STANDARD

FOR

PERIODICAL INSPECTION

OF

MACHINERIES

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APPENDICES:

1. SCOPE

This Standard covers general requirements and guidance for periodical inspection of machineries during operation and idle time, to prepare preventive maintenance schedual for machineries.

A preventive maintenance schedual is given in Appendix A for centrifugal and reciprocating machines.

In addition to this Standard the manufacturer’s maintenance procedure shall also be taken into considered in each individual case and the more stringent one shall be followed.

2. REASONS FOR INSPECTION

Basically the reasons for inspection are to determine the physical condition of the pump, compressor, or driver, and the rate, type, and cause of deterioration.

With this data, safety and efficient and continuous operation are enhanced and better predictions of service life can be made.

2.1 Safety

2.1.1 External leakage

Leakage from the equipment that handles flammable and toxic products can be very serious. Common sources of leakage in the equipment are:

1) Cracks or holes in the casing
2) Failure of small piping attached for the purpose of draining, warm-up, venting, and so forth
3) Thread corrosion on threaded pipe connections
4) Inadequate thread engagement at threaded connections
5) Shaft sleeves
6) Poor gasketing
7) Packing or seals

2.1.2 Internal leakage

Any hydrocarbon lubricating oil entering a compressor handling high-pressure air or any gas that contains oxygen can cause an internal explosion. Oil may leak into the compressor because of:

1) Oil from the bearing housing that may leak into the gas stream
2) The use of a closed return loop from the discharge to the intake
3) Housing vent piping with bends that can cause oil-mist carry-over to form pockets of oil

2.2 Efficient and Continuous Operation

Excessive wear of labyrinth and wearing rings of centrifugal compressors and pumps results in high leakage between stages as is usually indicated when rated capacity cannot be obtained.

Seal leakage on all equipment handling flammable or toxic material is a common reason for equipment outage. Seal leakage may also cause difficulty with steam turbines inasmuch as the steam that leaks past the seal frequently condenses in the bearing chambers and contaminates the lubricating oil.

Improper, inadequate, or excess lubrication may cause trouble with all types of equipment including electric motors. Contamination of lubricating oil by process gas in centrifugal compressors handling gas that contains hydrogen sulfide and other contaminants has been responsible for considerable downtime of some equipment.

Dilution of lubricants with process hydrocarbons may affect lubricity. Failure of such parts as worm gear drives for oil pumps on high-speed compressor pressure lubrication systems is also a cause for equipment shutdown. inadequate filtration of lubricating oil will considerably shorten the life of bearings and seals.

2.3 Condition of Case, Heads, and other Pressure Pats

Inspection is also necessary to determine that the pump, compressor or turbine cases, heads, and other pressure parts are in good condition.

3. CAUSES OF DETERIORATION

3.1 Mechanical Wear

Mechanical wear is the predominant reason for deterioration of pumping and compression equipment and their drivers especially on reciprocation-type equipment. Wear is the usual reason for replacement of cylinders, piston rings, pistons, valves, bearings, labyrinths, wearing rings, mechanical seals, piston rods, pump shaft sleeves, and other parts. With proper lubrication most parts are so designed that long life may be obtained before metal loss dictates retirement.

Such parts as labyrinths in centrifugal compressors wear from the combined effects by small solid particles entrained in the air or gas and from contact with the shaft and impellers. The degree of contact is controlled by bearing wear and vibration of the rotating element. Wearing rings on pumps are subject to wear as a result of contact between the impeller and the case wearing rings. Most mechanical seal installations require some lubrication and cooling, which is often done with the process fluid. Service life is adversely affected when these facilities are not provided.

Engine valve wear results from the frequent striking together of two metal face s, and the life of the parts is affected by the area of contact and the hardness of the metals. Compressor valve life is adversely affected by moisture or solids in the gas being handled.

3.2 Erosion and Corrosion

Erosion and corrosion are also responsible for an appreciable amount of the deterioration experienced on this equipment especially in pumps. Severe erosion occurs because of the large amount of solids in the oil. Damage from erosion for a given material increases with the velocity (pump speed), the loading (weight of solids per unit volume of liquid), and the corrosiveness of the liquid. There are several types of erosive and corrosive attack that should be detected by the inspector. Not all types of corrosion result in a loss in metal thickness.

An example is hydrogen blistering where the metal loss on the case as a result of corrosion is usually negligible; however, a great deal of internal cracking and fissuring is often found.

