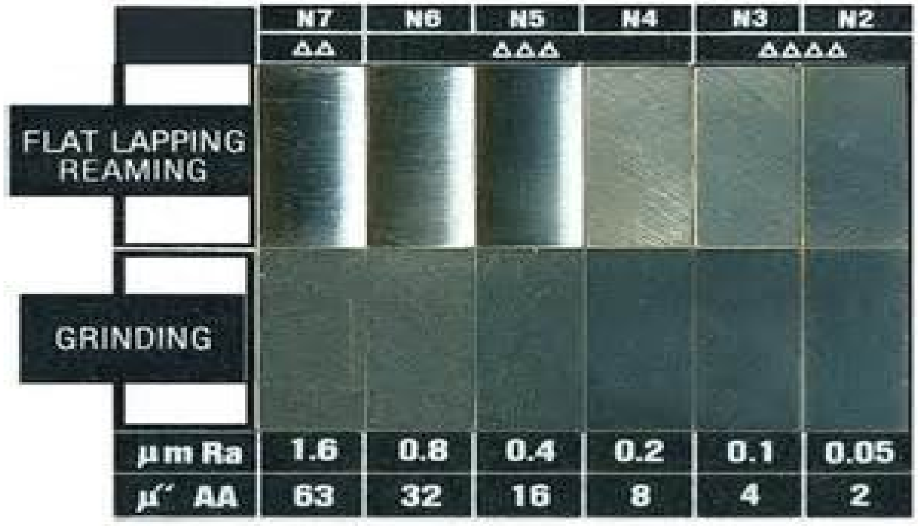
11.3.7 Shafts, Wear Rings, Sleeves, Bushings, and Thrust Balance Drums

Generally, these parts are machined from bar stock. Large sleeves, wear rings, and bushings can also be manufactured from centrifugal casting raw material. Shafts of large multistage pumps often have UT inspection; otherwise, visual, dimensional, MP, or PT examinations are routinely used for these parts.

The intent of this section is to ensure that the components match the engineering documents.

Visual examination includes surface finish.

Below are machining finish charts for different machining operation.



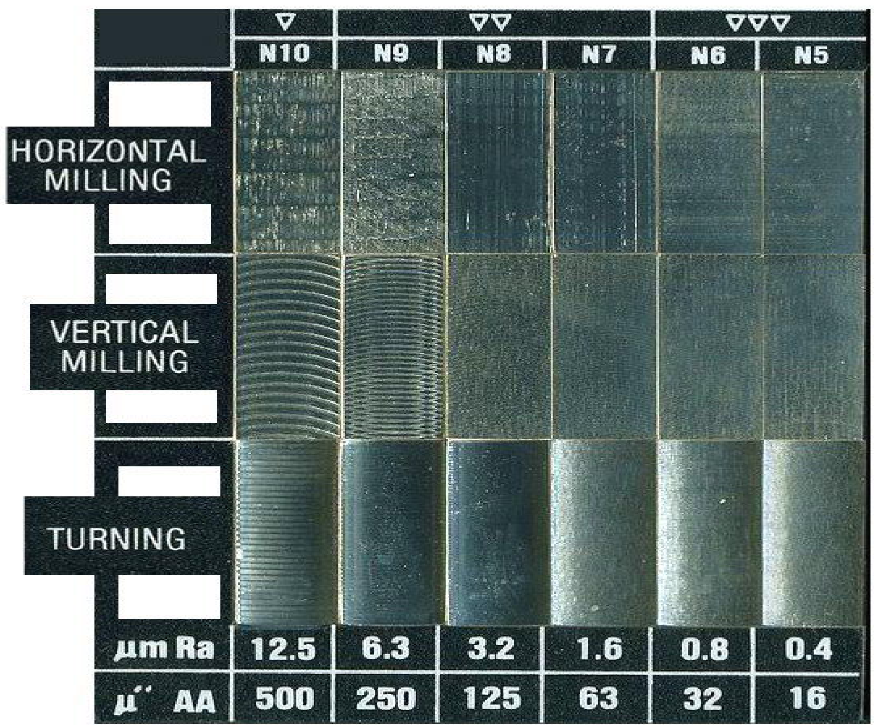


Figure 5—Surface Comparators (Typical)

Figure 6—Rotor Assembly

11.3.8 Pump Rotors

A pump rotor is a major subassembly that requires separate examination. Rotor assembly consists of impellers, shafts, interstage sleeves, thrust balance drums, etc. Pump rotors should be dynamically balanced per API 610, the purchase order, or ITP requirements. If a rotor needs to be disassembled, rebalancing may be required after the reassembly of the rotor if included in the ITP.

Residual unbalance is the amount of unbalance remaining in a rotor after balancing. Although some balancing machines may be set up to read out the exact amount of unbalance, that measurement may be erroneous as it depends on the calibration. The recommended method of determining the residual unbalance is to test the rotor with a known amount of unbalance. See API 610 for this procedure to determine residual rotor unbalance.

Figure 7—Mechanical Seal

11.3.9 Mechanical Seals for Centrifugal Pumps

API 610 requires seals to be selected and designed per API 682. See API 610 for seal design requirements for pumps.

An API 682 seal is a cartridge consisting of a gland, one or more primary and mating faces, drive mechanism (spring or bellows), O-rings, and a shaft sleeve, for example. Pump seals shall be subject to a qualification test per API 682.

The pump vendor and seal vendor collaborate for proper seal design and material selection. Reference documents for this design include the API 682 seal chamber drawing data sheet, API 610 pump data sheet, and related specifications. The seal vendor should prepare and submit for review and approval the seal cross-sectional drawing with detailed BOM and all dimensions that are required to check the seal design and proper fit to the pump. All documents should be listed on the purchaser's VDDR.

Only the contractually designed seals should be used in the pump for the performance test. Some seals are not designed to run on water; in this situation, the vendor shall supply a test seal for the performance test of the pump. Mechanical seals should be installed during the pump hydrostatic test, but should be used during all the running or performance tests. Seal leakage during performance testing shall be in accordance with API 610 or purchase documents, whichever is stricter. Many users require no visible leakage. If seals are removed from the pump after the performance testing for any reason, such as fixing a leak or installing contract seals, the seal should be retested with an air test of the pump. If specified, seal leakage during tests may require the assembled pump and seal to be rerun to demonstrate satisfactory seal performance.

There are two basic designs of mechanical seals:

— Single seal: has one set of stationary/rotating elements;

— Dual seal: has two sets of stationary/rotating elements.

11.3.10 Seal Flush Piping and Accessories

Mechanical seals need to be lubricated and cooled for successful operation. This is achieved by providing flush liquid across the stationary and rotating sealing rings. Different arrangements of seal flush piping are described in API 682. Some seal flush plans have heat exchangers, reservoirs, flow control panels, and other equipment and instrumentation. Pump and seal vendors have to submit drawings, schematics, data sheets, and BOM for piping, equipment, and instrumentation for purchaser review and approval. All these documents should be available during the final inspection (see Section 11.5 [Final Inspection] for more detailed information).

Users typically have inspection requirements for auxiliary piping/tubing, such as smooth bends instead of fittings and properly sloped tubing, and welded connections (except pipeline). During performance testing, the pump vendor may substitute their own generic seal flush system and bearing cooling system, with purchaser approval.

11.3.11 Pump Drivers and Gears

Pumps and compressors are driven by electric motors, gas or steam turbines, or diesel engines. When the speed of the pump is different than the speed of the driver, a gear is used for synchronization. In most cases, pumps and drivers are installed on the same baseplate. Compressors may have drivers installed on a separate baseplate or sole plate. A data sheet is provided for that driver or gear according to an applicable standard. Gears are generally purchased to conform to either API 677 for general-purpose gear units or to API 613 for special-purpose gear units.

11.3.12 Couplings and Guards

Requirements for couplings and guards can be found in the applicable API rotating equipment standard. There may be two types of guards: one at the coupling and another between the bearing housing and seal gland. The pump or compressor data sheets include information such as coupling service factor, applicable standard (e.g. if the coupling has to comply with API 671 or not), vendor, model, size, and balancing requirements. Special attention should be paid to the requirements for coupling installation options, such as taped shaft or hydraulic fit design. Refer to the applicable API rotating equipment standard for guidance. Coupling and shaft guards should be constructed in accordance with the purchase order or contract.

11.3.13 Baseplates, Mounting Plates, and Sole Plates

Pumps and their drivers and gears are typically installed on fabricated or cast baseplates. API 610 specifies requirements for baseplate design and requirements. Job-specific requirements for baseplate design options and inspection are listed on the pump data sheet. Baseplates may be with or without grout, have special anchor options, or have special paint requirements. Inspection of baseplates involves visual inspection of all welds to make sure that welds are continuous and of good quality, dimensional inspection, bolt hole/anchor bolt location, and machined pedestal flatness check.

11.3.14 Lube Oil Piping

If forced lubrication is required for one or more components of the pump train, the pump supplier typically provides lube oil piping to connect the pump train and the lube oil system. Lube systems can be mounted on the same baseplate as pump/drive train or on a separate foundation and baseplate. See API 610 for lube oil piping and system requirements. The pump vendor should provide for purchaser's review and approval a detailed drawing with BOM showing all parts, instrumentation, gaskets, and fasteners used for lube oil piping.

NOTE For dry gas seal systems, see the compressor sections of API 692.

Lube oil piping, components, welding, and configuration should be selected or designed according to API 614 and related job specifications. The basic requirements for oil piping are listed in API 614. For more detailed information, see the Lube Oil System section. Lube oil piping is subject to hydrostatic test at 1.5 times maximum operating pressure.

11.3.15 Cooling Water Piping

When required, the vendor provides cooling water piping. Piping schematics can be found in API 610. Piping material for cooling water piping and components are specified on the pump data sheet. Cooling and water piping is subject to hydrostatic test at 1.5 times maximum operating pressure.

11.3.16 Instrumentation

The source inspector should verify that all instruments, panel boards, junction and terminal boxes, wiring, etc. are in full compliance with the job specifications and conform to the classification as specified (e.g. code, NEC code, CSA, UL). Vendors typically are required to submit all engineering data, such as process and instrument diagrams, wiring diagrams and schematics, instrumentation lists, and instrumentation data sheets in a format requested in the purchase order. If specified in the ITP, the vendor should supply a scale drawing with the project drawing. The inspector should verify the access shown on the drawing is actually present on the mounted equipment on the skid.

Each instrument should have an assigned tag number. The source inspector should verify that all instruments, boxes, and wires have proper tagging, as shown in accompanying documents. All instruments should have a manufacturing nameplate with at least a serial number, area classification, and latest calibration date listed. Measurement ranges and units of measurements should be verified with data sheets and instrumentation list. The source inspector should also verify the equipment component specification against the component certificate document.

11.4 Testing

11.4.1 Pump Performance and Mechanical Run Test

Pump data sheets specify process data such as rated flow, rated total differential head, NPSH3, and NPSHA. Based on these requirements, the vendor selects and submits a proposal for a pump that is the best fit for this application. The purpose of the pump performance test is to confirm that pump performance is as specified on the purchase order and pump data sheet; to check for pump vibrations; and to check NPSH3 and run to bearing temperature stabilization if specified in the PO and as documented on the ITP. Performance test requirements, tolerances, and acceptance criteria are specified in API 610, Section 8.3.3.

These data should be communicated to the owner as expeditiously as possible for owner review and approval.

This test procedure may include detailed information, such as:

— pump test setup;

— measurements schematic;

— instruments being used and most recent calibration;

— test results collection;

— interpretation and final presentation in a form of numerical tables;

— performance curve and test data corrected specified operating conditions;

— vibration reading presented in tables and graphs;

— bearing temperature or oil temperature versus time;

— final visual inspection of oil and hydrodynamic bearings;

— recording of collected data.

A sample of the test result curve can be seen below.

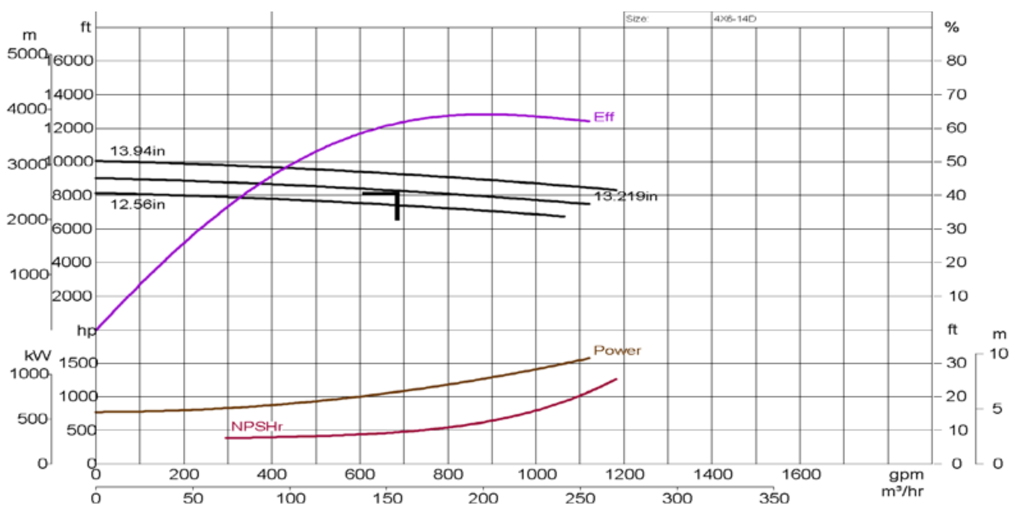


Figure 8—Typical Pump Performance Curve Report

11.4.2 Performance Test Setup

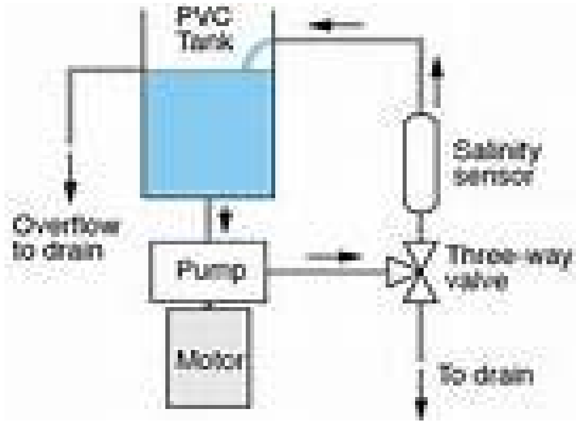


Figure 9—Typical Pump Test Setup Schematic

Performance test setup should include:

— piping loop that includes suction tank;

— suction pressure control devices, such as:

  — vacuum pump and pressurized suction tank;

  — discharge piping with discharge pressure control valve;

  — minimum flow bypass line;

— calibrated shop or job motor;

— coupling with torque meter, if required;

— test stand where pump and motor are securely installed and aligned;

— machine monitor system as agreed in the purchase order or ITP;

— performance-collecting instruments, such as pressure transmitters, flow meters, volts, amps, and power (for motor); temperature monitoring for the lubricating oil; bearings; and test water;

— noise measurement microphone (if specified) with digital reading device.

If specified, instruments that are supplied with the pump should be installed and used for test.

11.4.3 Pump Flow Rate

The common units are m³/h in metric units and GPM (gallons per minute) in U.S. Customary units (USC).

Instruments for flow measurement are:

— turbine, electromagnetic, Venturi, pitot, ultrasonic, positive displacement meter.

11.4.4 Total Differential Head (TDH)

Total differential head is defined as a difference between pump suction pressure and pump discharge pressure converted to static pressure head. Conversion is necessary to exclude specific gravity (SG) of the liquid being pumped by the pump.

For example, if test water has SG = 1.0 and actual liquid that is pumped has SG = 0.5, the pump will have the same TDH regardless of fluid pumped, but differential pressure created by the pump when operating on water will be twice as high as when operating on liquid with SG = 0.5.

11.4.5 Conducting the Test

Vendor personnel start the pump and bring the flow to the rated point. They let the pump run briefly to establish a stable flow and monitor pump parameters to ensure that all equipment is operating properly. After that, test personnel should collect performance data and vibration and temperature readings per API 610, ANSI B73.1, or B73.2. Stable suction pressure should be maintained at each point. If specified on the pump data sheet, the pump is given a mechanical run until oil temperature stabilization as defined in API 610. See the pump data sheet and ITP for test requirements.

11.4.6 Submitting Results of the Test

The vendor should prepare a test report that includes all data collected, performance curve, and vibration graphs (if specified). If specified, the results of the oil and bearing inspections should also be included. This report should be submitted to the purchaser for review and approval. The pump should not be released for final inspection unless all the documents, including a test report, have been approved by the purchaser.

11.5 Final Inspection

Final inspection should be conducted in two stages. The first inspection is when the equipment is fully accessible for dimensional and visual inspection, and the second is when the equipment is prepared for shipment.

11.5.1 Dimensional and Visual Inspections

Following is the list of documents that are typically required for final dimensional and visual inspection and the actions required based on these documents:

— data sheets;

— pump train general arrangement;

— auxiliary equipment GA, P&ID, and BOM (seal reservoir, LOS, seal, driver, junction boxes);

— packing list.

During visual inspection, the following areas of concern should be addressed:

a) All assemblies should be accessible for maintenance, disassembly, and gasket replacement, and match the GA and piping isometric drawings.

b) Valve handles should have enough space for safe open-close action by an operator to prevent hand jamming and injury.

c) All equipment should be mounted securely and according to the drawings.

d) Workmanship of installation, welding, and wiring should be without visible defects and comply with agreed industry standards.

e) There should be no equipment or piping extending beyond the perimeter of the baseplate, except those shown on the approved GA drawing.

f) Painting and paint thickness should be inspected and verified.

g) Quantity, condition, and packaging for items shipped loose should be inspected and verified. Packaging should be sturdy and compliant with the purchase order requirements.

12 Drivers

12.1 Electrical Motors

12.1.1 General

Requirements for selection of electric motors for pumps and compressors can be found in the applicable API standard for the driven equipment.

12.1.2 Design and Fabrication Standards

Electrical motors used in API services should comply with the standards listed in the purchase order and motor data sheet. If the job motor(s) is at the equipment vendor facility, the inspector should ensure that the motor nameplate matches the requirements of the motor data sheet.

12.1.3 Materials of Construction

All major components of electric motors (such as stator, stator winding, rotor, shaft, bearing housings, and bearings) may require NDT tests and material certificates. Requirements are found on the data sheets. Ensure that material certifications and NDT reports have purchaser approval.

12.2 Tests and Inspections

There are electrical/insulation tests that are performed on motor parts, such as stators and windings, before the motor assembly, and tests that are performed on the assembled motors during motor routine or complete tests. Testing requirements for motors may be found in IEEE 841, API 541, API 546, and API 547, for example. Stator testing is described in API 541 and includes tests on stator core, stator winding, and visual inspection before final assembly.

All these tests are optional, but may be specified on the motor data sheet if required. The source inspector should be aware of these requirements and confirm their completion and acceptance if required as a part of the purchase requirements.