Uniform metal loss or pitting attack may result from corrosives in the process stream (either from chemicals that are being transferred or from leaking water that is being used of cooling or steam generation). Another from of corrosion mentioned previously occurs in the lubrication system of centrifugal compressors having bearing housings integral to the casing and handling a sour gas: that is, a gas containing appreciable quantities of hydrogen sulfide. If a seal gas system is not installed or becomes inoperative, the lubricating oil absorbs the hydrogen sulfide or other corrosive contaminant which in turn corrodes the system. The corrosion products appear in suspension in the oil turning it a dark blue color. Sulfide corrosion of the babbitted bearing surface will form a hard build-up that may eventually cause bearing failure if it is not removed.

3.3 Improper Operation

The term improper operation includes such items as excess speed, lack of lubricant, excess temperature or pressure, and operating without pumping medium. Any of these abnormal conditions may result in deterioration. Operating personnel must be responsible for maintaining normal operating conditions. Operation of a centrifugal compressor under surge or of any high-speed equipment at or near its critical shaft (whirling) speed will cause vibration and resultant damage to bearings, among other things. A centrifugal or axial compressor may be damaged if operated beyond its pumping limits or run with the suction valve closed.

3.4 Piping Stresses

Centrifugal pumps, compressors, and steam turbines are designed with the expectation that they will not be subjected to loads from poorly fitted piping. Heavy piping loads cause excessive stress on the machine and may distort the case (thus causing wear or seizure) and may loosen anchor bolts on all equipment. Pipe loading will also cause coupling misalignment between driver and driven equipment with resultant short coupling and/or bearing life of both driver and driven equipment.

3.5 Cavitation

Cavitation is a form of erosion associated with the formation and collapse of vapor cavities in a liquid at the metal-liquid interface. Pump impellers are most frequently affected by cavitation. Cavitation results in a decrease in pump head, capacity, and efficiency, and causes vibration and noise.

3.6 Foundation Deterioration

Damage to the foundation, baseplate, and anchor bolts may occur as a result of vibration, weathering, settling, or chemical attack. Reciprocating machines may undergo foundation deterioration under the action of unbalanced reciprocating forces during normal service particularly when oil is allowed to accumulate on the grout. Anchor bolt failure very often results when the bond between the machine and the grout fails.

3.7 Abnormal Conditions

Abnormal conditions can cause serious damage, even complete failure, to a machine. Overspeed may cause excessive vibration as a result of an unbalanced condition that exists in the rotating element; in rotating machines it can cause the rotating element of fail. In reciprocating machine overspeed results in excessive vibration. Low oil pressure or high oil temperature may result in bearing failures causing excessive vibration.

The vibration resulting from these conditions can result in failure of other parts of the machine or even complete failure of the machine. Various devices are used to warn or protect against abnormal conditions. These consist of the following alarm or trip devices: overspeed, low oil pressure, high jacket-water temperature, high gas discharge, high oil temperature, high level on knockout drums, overload relays, vibration monitors, bearing load cells, and temperature indicators imbedded in bearings.

4. FREQUENCY OF INSPECTION

The time for inspection will usually be governed by availability of the machine, the manpower, and the repair parts. Inspection frequency should be established consistent with availability. At the same time unsafe conditions should be avoided and continuity of service should be maintained.

The frequency can be established after consideration of past service experience, corrosion rate, retirement thickness, tests and observations, fluid handled, and anticipated service demands. Regular intervals between inspections are desirable and should be scheduled.

The minimum interval between inspections may be limited by the regular offstream period of the process unit in which machine serves. If a spare is available, operation of the unit is not necessarily a factor. Seasonal temperature change is another possible variant. Actual periods cannot be given here inasmuch as they are dependent on factors known only to those directly concerned with the equipment.

Because a general inspection of such large machinery as a gas-engine-driven compressor is expensive and requires substantial time, labor, and material, considerable care should be taken in arriving at a sound schedule. Unless safety is involved, the selection of inspection intervals is often guided by an economic analysis of each individual situation.

Inspection is an essential part of preventive maintenance whether performed by operators, maintenance, or equipment inspectors. This joint responsibility permits more frequent inspection for mechanical faults.

Offstream time for internal examination, measurement for metal loss, and replacement of parts is necessary and requires specialized activity as well as coordinated action among the groups.

Safety devices on such machines as engines, compressors, and turbines should be tested at regular intervals. These safety devices can prevent major damage to a machine and they must be in good condition to function properly. Equipment that is not actuated at frequent intervals may not work when needed. For this reason the testing and recalibrating of machinery safety devices on a definite schedule and at frequent intervals is necessary for safe, efficient operation.

5. PRELIMINARY WORK AND TOOLS

5.1 Preparation for Inspection

Before inspecting such mechanical equipment as pumps, blowers, and the like, a study or review of the construction of the machine is important so that a thorough understanding of the function of each part may be gained. Machinery inspection may be divided into two categories: that which detects faults causing maloperation and that which reveals deterioration of materials of construction.

There can be an overlapping of the two and both are often accomplished simultaneously. Part of the work may be done while the machine is in operation; some may be done while the machine is idle but not completely dismantled. A thorough inspection requires complete dismantling and cleaning. External insulation may require removal.

5.2 Tools

Prior to the inspection the tools needed should be checked for availability and proper working condition.

This includes those tools and equipment needed for the safety of personnel.

Tools listed in Table 5.1 should be available for most inspections, those in Table 5.2 should be obtainable if the need for their use arises.

TABLE 5.1 - TOOLS GENERALLY REQUIRED

Calipers	Magnifying glass
Gages of various kinds	Machinist level
Dial indicator	Roughness compactor pencil
Straight edge	Bearing clearance gage
Rule	Note book
Chalk line	Sample cans
Scale	Scraper
Micrometers various	Mirror
Ranges	Flashlight

TABLE 5.2 - TOOLS AVAILABLE IF NECESSARY

Vibration indicator and vibration analyzer
Magnetic-particle inspection equipment
Temperature measurement-pyrometer
Penetrant-dye inspection equipment
Nondestructive thickness-measuring Equipment
Engine indicator and/or analyzer

6. INSPECTION OF MACHINERIES

6.1 External Inspection while in Operation

During operation, routine visual examination of the following will indicate their general condition:

1) Foundation
2) Baseplate
3) Anchor bolts
4) Cover-plate bolts
5) Piping and valves
6) Insulation
7) Safety equipment
8) Accessory equipment (lubrication, temperature, and other)
9) Pressures and temperatures of both process and lube oil

Centrifugal machinery is rarely subject to foundation failures in normal service; however, deterioration is often caused by product leakage. Visual examination will reveal product leakage.

All rotating machinery has some inherent level of vibration that is both normal and acceptable. This level of vibration will normally remain nearly constant for about 90 percent of the equipment's useful life; then the vibration level will increase rapidly over the last 10 percent, indicating that repair is necessary.

Vibration can be caused by many things: unbalance, misalignment, dissymmetry, thermals, rubs, loose parts, foundations, and oil whirl bearings. Therefore periodic examination of the vibration level should be made using electronic analysis of the machine vibration. Vibration levels can be checked by displacement, velocity, or acceleration meters.

A velocity meter will provide the easiest and most reliable method of checking a machine for vibration levels. Readings must be recorded from the initial startup of equipment and then periodic rechecks must be made to note if and when changes occur. Velocity readings will provide a basis for establishing vibration standards for all rotating equipment regardless of operating speed, construction, or surrounding conditions. The recorded history of the velocity changes then can be used to plan the shutdown and repair of the machine.

A vibration analysis is used to determine what is causing the vibration by recording amplitude (micron), frequency (cycles per minute), and phase (ϕ) over a period of time and comparing the readings with the past history of the machine or similar equipment.

Large, high speed, and/or critical equipment will have vibration monitors installed to indicate the vibration levels with alarms or shutdown indicators or both. These monitors can be connected to recorders and analyzing devices.

Regardless of the vibration level any sudden increase in vibration should be investigated as it will indicate a potential machine failure.

Vibration can be caused by many things; therefore, periodic examination for it should be made by feel or preferably by a vibration amplitude meter calibrated in micron. The readings of the vibration amplitude meter should be compared with past experience with the particular machine involved and with appropriate IPS Standard. Regardless of the level of vibration encountered any sudden increase in vibration is cause for alarm.

Inspection of all assembly bolts, gaskets, and cover plates may reveal bad bolts, leaking gaskets, or cracked plates or casings. Inasmuch as case cracks will generally require the shutdown of the machine involved, the cause of the crack which is hard to determine) should be sought by looking for piping strains, casting flaws, stress points, and the like. Cast casings are subject to the usual faults of castings: that is, inclusions, porosity, gas pockets, unfused chaplets, and so on. In corrosive service even alloy castings with these defects will deteriorate and may become perforated.