Motor routine testing is mandatory for each motor. As an example, API 541, Section 6.3.2.1 states: *“Each machine shall be given a routine test to demonstrate that it is free from mechanical and electrical defects.”* Motor rotors should be balanced and residual unbalance checked if required on the data sheet. Test reports should be submitted to the purchaser for review.

Motor complete testing is optional, and may be requested on the motor data sheet. See API 541 for the detailed description of a complete test. The main purpose of the complete test is to determine accurate motor efficiency, power factor, and torque values under different loads. The oil condition should be checked after the test. Oil should be clean and should not change color when compared with unused oil. If specified, hydrodynamic bearings may be removed after the test and inspected for excessive or uneven wear, foreign material inclusions, hot spots, and other signs of unsatisfactory performance.

12.3 Final Inspection and Shipping Preparations

Motor final inspection includes inspection of dimensions per motor general arrangements drawings, paint inspection per paint specification, instrumentation inspection per motor data sheets and P&ID, name tag and nameplate inspection, main terminal box inspection, and wire connections.

13 Gears

13.1 General

Gears can serve two main purposes:

— to reduce RPM from driver RPM;

— to increase RPM.

Gears are used with rotating equipment when drivers rotate at a speed either higher or lower than the required speed of the driven equipment to provide required process flow and pressure. Increasing rotating speed of the driven equipment increases flow and discharge pressure, and conversely for speed reduction. An example for pumps can be calculated with using affinity laws.

Another application of gears with pumps is a right-angle gear—the pump driver is a horizontal machine and the pump itself is vertical. Right-angle gears can be found on pumps in fire water pumps, cooling water pumps and basins, and cooling tower fans.

Figure 10—Right Angle 1:1 Gear Set

Gears should be designed for the full operating speed range, including trip speed. See API 677 for driver trip speeds.

Gears have at least one low-speed and high-speed shaft. Slower shafts have the largest diameter gear, which is referred to as the gear wheel (bull gear). Faster shafts have the smaller diameter gear, which is called the pinion.

Figure 11—Gear-Pinion Set

Gear boxes have many different combinations and orientations. See API 677 for typical gear box designs.

13.2 Design and Manufacturing Standards

API 677 is the standard for general-purpose gear units. See API 677 appendices for additional referenced specifications.

Gears can have the same level of instrumentation as the main equipment. Hydrodynamic bearings can have X-Y proximity probes for each side and embedded RTDS in each sleeve and thrust bearing. Shafts with rolling element bearings can have accelerometers if specified. Source inspectors should check gear data sheets for instrumentation requirements.

Unless a lube oil system is independently supplied, gear casings serve as an oil reservoir. Casings can have oil level gauges and switches, an oil heater, and other features that are installed on external reservoirs.

13.3 Gear Unit Materials

Main gear parts are the casing (gear box), gear wheels, pinions, shafts, and bearings. Casings can be fabricated or cast. General requirements for material of construction and weld requirements are specified in API 677.

Steel is typically used for fabricated casing, while steel or cast iron is typically used for cast casing. The casing has a bottom half that can also serve as an oil reservoir. The gear box has precisely machined mounting feet to allow for mounting without distorting the casing and internal gear alignment. Gear boxes are typically split horizontally into an upper and lower half.

If specified, the gear casing should be given a fluid fill leak check to test for oil tightness. Gear pressure lube system components should be given a hydrostatic test as specified in API 677

Figure 12—Three-stage Gear (Upper Cover Removed)

See API 677 for gear shaft requirements. Shafts should be made of one-piece, heat-treated, forged, or hot-rolled steel, and shall be accurately machined throughout their entire length and suitably finished at their bearing surfaces. Additional NDT requirements are also part of shaft manufacture.

See API 677 appendices for material specifications for general-purpose gear units.

13.4 Internal Component Inspections

Inspection requirements for internal components are specified in API 613 and API 677. The gear manufacturer should provide an ITP/quality plan based on API 613 or API 677, as well as the purchase order, job-specific inspection, and test requirements. Acceptance standards should be documented and agreed to by the purchaser and vendor.

API 613 and API 677 contain typical inspection and quality assurance requirements for gear mating pairs, checking the gear contact area, and axial movement of the pinion relative to the gear. See API 613 or API 677 appendices for these inspection requirements.

Gear rotors should be balanced. If specified, a residual unbalance check should be performed. See API 613 or API 677 for residual unbalance worksheets.

The source inspector may be required to observe the internal inspection after testing and should be familiar with these inspection activities.

13.5 Testing of Gears

When required by the purchaser, run testing of the gear unit may be performed by the vendor and witnessed by the source inspector. In those instances, the source inspector should be completely familiar with the equipment, the purchase requirements, and the agreed-upon run test procedure.

Refer to test requirements as defined in API 677. API 613 should be applied for special-purpose gears.

— Mechanical run testing shall be conducted by operating at the maximum continuous speed for not less than 1 hour after bearing temperature and lube oil temperature stabilization.

— The contract bearings shall be used in the machine for the mechanical run test.

— All oil flows, pressures, viscosities, and temperatures shall be within the range of operating values recommended in the vendor operating manual.

— All joints shall be checked for tightness and any leaks corrected.

— All warning, protective, and control devices used during the test shall be checked and adjusted as required.

— Testing with contract coupling or couplings is preferred.

— Mechanical run test should be performed with the job lube system, if purchased with the unit.

The following are the minimum requirements as defined in API 677 for run testing:

— During a run test, the mechanical operation of all equipment being tested shall be within the defined limits as specified in the purchase agreement.

— Unfiltered vibration shall be recorded and not exceed the limits as defined in API 677 throughout the testing speed range.

— Vibration devices shall have been calibrated and be operating within designed frequency range.

— Vibration probes and oscillation-demodulators shall meet the accuracy requirements of API 670.

— The vendor shall keep a detailed log of the final tests, making entries at 15-minute intervals for the duration of the test. Each entry shall record the following:

  — oil temperature and inlet pressures;

  — outlet oil temperature, when available;

  — vibration amplitude, unfiltered and filtered one time for operating speed of each rotor;

  — bearing temperatures.

The source inspector should confirm that the vendor has documented the conditions of the test and that all readings were correctly recorded with devices that are within their calibration period and properly documented.

After run testing is complete, the tooth mesh should be inspected for surface damage and proper contact pattern.

When spare gear elements are ordered, each spare element should have a mechanical run test in accordance with the requirements of API 613 or API 677.

Final acceptance of the mechanical run test is the responsibility of the purchaser, not the source inspector.

13.6 Final Inspection and Shipment

Final inspection at the gear manufacturer facility should be performed in accordance with the approved packing and shipping procedure and relevant documents.

Painting, tagging, final marking, and cleanliness should also be checked per purchase order and specifications.

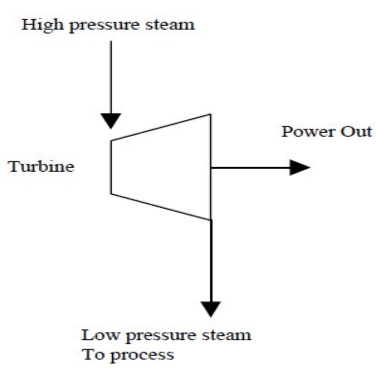
14 Steam Turbines

14.1 General

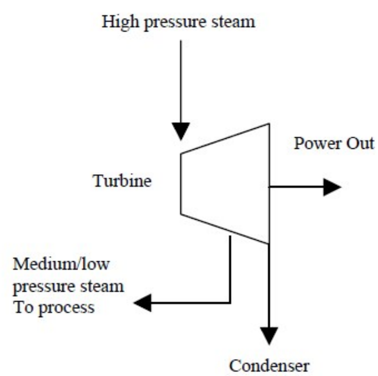
Governing specification for steam turbines used in the oil and gas industry may be either API 611 or API 612. The secondary and supplemental specification for steam turbines is NEMA SM23.

14.1.1 Single-stage Turbines

Figure 13—Single-stage Steam Turbine



Back-pressure Steam Turbine



Condensing Steam Turbine

The steam turbine vendor should provide the following documents as specified. These documents also should be used during the final inspection:

— general arrangement (completed with all connections and nozzle loads);

— steam turbine data sheet;

— steam turbine performance characteristic curve;

— instrumentation and piping diagram;

— condenser and ejector general arrangement;

— turbine trip and throttle valve cross-sectional drawing;

— manual and mechanical trip linkage drawing;

— gauge board assembly drawing;

— electronic governor operation and installation instruction;

— trip and throttle valve general arrangement (if supplied separately).

Each steam turbine has an emergency trip mechanism to protect it from overspeeding. This overspeed trip can be either a mechanical or an electronic device.

14.2 Design and Construction Standards

Steam turbines may be classified by several different design options:

— single or multi-stage;

— condensing or non-condensing:

  — back pressure when exhaust pressure is higher than atmospheric pressure;

  — condensing;

  — extraction;

  — induction;

  — atmospheric when exhaust pressure is vented to atmosphere.

Steam turbines covered in this study guide should comply with API 611 or API 612. Major parts of steam turbines are pressure casing, rotors, bearing housings, governors, speed control mechanisms, seals, gland seal systems, and overspeed trip mechanisms.

14.3 Materials of Construction

Requirements for materials of construction for steam turbines are described in API 611 or API 612. These are noted on the data sheets for those two standards.

14.4 Turbine Casing

The casing of steam turbines consists of a high-pressure casing and lower-pressure exhaust casing. Both parts are castings, and the most commonly used material is carbon steel. See API 611 or API 612 for detailed descriptions of all NDT, hydrostatic, and other required inspections.