Flange leaks may indicate piping strains, faulty gaskets, or faulty flange faces. Weld leaks may indicate cracks, pinholes, or thin pipe. Thread leaks may reveal unsuspected cracks in threaded piping. Normally the operability of drains is not checked during operation; however, special cases may require such attention.

Leaking drains may be plugged off during operation. Leaks may indicate a need for pipe or valve replacement. Hangers and supports should be checked for control of piping movement and vibration.

The condition of the insulation and waterproofing can be determined by visual inspection. Insulation may be damaged mechanically or may crack, fall off, or become soaked with oil. If any of these problems occurs, heat conservation requirements and the danger of personnel being burned must be considered before an appropriate plan of action can be established. Paint is generally used to improve appearances and to prevent external corrosion; susceptibility to corrosion and the degree of emphasis on appearance will dictate the type and extent of the painting required.

All safety guards should be checked for secure support and for deterioration of the wire mesh if mesh is used. where possible, safety devices should be operated periodically to insure proper operation; this must be done in conjunction with the operating personnel.

While the operating conditions are not normally under the control of the inspector, he should be able to detect abnormal operation. The efficiency of most machines decreases with the operating time and the minimum allowable efficiency varies for the same machine in different services. Usually the operators complain that the machine will not carry the load. The machine may be tested to determine its efficiency. How ever, this is usually not practicable; and if the operators are sure there are no operational troubles (such as line blockage, starved suction, improper valving, clogged strainers, and the like) the machine should be opened for inspection.

Unusual noise, excessive temperature, or increased vibration usually indicate impending failure; therefore, immediate action should be taken to remove the machine from service.

6.2 Detailed Inspection when Machine Is Idle

6.2.1 Centrifugal pumps

Any detailed inspection of a centrifugal pump will require that the pump be disassembled. Mechanical components should be checked for wear, clearance, deformation, corrosion, erosion, and any other changes detrimental to safe operation.

Disassembly should be accomplished according to the manufacturer's recommendation and individual plant practice.

Good hydraulic performance is dependent on wearing-ring clearances. These clearances should be checked by measuring mating rings with micrometers and taking the difference between the readings. A large increase in this clearance is usually the reason for a loss in efficiency. The clearance used between these parts is dependent on the material used for the rings, the pumping temperature, the nature of the liquid being pumped, and the size of the pump. There are tests that can determine the point at which to replace the wearing rings.

The design of the rings (step, labyrinth, straight, and so forth) will affect the allowable clearance. Manufacturer's recommendations, IPS Standard, and judgment based on past experience should be used to determine the exact amount of allowable clearance.

Unless impeller destruction or excessive vibration is encountered, cavitation as evidenced by noise is generally not harmful. Cavitation is less pronounced in pumps handling liquids other than water and consequently does not often have harmful effects in process pumps. If the cavitation is severe, metal loss from cavitation occurs in localized areas of the impeller vanes or enlarged balancing ports causing a loss in efficiency.

Unpredictable vibration may be encountered in a centrifugal pump that has been repaired. If the impeller is statically balanced, excessive vibration is less likely during operation. Vibration limits (whether for the bearing housing or the shaft) should be established before checking a repaired or new pump. The vibration can be measured by a vibration indicator that is obtainable commercially. Dynamic balancing may be necessary for mating shaft surface and coupling bore should be inspected to assure that surface do not have score or galled marks.

The pump-casing wall thickness should be measured. The case of the pump may be considered as a pressure vessel and inspected from that standpoint. Refer to Section 7 for recommendation of retiring limit. Thickness measurements of the case can be made with calipers or by drilling. The case is not often drilled because the hole must be either welded or plugged. The flanges should be inspected for cracks and the gasket seats checked for satisfactory finish. Localized areas of erosion or corrosion in steel-case pumps can be built up by welding. It should be noted that extensive welding on pump cases may cause warpage which will require complete reboring and remachining of the case. Standard measurements should be obtained and drawings should be obtained or made for remachining the case before welding is started.

After reassembling the pump use a dial indicator to check the axial and angular alignment between the pump and driver. Mark the coupling halves and place a piece of rubber between them at the center to hold them apart. Always rotate the halves together. Mount the indicator on one coupling half. To check axial (or rim) alignment set the indicator pin directly on the rim of the other coupling half. To check angular alignment mount a small post on the other coupling half, normal to the shaft centerline, and set the indicator pin against this post. Slowly rotate couplings and take readings at the top, bottom and both sides. Axial alignment should be within 767 micron (0.003 inch) and angular alignment within 25.4 micron (0.001 inch), depending on size.

If necessary, a straight edge can be used across the halves and a thickness gage between the faces. Align the pump and driver with the piping loose; then tighten the piping and watch for signs of strain. Alignment should be checked in the heated (that is, as-operated) condition if possible. This is especially true of turbine-driven pumps. Alignment should conform to the manufacturer's specifications for the particular coupling.

Pressure tests at appropriate pressure in conjunction with the piping system are usually made with water. When steam is used, care should be taken so that the flexible seal parts are not damaged from excessive heat. The possibility of the pressure medium carrying scale or dirt into the seal area should also be considered. Leaks in the case or at flanges may thus be revealed.

The hydraulic performance of centrifugal pumps can be checked. It is necessary to know the capacity at the pumping temperature, discharge pressure, suction pressure, pump speed, and the specific gravity of the liquid high-speed multi-stage, close-clearance pumps.

The critical parts of a mechanical seal are the rotating and stationary faces. It is good practice to check all new and used seal faces for flatness before assembly. If flatness is not within one light band, they should be lapped. If they have suffered considerable material loss, cracking, or heat checking, they should be replaced. The flexible seal parts (O-rings, bellows; U-cups, wedge rings, and so forth) made of rubber, teflon, or other elastomers should be replaced if they show signs of cracking, pitting, or hardening. The metal collars, rings, drive bands, springs, and setscrews are not ordinarily subject to wear but should be replaced if they exhibit considerable pitting, deformation, or other forms of damage. The seal manufacturer's catalogue and drawings should be referred to when reassembling the seal.

Conventional packing is usually replaced without inspection. The shaft sleeve should be inspected at each repacking.

The shaft should be visually inspected for corrosion, wear pots, and worn threads and keyways. All areas that mate with one another should be measured with a micrometer and checked against the original size. The shaft should be checked for straightens in a lathe or straightening machine and held to 76 micron (0.003-inch) maximum runout. Shaft sleeves should be checked for wear and corrosion. Manufacturers' recommendations and past experience will determine replacement time.

Ball bearings do not wear in the ordinary sense of the word. It is difficult to tell how much life is left in a ball bearing that has been in service. If the bearings feel rough when turned in the hand, they should be replaced. A bearing that has little internal looseness, turns freely, and has no sign of metal fatigue on the raceways or ball may be used again.

Sleeve bearings are subject to wear, pulling of babbitt, cracks, and loosening of babbitt in the shell. Repairs consist of melting the old babbitt from the bearing shell and repouring the bearing. It is then necessary to bore the bearing to proper size. Some bearings have replaceable liners. The clearances to be used between bearing and journal can be obtained from the manufacturers; past experience also dictates bearing clearances.

The general mechanical condition can be noted while the pump is disassembled. All bolts should be inspected for cracks, corrosion, worn threads, and deformation.

Worn shaft keys should be replaced. Couplings should be inspected for faulty bolts, worn gear teeth, corrosion, cracks, or deterioration of the resilient spacer. The fit of the coupling on the shaft should be checked by measuring the shaft diameter and the coupling bore. The hydraulic performance can be calculated from these data. By means of the manufacturer's test performance curve the current operating condition of the pump can be compared with the original factory condition. One of the inherent features of a centrifugal pump is the fact that it can easily be restored to its original efficiency.

6.2.2 Reciprocating pumps

For purposes of discussion reciprocating pumps may be divided into two groups: those that are direct-acting and those driven by motors or turbines through a crankshaft.

The direct-acting pumps have few bearings and these are confined to the valve control linkage. Breakage of valves, leakage of piston rings, packing leakage, and wear of the cylinder liners constitute the major items requiring inspection. In general, the clearance between parts of direct-acting pumps is not as critical as in centrifugal pumps.

The liquid end of the pump can be calipered to determine wall thickness. Cylinder liners can be calipered to determine loss of metal through wear. Piston rings can be placed in the cylinder and the gap measured to determine wear. Out-of-round liners can also be detected by measurement. The steam or driving end seldom requires inspection for thickness unless corrosive steam conditions prevail.

Liquid end valves should be inspected for broken discs, springs, stems, and follower plates. Seats should be checked for wear, scoring, and breakage. Measurements of metal thickness at valve seats and valve cap openings will reveal metal loss and permit predicting replacement.