14.4.1 Rotating Elements

See API 611 or API 612 for the requirements for shafts and blading. Most common material for shafts is steel or carbon steel alloy 4340. For blades and wheels, the most common materials are 4140 and 403SS. Check with API 611 OEMs for these materials.

14.4.2 Seals and Packing

Outer glands should be sealed at the shaft by a carbon ring, a replaceable labyrinth packing, a combination of both, or by mechanical seals.

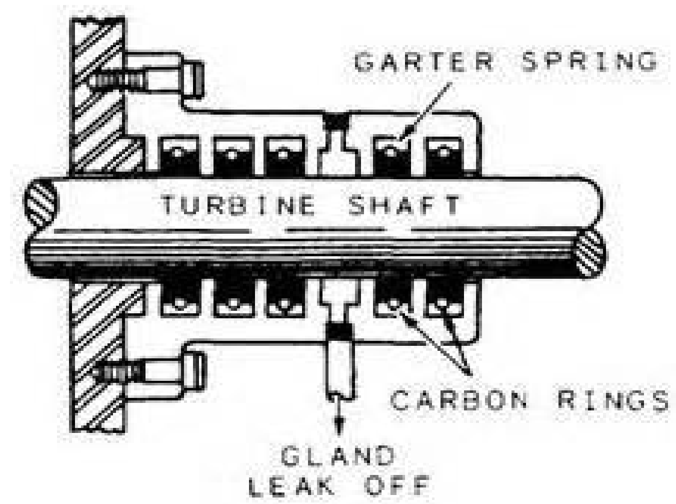


Figure 14—Steam Turbine Seal Rings

14.4.3 Bearing Housings and Bearings

Steam turbine bearings and bearing housings are cast parts usually made out of cast steel. Bearing housings can be axially split when a hydrodynamic sleeve bearing is selected; for an anti-friction ball bearing, the bearing housings are radially split.

14.4.4 Condenser

For some applications, a purchaser may order a condenser and ejector as part of a package with the steam turbine. Condensers are essentially heat exchangers and have to follow all the requirements for design and inspection of the heat exchangers. These devices are not covered in detail by API 611 or API 612.

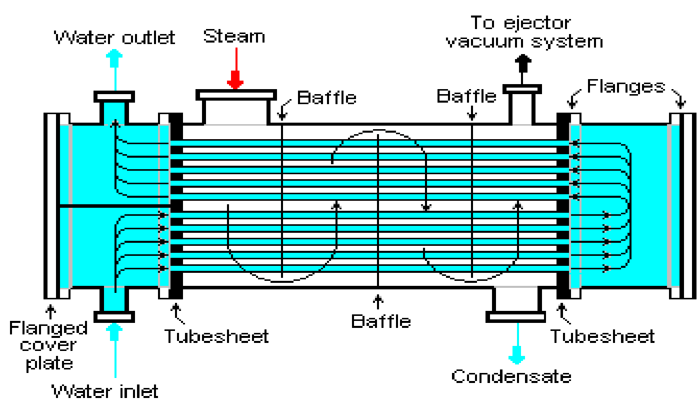


Figure 15—Condenser

A steam turbine gland vacuum system with ejector mounted on the top of the condenser is shown in Figure 16.

Figure 16—Steam Turbine Gland Vacuum System

14.5 Component Inspections

See the API 611 and API 612 documents and appendices for information on inspection and testing, as well as an inspector's checklist. The turbine vendor should provide an ITP listing all the requirements for inspection and testing. Inspection of steam turbine components may include the following:

— pressure casing, blade wheel, blading, shroud peening, piping welds, and shaft NDT and visual inspection;

— material certifications and PMI review;

— rotor balancing and, if specified, determination of residual unbalance;

— hydrostatic test of turbine casing sections;

— cleanliness inspection of assembled steam turbine, including bearing housings;

— auxiliary equipment inspection (condensers, ejectors).

The source inspector should be familiar with the referenced codes and ensure that the vendor has completed these component inspections by witnessing or reviewing vendor documentation.

14.6 Testing of Steam Turbines

Steam turbines should have a mechanical run test per API 611 or API 612. The source inspector should confirm that the test procedure has been jointly agreed by the purchaser and vendor.

If a mechanical run test is specified, the vendor should demonstrate the following as agreed:

— Selected running speed is controlled by the governor and the turbine holds the speed at a selected (rated) RPM. The turbine is tripped when the running speed exceeds the maximum (trip) RPM.

— The hand lever trips the steam turbine as per API 611 or API 612 with maximum inlet steam flow and pressure.

— The ability to reset the manual trip back to its operating position under maximum inlet steam pressure.

— If the turbine has hydraulic actuators and a minimum oil pressure switch or transmitter, that the turbine will trip on low, low oil pressure level.

— Check relief and sentinel warning valves for proper operation.

— Job vibration and temperature instruments should be used during the mechanical run test, and readings meet agreed test acceptance criteria.

The source inspector should confirm that the vendor performed the mechanical run test in accordance with agreed procedure(s) and that the test results are documented accurately. Final acceptance of the mechanical run test is the responsibility of the purchaser and not the source inspector

14.7 Final Inspection

The following documents are typically required for the steam turbine final inspection:

— API 611 or API 612 data sheets;

— P&ID;

— bill of materials;

— instrument list;

— ISA data sheets for all instruments and orifices;

— general arrangement;

— packing list;

— shipment and preservation procedure.

Typical final inspection points:

— The source inspector should verify that all dimensions are as shown on the steam turbine GA.

— The source inspector should check that all flanged/screwed customer connections are as shown on general arrangement drawings.

— The source inspector should check flange sizes, face type, rating, and protection for shipping. All NPT connections need to be plugged for the shipment.

— The source inspector should verify tagging of equipment and instruments per drawings.

— Verify that all testing and final documentation is correct.

15 Lube Oil Systems

15.1 General

Lube oil systems for pumps and their drivers should be designed per API 614.

Figure 17—Mounted Lube Oil System

Figure 18—Simplified Lube Oil System

15.2 Design and Construction Standards

Lube oil systems can be mounted on the same baseplate as the equipment train or on a separate skid mounted next to the train.

Each system consists of a reservoir, pump(s), cooler(s), filters, connecting piping, pressure controlling valves (PCV), pressure safety valves (PSV), temperature control valve (TCV), pressure, temperature and oil level measurement instruments and indicators, gauge panel, terminal boxes, and mounting baseplate. The purchaser specifies the system equipment scope of supply on the API 614 data sheet.

15.3 Materials of Construction

See API 614 for minimum requirements for piping materials for cooling water, lubricating, control, and seal oil.

15.3.1 Lube Oil Reservoir

The reservoir stores the oil and typically has a level gauge, level switch or transmitter, oil heater with thermostat, temperature gauge, and temperature transmitter. For requirements for reservoirs, see API 614.

15.3.2 Typical Inspection Points for Lube Oil Systems

The following are the recommended inspection points the source inspector should be familiar with during the inspection of lube oil systems. The source inspector should follow the ITP for actual inspection points:

— The source inspector should check the actual oil tank with the LOS data sheet for all options.

— The source inspector should open the service access and make sure that there is a separating screen, with its bottom sloping away from the pump suction.

— The source inspector should check if the minimum and maximum oil levels are shown on the level gauge indicator.

— The source inspector should verify that all return pipes enter the reservoir above the maximum operating level.

— The source inspector should verify that the oil heater hot section is located at least 2 in. below minimum oil level.

— The source inspector should check for grounding clips.

15.3.3 Lube Oil Pumps

Depending on the LOS class, there may be one or two pumps.

For API 610 pumps, LOS should be Class 2 or Class 3 only, and should have two lube oil pumps. The majority of pumps have a Class 2 LOS with a main lube oil pump driven by a shaft of the main pump or gear (if provided) and an auxiliary lube oil pump is driven by an electric motor or steam turbine. See API 614, Part 2, Section 4.4 or Part 3, Section 4.5 for the requirements for pumps and pump drivers.

Typical inspection points:

— The source inspector should verify that the motor nameplate is in compliance with area classification.

— The source inspector should verify the setting of pump oil pressure relief valves.

— The source inspector should make sure that pump casing is made of steel if the pump is located outside the oil tank. Pump casing may be cast iron when the pump is installed inside the oil tank.

15.3.4 Coolers

See API 614, Part 2, Section 5 or Part 3, Section 4.6 and the LOS data sheet for cooler requirements. Coolers should be a bundle removable type. The source inspector should check whether code compliance and stamping is required.

Typical inspection points:

— The source inspector should compare the cooler with the LOS data sheet to verify all options.

— The source inspector should verify the nameplate and stamping if required.

— The source inspector should verify that the bundle can be removed without obstructions.

— In case of dual cooler design, the source inspector should verify that the switch valve is easily accessible and operates without obstructions.

15.3.5 Mounting Baseplate

The lube oil system may be designed as a separate console or to be integral with the baseplate of the equipment it serves. If the LOS is installed as a separate console, a weld fabricated baseplate should be supplied. See API 614, Part 2, Section 2 or Part 3, Section 4.3 for the requirements for baseplates.

Typical inspection points:

— The source inspector should verify that all welds are continuous.

— The source inspector should verify that drainage from the baseplate is unobstructed by the installed equipment.

— The source inspector should verify that each closed compartment of the baseplate has a grout hole and vent holes for grouting.

— The source inspector should verify that a leveling screw is provided next to the anchor bolt holes.