Piston rods should be measured for wear and visually inspected for scoring, worn threads, and deformation.

Valve linkage should be checked for wear at connections to crosshead, arm, and valve stem. These bushings are subjected to normal wear. Unallowable wear can be detected generally by feel.

Pumps driven by geared crankshafts should be checked for alignment of the shafts. This is done by accurately measuring the distance between shaft centerlines. Measure at two places to certify parallelism of the shafts. The drive mechanism should be inspected for worn gears, belts, and pylleys.

Reciprocating pumps of the direct-acting type may be checked for efficiency of operation by the slip test. If the pump is shut down, the discharge valve closed, and the steam valve opened slowly, the piston will not move or will move very slowly. Leaking suction valves or leaking piston rings will allow the piston to move more rapidly, indicating excessive slip. Extreme care must be exercised in conducting this test because failure may occur from excess pressure. It should not be attempted without a gage on the discharge of the pump. The discharge gage should be watched and the pressure should not be allowed to go above the pump rated pressure.

If the suction valves do not leak but the piston rings do, it is possible to obtain a hydraulic cylinder effect because of the entrance of the piston rod into the pump case. Under these conditions rupture of the case is possible. Pressure tests on the case may be conducted simultaneously with the slip test.

6.2.3 Rotary pumps

Gear, lobe, screw, and similar types of positive-displacement pumps are not suited for corrosive service because they depend on very close clearances for sustained, efficient operation. Also a liquid relatively free from foreignparticle contamination is necessary for the practical success of this type of pump.

Caliper the pump case to determine wall thickness. The gears, lobes, or screws should also be measured with micrometers to determine wear. Measure the cylinder bore with micrometers to determine wear and concentricity. Because of the variety of types of rotary pumps it is difficult to cover all of the points of inspection. In general, gears should be checked for end clearance as well as clearance on the outside diameter. End clearance should be set according to the manufacturer's recommendation. Width of the vanes should be measured to determine if the vanes will be suitable for another run. Screws should be measured on the outside diameter to determine clearance in the body. This clearance should be kept to the manufacturer's specification or as low as possible without jamming the pump.

Check the safety-valve sitting. Rotary pumps should always be provided with a safety or relief valve on the discharge line of the pump inasmuch as they positive-displacement pumps. If the discharge line is closed while the pump is in operation, bursting pressures may be reached immediately or, at the very least, the pump driver will stall. Inspect the bearings and seal mechanism as described in Clause 6.2.1.

6.2.4 Centrifugal compressors

For the general inspection of a centrifugal compressor or blower the case is opened and the rotating element is removed. With bearings removed, jacking the shaft and measuring the movement with dial indicator gives labyrinth clearances' range without opening the case. The case and internals should be checked for cracks or corrosion. The shaft and impeller labyrinths are measured with micrometers for wear. The maximum clearance should be obtained from the manufacturer. The diaphragms or diffusers are checked for possible restrictions as a result of deposits of foreign material.

The inlet guide vanes to each stage are checked for incipient cracking of the vanes or metal loss and for free operation. The journals and bearings are measured with a micrometer to determine wear and to check the clearance. The bearings should be replaced or rebabbitted if the clearance is in excess of the manufacturer's recommendation. The rotor position should be checked before it is removed from the case and the thrust-bearing clearance checked at the same time. The thrust-bearing clearance may be checked by moving the rotor as far as it will go and using a dial indicator on the end of the shaft. The impellers and vanes should be inspected for dirt and wear especially at the rivets or welds, depending on construction. The shaft seal should be checked for wear of the sealing elements or for other defects. Ordinarily shaft seals should be replaced at each overhaul. If the oil pump is shaft-driven, it should be inspected in accordance with the rotary pump section and its worm gear drive should be measured carefully for wear.

All main, auxiliary, and emergency pumps, blowers, and so forth should be inspected. All control equipment, such as regulators and gages, should be inspected and repaired and calibrated as necessary. The oil coolers should be cleaned and tested. The oil should be replaced. Oil strainers or filters should be checked and replaced with new elements, if needed.