15.3.6 Instrumentation and Electrical Systems

See API 614, Section 6 for instrumentation and electrical system requirements. See Part 3, Table 3 for minimum instruments required for alarms and shutdowns.

Typical inspection points:

— The source inspector should check the nameplates to make sure that instruments match their description, power requirements, units of measurements, and area classification.

— The source inspector should verify that pressure and temperature indicator ranges are selected in a manner that the normal operating pressure is in the middle of their range.

— The source inspector should verify that indication instruments are located in such positions that their dials are easily accessible for reading.

— Actual inspection points are defined in the inspection and test plan.

15.4 Inspection and Testing of Lube Oil System

The following are the typical tests performed on lube oil systems. All tests should be conducted to a detailed and documented procedure or written practice. The source inspector's responsibility is to confirm that the vendor has performed the tests and documented them correctly.

15.4.1 Hydrostatic Test

The hydrostatic test is to be performed in accordance with API 614. The LOS vendor should provide a test procedure for the piping hydrostatic test. The source inspector should check the hydro test reports for coolers and filters since they are supplied by sub-vendors and normally are a standard equipment. Piping should be tested while fully assembled. Alternatively, and by prior agreement, the piping spools may be tested individually instead of during the assembled hydrostatic test.

15.4.2 Lube Oil System Performance Test

See API 614 for operation and performance test requirements.

Typical Inspection Points:

— Verify that oil-pressure limiting valves (PLV) operate smoothly, without chattering, and without causing a drop in a supply pressure to the equipment. PLV piping should be sized for the full flow of each pump; the valves should not chatter and not produce excessive noise.

— If the scope of supply includes the lube oil system, the system needs to supply regulated oil at standby, acceleration, and steady state conditions.

— Verify that all instruments show reading in required units.

— Verify that calibrated shop instruments are used to verify flows, pressures, and temperatures.

— The following test should be performed:

  — Test both main and standby pumps to ensure proper system operation.

  — Test both pumps operating at the same time to ensure system stabilization.

  — Test the standby pump when the main pump trips to ensure that the standby pump will pick up pressure without tripping the system due to low pressure. The reverse process should be completed if the capability is available.

— Both main and standby pumps should be tested individually to ensure proper system operation.

— Confirm that the vendor has conducted a system cleanliness test as required per API 614.

— After all run tests are complete, filter elements should be inspected and replaced with new ones.

— Document and notify the purchaser of any changes or modifications made to any components during the oil system performance test.

15.5 Final Inspection and Shipment

At a minimum, the following documents supplied by the LOS manufacturer are typically required for final inspection (review ITP and purchase order):

— API 614 LOS data sheet;

— P&ID;

— bill of material;

— instrument list;

— Instrument Society of America (ISA) data sheets for all instruments and orifices;

— LOS general arrangement;

— packing list;

— shipment and preservation procedure.

Final inspection of a LOS should confirm that:

— all open flanges have face-protecting covering with gaskets;

— all dimensions were verified per the GA;

— all connections have tags;

— the piping arrangement allows easy access to all control and safety valves;

— handles of valves are installed per the purchase order requirements and that there is clearance to allow safe opening or closing without risk of jamming the hand of an operator;

— there is no equipment or piping hanging over the baseplate perimeter;

— all assemblies are accessible for maintenance, disassembly, and gasket replacement, and match the GA and piping iso drawings. All loose items should have tags and should be listed in a packing list. Final packing should be done per an approved preservation and packing procedure.

16 Reciprocating Compressors

16.1 General

Reciprocating compressors (also known as positive displacement “piston/plunger-type” compressors) are often applied for services with relatively low capacity and a relatively high differential pressure. They can be single- or multistage compressors driven by a single driver.

The scope of supply typically includes driver, suction and discharge pulsation suppressors (bottles), flywheel, cylinder and packing/cylinder lubricator systems, running gear lubrication systems, cylinder/packing jacket coolant system, instrumentation, control system, and auxiliary piping and manifolds.

Equipment can be designed for package skid mounting or be baseplate-mounted depending on the scope of supply and the size of the equipment. Compressors should comply with requirements of API 618.

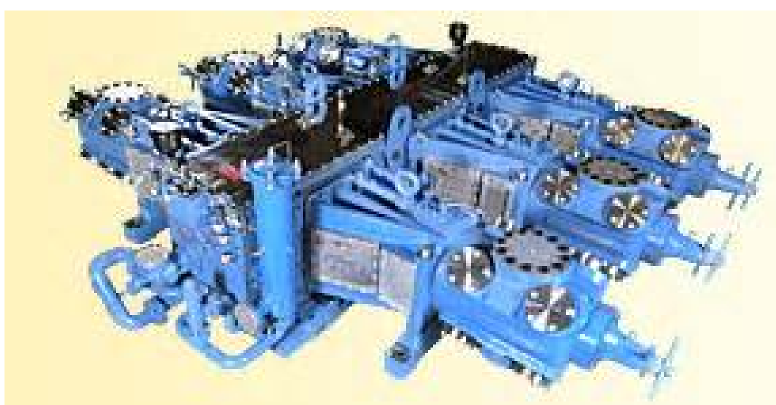


Figure 19—Six Throw Reciprocating Compressor

16.2 Design and Construction Standards

Reciprocating compressors should comply with the requirements of API 618 and purchase order requirements.

The frame lube oil system, instruments, piping, coolers, filters, and electrical equipment should comply with the requirements of API 614 and purchase order requirements.

The LOS also should comply with API 614, Parts 1 and 3. In some cases, the LOS should comply with API 614 Part 2 instead of Part 3.

Electric motors should comply with NEMA MG1, IEEE 841, or API 541/API 546 for North America, or equivalent standards for IEC specification.

Suction and discharge pulsation suppression devices (bottles), heat exchangers, and oil filter housings should comply with ASME Section VIII. Welding should comply with ASME Section IX.

For packaged compressors, API 686 may apply, depending on scope of fabrication (piping, foundations, and alignment).

The condition monitoring/protection system should comply with API 670 or purchase order requirements.

16.3 Materials of Construction

Reciprocating compressors are used mostly with process gases. As stated in API 618, Section 6.15.1.1, “Unless otherwise specified by the purchaser, the materials of construction shall be selected by the manufacturer based on the operating and site environmental conditions specified” (Refer to API 618, Annex H).

Special attention should be paid to materials if compressor parts will be exposed to H_2S. These components are expected to comply with NACE MR0175, and should include:

— all pressure-containing cylinder parts, such as the cylinder, heads, clearance pockets, valve covers, and fasteners directly associated with those parts;

— all components within the cylinder, such as piston, piston rod, valves, unloaders and fasteners;

— components within the outboard distance piece, such as packing box, packing, and fasteners;

— suction/discharge pulsation suppression devices (bottles) should also be covered by NACE requirements.

Reference API 618 for maximum gauge pressures for cylinder materials, material selection, quality requirements, welding, NDT, and repair of pressure-containing parts and piping. API 618, Annex A provides a compressor data sheet that contains the information about the material selection and inspection requirements.

The supplier should submit material certificates for all major compressor components as specified on API 618 data sheet. Below are some special requirements for the material of specific parts as required per API 618:

For all reciprocating compressors:

— Piston rods: Unless otherwise specified, all piston rods, regardless of base material, should be coated with a wear-resistant material. Rolled threads are required per API 618.

— Fasteners: For reciprocating compressors, rolled threads are often specified in lieu of machined threads. Typically, frames, distance pieces, crossheads, cylinders, and cylinder heads may be subject to rolled thread requirements.

For compressors with power above 150 kW (200 hp):

— Crankshafts: Crankshafts should be forged in one piece and should be heat treated and machined on all working surfaces and fits.

— Connecting rods: Connecting rods should be made of forged steel with removable caps. Rolled threads are required for all con-rod bolting.

— Crossheads: Crossheads should be made of steel.

16.4 Internal Component Inspections

Reference the compressor data sheet and vendor-submitted ITP for inspection requirements.

The ITP should identify inspection requirements for the following components:

Crankcase group:

— crankcase;

— crankshaft;

— connecting rods;

— bearings;

— crosshead pins;

— crossheads;

— crosshead extensions;

— fasteners.

Cylinder groups:

— cylinder;

— cylinder head;

— piston;

— piston rod;

— distance piece;

— suction cylinder valves;

— discharge cylinder valves;

— fasteners.

Accessory equipment and components:

— drivers;

— intercoolers, aftercoolers, and separators;

— suction and discharge dampeners (bottles);

— lube oil system;

— instrumentation and control system;

— process piping;

— cooling water piping and equipment;

— lube oil piping;

— baseplate.

The source inspector should be familiar with the ITP and drawings for observed inspections during assembly of the compressor. The vendor is responsible for the quality of the work and documentation.

16.4.1 Couplings and Guards

Requirements for couplings and guards can be found in the applicable API rotating equipment standard. The compressor data sheets include information such as coupling service factor, applicable standard, vendor, model, size, and balancing requirements.

Refer to the applicable API rotating equipment standard for guidance. Coupling and shaft guards should be constructed in accordance with the purchase order or contract.

16.4.2 Baseplates, Mounting Plates, and Sole Plates

Job-specific requirements for baseplate, mounting plate, and soleplate design options and inspection are listed on the data sheet. An inspector should verify manufacturing is dimensionally and structurally in accordance with applicable drawings. This includes requirements for machine mounting surfaces, including flatness, surface finish, level, and parallelism limits.

16.4.3 Testing of Reciprocating Compressors and Associated Equipment

The vendor should submit an ITP that is in full compliance with API 618. The ITP should be reviewed and approved by the purchaser. The following is the list of inspections/tests usually specified by the purchaser:

— PMI test on major pressure-containing parts and parts that are in contact with process gas;

— visual inspection of major castings, weld fabrications, and piping;

— hydrostatic test for pressure-containing parts and piping;

— leakage test for cylinders, as well as suction and discharge valves;

— mechanical run test of compressor and associated equipment per API 618 and the purchase order;

— if specified, performance run test of compressor and associated equipment per API 618.

The purpose of a mechanical run test is to verify the assembly integrity as being free from rubs, excessive vibration and noise, lubricant leaks, and overheating. The source inspector should confirm that the run test was performed in accordance with the vendor’s written procedure and that results of the test are correctly documented.

16.5 Final Inspection and Preparation for Shipment

The purpose of a final inspection is to verify:

— that dimensions are per the compressor GA;

— compliance with standards;

— instrument and connection tagging;

— piping compliance to P&ID;

— proper piping support;

— electrical and instrumentation wiring is in compliance with the drawings;

— junction/terminal boxes are mounted and correct per drawings;

— nameplates contain correct information and are in compliance with API 618 and purchase order documents;

— preparation for shipment is per purchase documents.

The source inspector should follow these typical inspection points unless the ITP is more specific.

API 618 specifies procedures and requirements that should be followed in preparation for shipment. All documents submitted by the vendor should be reviewed and approved by the purchaser. Compliance with preservation procedures should be verified. The packing list should clearly list the shipped items' tag numbers, names, and quantity, and the box numbers where they are located. Parts that don't have separate tag numbers should have references to assembly or GA drawings, such as balloon numbers, part numbers, etc.

17 Rotary- (Screw) Type Compressors

17.1 General

A rotary screw compressor uses mating sets of helical vane (screw) shape rotors. They combine the advantages of positive-displacement compressors and centrifugal/axial flow compressors and are used in a wide range of applications. Another advantage is that this type of compressor cannot surge; therefore, any complex control schemes and unloading bypasses are avoided.

Two different types of rotary screw compressors are: oil-flooded compressors and oil-free compressors.

The screw compressor is characterized by the following:

— high volumetric and good adiabatic efficiencies;

— wide compression range;

— lack of valves;

— flooded screw may have stepless capacity modulation with sliding valve.

Compressors can be single-stage or multistage with two or more sets of screws. Rotary screw compressors should comply with API 619.

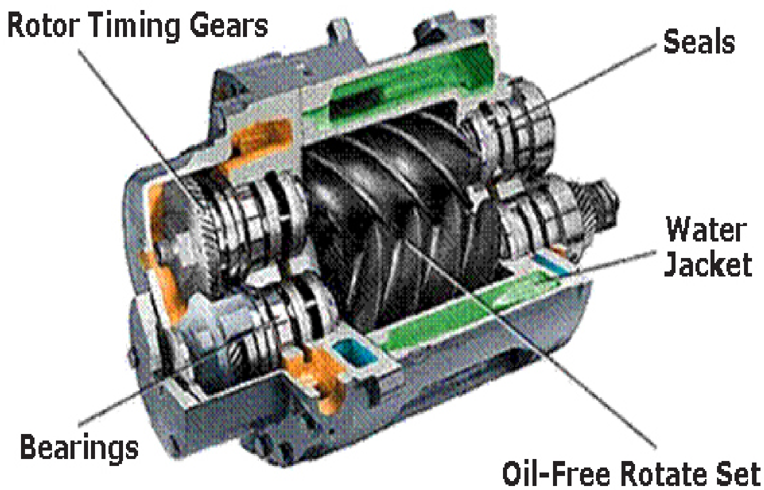


Figure 20—Oil-free Rotary Compressor

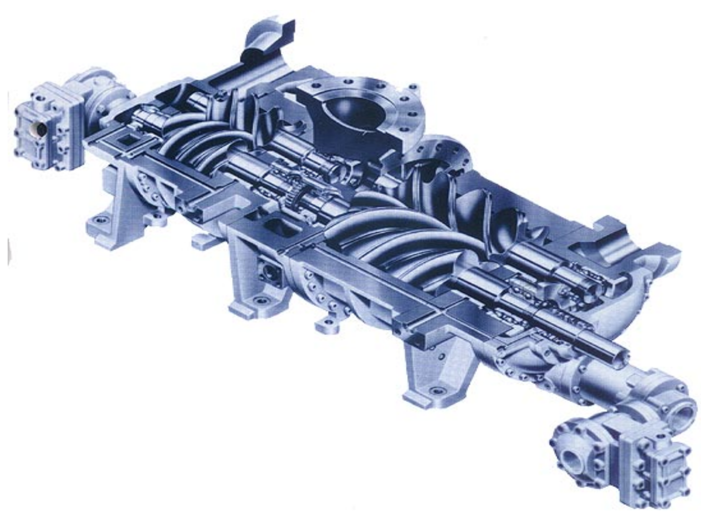


Figure 21—Multistage Oil-Flooded Compressor

The difference between oil-free and flooded rotary compressors is that oil-free compressors have timing gears that drive the idle rotor. There is no mechanical contact between rotors. Flooded compressors have no timing gears; the driven rotor drives the idle rotor by mechanical contact. The flooding oil provides cooling, lubrication, and sealing between the rotor. Flooded screw compressors have fluid injection and fluid separation systems with cooling and storage tanks.

17.2 Design and Construction Standards

Rotary screw compressors should comply with the requirements of API 619. All instruments, piping, coolers, filters, and electrical equipment should comply with the requirements of API 614.

Gear units should be either special-purpose units conforming to API 613 or general-purpose units conforming to API 677, as specified.

The machine monitoring system (MMS) (instrumentation) should comply with API 670.

17.3 Materials of Construction

Reference API 619 for material selection, quality requirements, welding, NDT, and repair of pressure-containing parts and piping. The API 619 data sheet, ITP, and contract documents contain information about material selection and inspection requirements. The vendor typically submits material certificates for all major compressor components as specified on the API 619 data sheet.

17.3.1 Internal Component Inspections

Reference the API 619 data sheet and approved ITP for the inspection requirements. API 619 provides information on document requirements, notifications, and a list of specifications that should be used for material inspection, certification, and NDT. Refer to API 619, Annex H for the inspector's checklist.

17.3.2 Rotary Compressor Drivers and Gears Units

Rotary compressors are driven by electric motors, gas or steam turbines, or diesel engines. When the speed of the compressor is different than the speed of the driver, a gear is used for synchronization. In most cases, compressors and drivers are installed on the same baseplate. Compressors typically have drivers installed on a separate baseplate or soleplate. A data sheet is provided for that driver or gear according to an applicable standard. Gears are generally purchased to conform to either API 677 for general-purpose gear units or to API 613 for special-purpose gear units.

17.3.3 Bearings

Bearings are one of the following arrangements: rolling element radial and thrust, hydrodynamic radial and rolling element thrust, or hydrodynamic radial and thrust. Each shaft is supported by two radial bearings and one double-acting axial (thrust) bearing, which is sometimes combined with one of the radial bearings.

17.3.4 Shaft Seals and Auxiliary Sealing Systems

Shaft seals are provided to restrict or prevent process gas leakage to the atmosphere.

17.3.4.1 Shaft Seals for Dry Screw Compressors

NOTE For figures of seals described below, see API 619.

Labyrinth type

The labyrinth seal may be the restrictive-ring or mechanical-contact type. Labyrinths may be stationary or rotating.

Restrictive-ring type

Restrictive-ring-type seals include rings of carbon or other suitable material mounted in retainers or spacers. The seals may be operated dry or with a sealing liquid.

Mechanical-(contact) type seal

Single mechanical-(contact) type seals will be provided with labyrinths and slingers or restrictive rings to minimize oil leakage to the atmosphere or into the compressor. Oil or other suitable liquid furnished under pressure to the rotating faces may be supplied from the lube oil system or from an independent seal oil system.

Dry Gas Seal

The seal arrangement will be single, double, or tandem as specified in the purchase documents.

17.3.4.2 Shaft Seals for Oil-flooded Screw Compressors

Mechanical-(Contact) Type Seal

Single mechanical-(contact) type seals will be provided with labyrinths and slingers or restrictive rings to minimize oil leakage to the atmosphere or into the compressor. Oil or other suitable liquid furnished under pressure to the rotating faces may be supplied from the lube oil system or from an independent seal oil system.

If specified that gas leakage to atmosphere is not permissible, oil-flooded screws require dual seal designs with an independent seal fluid system.

Couplings and Guards

Requirements for couplings and guards applicable to rotary screw compressors can be found in API 619. There may be two types of guards: one at the coupling and another between the bearing housing and seal gland. The compressor data sheets include information such as coupling service factor, applicable standard, (e.g. if the coupling is to comply with API 671), vendor, model, size, and balancing requirements.

Special attention should be paid to the requirements for coupling installation options, such as keyed tapered shaft or hydraulic tapered fit design. The proper fit of the coupling hub to the shaft is critical to reliable compressor operation. Inspection requirements should be noted with the purchase agreement.

Baseplates, Mounting Plates, and Soleplates

Rotary type compressors, their drivers, and gears are typically installed on fabricated baseplates or soleplates. API 619 specifies requirements for baseplate design. Job-specific requirements for baseplate design and inspection are listed on the compressor data sheet and contract documents. Baseplates may be grouted, have special anchor options, or have special coating requirements. Inspection of baseplates can include visual quality inspection of all welds, dimensional inspection, coating thickness inspection, anchor bolt location, and machined pedestal flatness check.