One of the most important observations to be made is for excessive vibration. See also IPS-M-PM-170 for guidance relative to acceptable vibration levels. If the compressor was vibrating excessively prior to shutdown, the cause may be one of the following:

1) Rotor out of balance
2) Excessive piping (flange) loading on equipment
3) Excessive bearing clearances
4) Coupling misalignment
5) Settling or lack of rigidity of foundation
6) Improper operation (surge, critical speeds, temperature)
7) Oil whip

If the vibration is higher than desired, the rotor should be rebalanced dynamically in a suitable machine. Balancing in the case is not easily accomplished because of the many complications. The electronic balancing equipment available will do a good job but will not pinpoint the imbalance as accurately as balancing machines; therefore, there is more chance for errors and delays in doing the job. Windage from the rotor is so great that the casing cover would have to be installed and removed during and after each run.

If the rotor is to be rebalanced or repaired, it is usually to the user's advantage to obtain the advice of the manufacturer of the equipment who has the facilities and experience to carry out such work.

Considerable care must be taken in aligning the coupling on high-speed equipment. Allowance must be made for vertical expansion of the case: and therefore a hot alignment check is made after operating the compressor for several hours at near normal temperature and loads, if possible. Coupling should be checked to see if it has match marks and is assembled accordingly. High speed couplings must be balanced and match marked for correct assembly.

Data, such as recommended clearances and fits, should be obtained from the manufacturer when the machine is purchased so that inspection will not be delayed for lack of information.

6.2.5 Reciprocating compressors

The general inspection of a reciprocating compressor depends upon the type and can be quite complicated. Among other things, both the amount of wear that has been experienced on the cylinder, piston, and piston rod and also the condition of the valves should be determined. Valve seats should be inspected and, if necessary, they should be resurfaced.

Some valves may be checked for leakage by filling the cavity with kerosine. Valve gaskets should be replaced with the proper material for the service. When reinstalling valves the suction and discharge valves should not be interchanged.

Measure cylinder, piston, and rod for wear with micrometers and check for straightens and concentricity. Wear is checked by measuring with a thickness gage the clearance around the rod where the rod goes through the stuffing box.

A dial indicator mounted on the frame and resting on the top of the rod next to the stuffing box may also be used. Bar the machine through one complete revolution and note any variation on the indicator. A variation of more than 127 micron (0.005 inch) is excessive and should be corrected. When wear has progressed so that excessive misalignment of the rod is encountered or excessive piston-cylinder clearance occurs, the cylinder is normally bored oversize and the piston built up or an oversize piston is installed. Building up may be done by metalizing or brazing bronze rings in grooves in the piston. Alternately the cylinder may be relined.

Excessive piston-rod wear may be corrected by building up the worn section by chromium plating or metalizing but the rod should usually be replaced. Packing rings should be replaced if a new rod is installed or if they are scored or broken. The threads on the piston rod at the crosshead end should be checked for wear or possible cracks by using magnetic-particle or penetrant-dye inspection methods. When the piston rod is replaced in the crosshead, the length of the rod and the torque applied in tightening the piston-rod nut and jam nut should correspond to the recommendation of the manufacturer. If the machine is regrouted or the cylinder supports otherwise changed, a careful check for piston-rod alignment should be made over the length of the stroke using a dial indicator as explained previously.

If the crosshead is not removed, measure the clearance between the top shoe and the frame with thickness gages 245 micron (0.010 inch) to 381 micron (0.015 inch) is generally normal. Check the manufacturer's recommendation. If the crosshead is removed, measure the crosshead shoes and guides in the frame with micrometers. Many types of crossheads are in service. Some crossheads are shima-djusted, other are wedge-adjusted, and eccentric-bolt-adjusted.

Inspect the force-feed lubricator in accordance with the manufacturer's manual. After reinstallation disconnect the oil line at individual users and check the flow with the hand crank.

Check cylinder and jacket walls for scale, rust, pitting, and the like. Excessive scale should be removed by acid washing. A check of corrosion losses should be made after cleaning.

The flywheel should be carefully inspected for cracks. If should first be thoroughly cleaned to remove all dirt, greases, or other deposits. After cleaning it should be inspected visually for cracks using a magnifying glass if necessary. Particular attention should be given to the periphery of the wheel and the junction of the spokes with the rim and hub and keyway.

All doubtful areas and all areas where the condition of the surface makes the detection of cracks difficult should be inspected by either the magnetic-particle or the penetrant-dye method. Cracked flywheels should be replaced. No attempt should be made to repair the crack because any repair may cause an unbalanced condition that will cause excessively high stresses and possible failure of the wheel unless complete rebalancing is accomplished. Wheel clamp bolts should be inspected.