17.4 Testing of Rotary Screw Compressors and Auxiliaries

The vendor will submit test procedures that are in full compliance with the purchase specifications and approved by the purchaser. The certified inspector should be familiar with the job-specific testing requirements prior to any testing activities.

The following is the list of tests often specified by purchaser:

— PMI test on major pressure-containing parts and parts that are in contact with process gas;

— inspection of major castings, weld fabrications, and piping;

— hydrostatic tests for pressure-containing parts and piping;

— a residual unbalance test of rotating components;

— a gas leakage test of the assembled unit;

— mechanical run test of compressor and auxiliary equipment;

— the performance test in accordance with API 619 and contract documents (power tolerance, head, flow, discharge temperature, bearing temperature, efficiency, etc.)

17.4.1 Factory Acceptance Test

The purpose of the mechanical run test is to verify the assembly integrity as being free from rubs, excessive vibration and noise, lubricant leaks, and overheating. The source inspector will typically observe the run test in accordance with the agreed test procedure. The source inspector should verify that the results of the test are correctly documented.

17.5 Final Inspection and Preparation for Shipment

All required vendor documents are typically submitted according to VDDR and reviewed and approved by purchaser.

The purpose of the final inspection is to verify:

— dimensions are as shown on the compressor general arrangement drawing;

— compliance with standards;

— instrument and connection tagging;

— piping compliance to P&ID;

— proper piping support;

— electrical and instrumentation wiring is installed per the approved drawings and area classification;

— junction/terminal boxes are correctly mounted per the approved drawings and area classification;

— nameplates contain correct information and are in compliance with API 619;

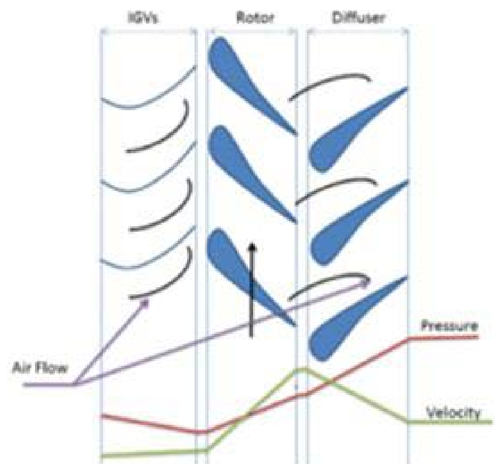
— API 619 specifies procedures and requirements that should be followed in preparation for shipment.

18 Axial/Centrifugal Compressors

18.1 General

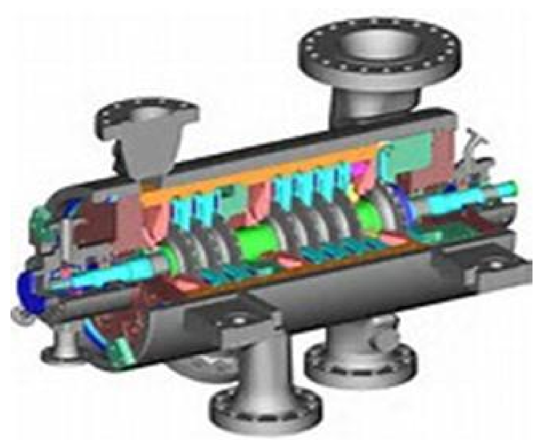
Axial compressors and centrifugal compressors are covered in API 617. Although they are grouped in the same API standard and have some mechanical features that look alike, they use different methods to compress gas.

Rotor blades drive the gas in axial direction through stator blades (vanes), where kinetic energy is converted to static pressure. This conversion occurs in the diffuser due to the reduction in passage area.



Principle of Operation of Axial Compressor

Centrifugal compressors generate a pressure increase in gas by using the same principle as centrifugal pumps. Impellers turn the flow from axial direction to radial direction, increasing the gas velocity. Then, gas enters the diffuser area, where part of the velocity head is converted to static head. Then, gas enters the suction eye of the next stage impeller and the process repeats until the final stage.



Multistage Centrifugal Compressor

18.2 Design and Construction Standards

API 617 for axial and centrifugal compressors specifies minimum requirements and gives recommendations for axial compressors, single-shaft, and integrally geared centrifugal compressors, and expander-compressors for special-purpose applications in the petroleum, chemical, and gas industries.

18.2.1 Part 1—General Requirements

This part of API 617 specifies general requirements applicable to all such machines.

It describes the basic principles of compressor operation, responsibilities of compressor manufacturers and purchasers, and industry standards that shall be applied in compressor design, manufacturing and testing, and auxiliary equipment design. Annexes provide detailed information on design and requirements for testing and inspection.

18.2.2 Part 2—Nonintegrally Geared Centrifugal and Axial Compressors

This part describes requirements specific to compressors with a single rotor having one or more impellers providing gas compression.

18.2.3 Part 3—Integrally Geared Centrifugal Compressors

This part describes requirements specific to compressors with multiple rotors. One rotor is the gear that drives one or more rotors, each of which have impellers.

18.2.4 Part 4—Expander-Compressors

This part describes requirements specific to compressors with a single rotor that is self-driven by an expander section. The opposite end of this machine provides gas compression through a single impeller.

18.3 Materials of Construction

General requirements for materials of construction are described in Part 1 of API 617. Additional requirements are found in the parts of 617 that are specific to compressor types. It is the purchaser's responsibility to specify any corrosive agents (including trace quantities) present in the motive and process fluids in the site environment, including components that may cause corrosion. The purchaser can specify additional optional tests and inspections, especially for materials used for critical components or critical services. The source inspector shall ensure that materials are provided as noted on the data sheets, the purchase order, and agreed BOM, including conformance to any NACE/ISO requirements.

The inspector shall ensure that all carbon and low-alloy-steel pressure-containing components for low-temperature service, including nozzles, flanges, and weldments, are impact tested in accordance with the requirements of Section VIII, Division 1, Sections UCS-65 through 68 of the ASME *BPVC* or equivalent standard. High-alloy steels shall be tested in accordance with Section VIII, Division l, Section UHA-51 of the ASME *BPVC* or equivalent standard.

All repairs that are not covered by ASTM specifications shall be subject to the purchaser's review. Purchaser order may require approval of any repairs.

Materials of construction, inspections, and repairs should be in accordance with API 617. API 617 requires the supplier to obtain purchaser approval for any major repairs of pressure-containing parts, and identifies three criteria for what defines a major repair. In addition, purchaser documents may define additional requirements for other types of repairs.

18.3.1 Component Inspection

The source inspector should be able to identify major components and understand requirements for their inspections as listed in the ITP.

18.3.2 Axial Compressor Drivers and Gears

Compressors are driven by electric motors, gas or steam turbines, or diesel engines. When the speed of the compressor is different than the speed of the driver, a gear is used for synchronization. In most cases, compressors and drivers are installed on the same baseplate. Some compressors may have drivers installed on a separate baseplate or a soleplate. A data sheet is provided for that driver or gear according to an applicable standard. Gears are generally purchased to conform to either API 677 for general-purpose gear units or API 613 for special-purpose gear units.

18.3.3 Couplings and Guards

Requirements for couplings and guards can be found in the applicable API rotating equipment standard or purchase order. There may be two guard locations required: one at the coupling and another between the bearing housing and seal gland. The compressor data sheets include information such as coupling service factor, applicable standard, (e.g. if the coupling has to comply with API 671 or not), vendor, model, size, and balancing requirements. Special attention should be paid to the requirements for coupling installation options, such as tapered shaft or hydraulic fit design.

18.3.4 Baseplates, Mounting Plates, and Sole Plates

Compressors and their drivers and gears are typically installed on fabricated or cast baseplates. The applicable API standard specifies requirements for baseplate design and requirements. Job-specific requirements for baseplate design options and inspection are listed on the compressor data sheet or purchase order. Baseplates may be with or without grout, have special anchor options, or have special paint requirements. Inspection of baseplates involves visual inspection of all welds to make sure that welds are continuous and of good quality, dimensional inspection, bolt hole/anchor bolt location, and machined pedestal flatness check per approved inspection plan.

18.4 Testing of Axial/Centrifugal Compressors

Testing of axial and centrifugal compressors should be noted in the purchase order and may consist of the following tests:

— performance test;

— mechanical run test, including vibration data collection, sound level test, and oil temperature monitoring;

— impeller overspeed test;

— control panel factory acceptance test (FAT);

— coupling fit test;

— gas leakage test;

— after-test disassembly inspection;

— unbalanced rotor response verification test (per API 617).

18.4.1 Performance Test

The purpose of the performance test is to verify guaranteed points of the compressor. See API 617 for a detailed description of a performance test. The test should meet ASME PTC 10-1997, *Performance Test Code on Compressors and Exhausters*, requirements. The supplier will usually use a substitute gas during the test. The test data with the substitute gas is extrapolated to show performance with the process gas. The vendor provides a comparison table between design condition and test condition at the guarantee point. The following quantiles are subject to performance test verification:

— quantity of gas delivered;

— pressure rise produced;

— head;

— shaft power required;

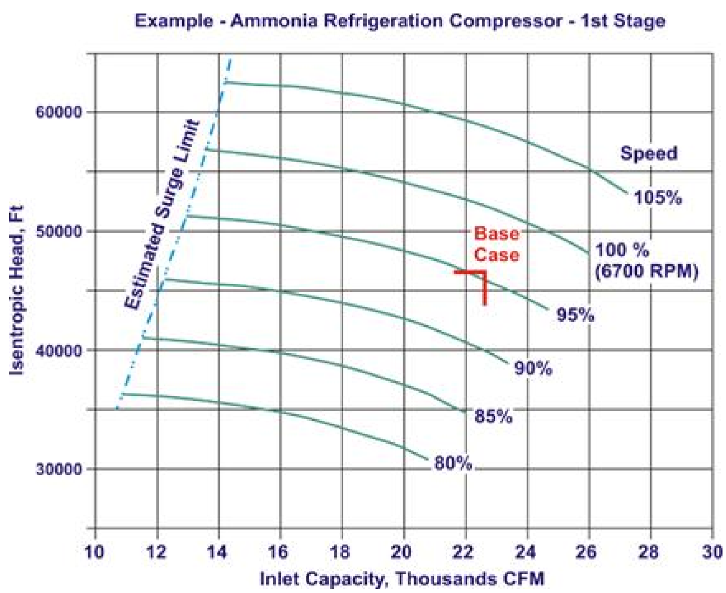
— efficiency;

— surge point;

— choke point.

Below is a sample performance curve of the centrifugal compressor. One of the most important results of the performance test is confirming the surge point(s) at operating speed or at the different compressor speeds for variable speed compressors.

Compressor performance data shall be compared to acceptance criteria during and after the test. Results shall not vary from ASME PTC 10-1997, Table 3.1 for Type 1 test, and Table 3.2 for Type 1 and Type 2 tests.



18.4.2 Mechanical Run Test

During the mechanical run test, the mechanical operation of all equipment being tested and the operation of the test instrumentation shall be satisfactory.

Below are normal testing parameters. The ITP will have specific testing requirements.

— Seal flow data shall be taken during the compressor mechanical run test.

— Lube oil inlet pressures and temperatures shall be varied through the range specified in the compressor operating manual.

— At the beginning of the test, the compressor is operated at slow speed (less than 1000 rpm) to check any abnormal conditions.

— Then, the compressor will be operated at speed increments of approximately 10 %, from zero to the maximum continuous speed, and run at the maximum continuous speed until the bearing and oil temperatures and shaft vibrations have stabilized.

— The speed will be increased to the trip speed and the compressor will be run for a minimum of 15 minutes, when the operating data,(including vibration data) will be measured and recorded every 5 minutes.

— The compressor will be operated at the maximum continuous speed for 4 hours. Data will be collected according to the contract.

18.4.3 Impeller Overspeed Test

Overspeed test requirements are described in API 617. Each impeller shall be subjected to an overspeed test at not less than 115 % of MCS for a minimum duration of 1 minute. Impeller dimensions identified by the manufacturer as critical (such as bore, eye seal, and outside diameter) shall be measured before and after each overspeed test.

18.4.4 Control Panel Factory Acceptance Test (FAT)

API 617 compressors may be supplied with control panels that house instruments such as PLC, HMI, power units, and I/O terminals. Control panels shall undergo FAT where logic and operation of all system components are verified. Input/output signals are simulated to achieve system response. Depending on contract requirements, the control panel may or may not be used during the compressor performance and mechanical run test. Part of FAT will include a wiring and panel layout check. All tagging should match supplied documentation.

18.4.5 Coupling Fit Test

After the running tests, hydraulically mounted couplings shall be inspected by comparing hub/shaft match marks to ensure that the coupling hub has not moved on the shaft during the tests.

18.4.6 Gas Leakage Test

The assembled compressor (including end seals) shall be pressurized with an inert gas to the maximum sealing pressure or the maximum seal design pressure, as agreed by the purchaser and supplier. Agreed pressure will be held for a minimum of 30 minutes, and be subjected to a soap bubble test or alternate method to check for gas leaks.

18.4.7 Unbalanced Rotor Response Verification Test per API 617

If specified or when the first critical speed is less than 127 % of maximum continuous speed (N_{mc}), an unbalanced rotor response test shall be performed as part of the mechanical run test. The purpose of the test is to verify the analytical model. See API 617 for specific information on unbalanced rotor response. Generally, results shall be as follows:

— The actual critical speeds shall be within ±5 % of the predicted critical speeds by analysis.

— The actual peak amplitude shall not exceed the predicted values.

18.4.8 After-test Disassembly Inspection

After completion of the mechanical run test, the compressor (including the bearings and seals) will be disassembled, inspected, and reassembled. The gas test shall be performed after the post-test inspection.

18.5 Final Inspection and Preparation for Shipment

All vendor documents are typically submitted according to the VDDR, and reviewed and approved by the purchaser.

The purpose of the final inspection is to verify:

— that dimensions are as shown on the compressor GA;

— compliance with standards;

— instrument and connection tagging;

— piping compliance to P&ID;

— proper piping support;

— electrical and instrumentation wiring is installed per the approved drawings;

— junction/terminal boxes are correctly mounted per the approved drawings.

18.5.1 Dimensional and Visual Inspection

Following is the list of documents that are typically required for final dimensional and visual inspection and actions required based on these documents:

— data sheets;

— compressor train general arrangement (GA);

— process and instrument diagram (P&ID);

— electrical and instrumentation wiring diagrams;

— auxiliary equipment GA, P&ID, and BOM (seal reservoir, LOS, seal, driver, junction boxes, gearbox);

— packing list.

During visual inspection, the following areas of concern should be addressed:

— The piping assembly should be accessible for maintenance, disassembly, and gasket replacement.

— Valve handles should have enough space for safe open-close action by an operator according to OSHA requirements to prevent hand jamming and injury.

— All equipment should be mounted using secured methods, so they are not shaky.

— Workmanship of installation, welding, and wiring should be without visible defects and within industry standards.

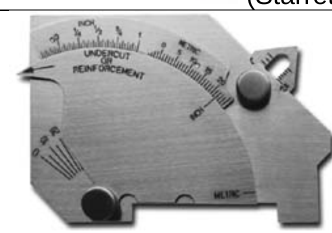
— There should be no overhung equipment or piping extending beyond the perimeter of the baseplate, except those shown on the approved general arrangement.

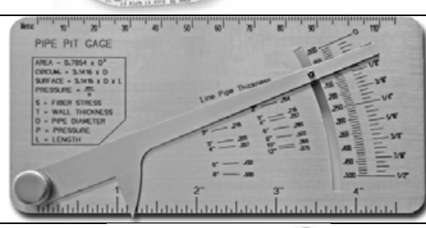
— Painting and paint thickness should be inspected and verified.

— Quantity, condition, and packing for items shipped loose should be inspected and verified.

Annex A

Photos of Various Types of Tools for Use by the Source Inspector

Equipment	Picture	Typical Usage
Flashlights (Krypton)	 (public domain)	Supplemental light source for visual inspection.
Tape measures (5 ft)	 (Starrett)	Dimensional inspection
Bridge cam gauges	 (public domain)	Multipurpose welding inspection gauge

Equipment	Picture	Typical Usage
Hi LO gauges		Measures internal alignment for components to be welded.
Radiograph viewer 4 in. x 17 in.	 (public domain)	Light source for reviewing radiographic film
Radiograph film densitometer		Tool designed to measure the degree or density of darkness of radiographic film.
Digital caliper		Instrument used to measure distance between opposite sides of an object. Typically used for close tolerance dimensions on machined parts.
OD micrometer		Instrument used to measure outside diameters/dimensions. Typically used for close tolerance dimensions on machined parts.
Pit gauge		Measures the depth of weld undercut or other surface discontinuities.
Inspection mirror		Tool designed to support visual inspection in limited and/or obscured areas.

Equipment	Picture	Typical Usage
Temperature indicator		Used for reading temperatures by changing from solid to liquid at a specific temperature.
Laser thermal gun		Tool for measuring surface temperature.
Clamp-on amp meter		Tool designed to measure electric current in amperage and voltage. May be used for checking welding machine settings.
Digital surface profile gauge		Tool designed to measure the surface roughness for a material that is about to be coated.
Surface profile replica tape		Tool designed to replicate surface profile and measure surface roughness.
Wet gauge		Tool for measuring uncured thickness of coating.
Camera		Tool for photgraphic recordkeeping.

Equipment	Picture	Typical Usage
Magnifying glass		Tool for enhanced visual inspection.
Positive material identification tool		Tool designed to verify or measure chemical content.
Ferrite meter		Tool to measure the ferrite (iron phase) content in stainless steels.
Portable Brinell tester		Tool for measuring surface hardness.
Vibration meter		Tool designed to measure mechanical oscillations.
Borescope		Designed for remote visual inspection.

Equipment	Picture	Typical Usage
Liquid penetrant kit		NDT technique for finding discontinuities open to the surface.
Ultrasonic thickness meter		Tool commonly used for measuring metal thickness.
Vacuum box		Tool for measuring leakage in welded components.
Ultrasonic flaw detection		Volumetric NDT method for finding weld flaws.
Inside micrometer set		Used for measuring inside diameters.

Equipment	Picture	Typical Usage
Depth micrometer		Used for measuring depth.
Precision gauge blocks		Used for callibration of precision measurement equipment.
Bore gauge		Measures inside diameter of components.
Magnetic particle testing		Tool designed to detect surface and near-surface discontinuities in ferrous materials.
Level		Device used to determine if something is horizontally level and/or vertically plumb.

Equipment	Picture	Typical Usage
Machinists' Level with ground and graduated vial		Device used for precision verification of level of machines and components.
Coordinate measuring machine (CMM)		Device for measuring the physical geometrical characteristics of an object. This machine may be manually controlled by an operator or controlled by a computer. Measurements are defined by a probe attached to the third moving axis of the machine. Probes may be mechanical, optical, laser, or white light, among others. A machine that takes readings in six degrees of freedom and displays these readings in mathematical form is known as a CMM.
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