Following inspection the performance of the compressor cylinders may be checked using an engine indicator that denotes whether the valves and piston rings are operating properly. If no repairs to the cylinder are necessary, the cylinder dimensions should be recorded for future reference. The retiring or maximum oversize to which an unlined cylinder may be bore should be obtained from the manufacturer. Replacement of the liner is common practice on badly worn, lined cylinders.

6.2.6 Rotary compressors

Inspection of the lobe and other types of rotary compressors should be performed along lines similar to that previously stated for centrifugal equipment. Wear on sliding vanes, lobes, or other types of rotating devices should be checked carefully. Repairs should be made in accordance with the manufacturer's recommendations.

Loss of metal resulting from corrosion or other causes may be determined by suitable measurements of the component parts in question. Bearings and seals should be checked according to recommendations given in Cause 6.2.4. Timing gears are used in many rotary compressors. These should be carefully inspected for tooth wear and proper fit on the shaft. Improper or worn timing gears will permit the lobes to contact and wear.

6.2.7 Steam turbines

The general inspection of a steam turbine should include opening the case and removing the rotating element much the same as with a centrifugal compressor (see Clause 6.2.4). The diaphragms should be checked for incipient cracking of the vanes. Magnetic-particle or penetrant-dye methods may be used. The blading shroud band and rivets or welds should be checked for erosion, cracks, looseness, deformation, or other signs of failure. Measurement of nozzel openings is difficult and requires special measuring tools recommended by the manufacturer.

The carbon seals should be checked for cleanliness, cracks, and flow paths, and for excessive clearance on the shaft. Carbon seal clearance can be checked by assembling the seals on the shaft and measuring the clearance with the shaft by means of a thickness gage. Follow the manufacturer's recommendations for clearance. Seal housings and seal faces should be carefully checked and inspected for pits and scoring. If necessary, they should be resurfaced. The bearings and journals should be checked as previously stated for the centrifugal compressor. If blade replacements or other repairs are made to the rotor, it should be balanced dynamically before being reinstalled. (See comments on balancing centrifugal compressor rotors in Clause 6.2.4). The overspeed trip setting should be checked .

The governor mechanism should be thoroughly checked and all mechanical parts should be disassembled and cleaned. Measure all parts with micrometers and inspect all wear surfaces and knife edges on the weights. Carefully inspect all springs for corrosion, wear, and loss of tension. Disassemble the governor valve and inspect the valve and seat for wear, wire drawing and erosion. Measure the valve stem and replace it if it is worn more than a few thousandths of an inch. Repack the valve when assembling.

The trip-throttle valve and mechanism should be disassembled, cleaned, and inspected in the same manner as the governor valve. The steam strainer should be checked, cleaned, and always reinstalled. All safety devices and control equipment should be inspected and repaired, if necessary; this includes the regulator for the auxiliary oil pump turbine driver.

Oil should be changed unless inspected and found to be in good condition, and the oil coolers should be cleaned and tested; new oil strainers should be installed if inspection indicates such action is necessary.

6.2.8 Engines (internal combustion)

A complete inspection of an engine (steam, gas, gasoline, or diesel) is extremely complex and requires knowledge of bearing and cylinder clearance and other data too detailed to mention herein. It suffices to say that inspection should be undertaken only after adequate preparation and reference. Because of the complexity of an internal-combustion engine (especially the large rotating type) the items to be inspected will vary with the length of time the machine has been in service.

Most manufacturers have inspection schedules set up that are a good starting point and should be varied to suit the individual conditions. The manufacturer's maintenance manual provides most of the necessary information for the accomplishment of the required work. Corrosion investigation follows methods similar to those already mentioned.

In addition to an inspection of cylinder bearings and fuel valves,the starting air check valves should be inspected. All safety devices should be tested and placed in good working order. Oil coolers should be cleaned, inspected, and tested. Oil filters should be checked and replaced if inspection indicates such action is necessary. Governors should be disassembled, cleaned , and checked for proper operation. All ignition wiring should be inspected and replaced as necessary.

7. LIMITS OF DETERIORATION

The retiring thickness of centrifugal pump cases may be calculated or provided on the manufacturer's specification sheet. Knowledge of the corrosion rate and the minimum thickness makes it possible to estimate when to retire or repair the case. Such an estimate for other fluid-handling machinery is more difficult to develop. Inasmuch as each presents its won unique problem, it can be handled best on an individual basis. In many cases (for these corrosion problems and most mechanical problems) whether to repair now or wait until later depends upon past experience and recent test data. This resolves itself into an economic analysis of the cost of repair versus the cost of production trouble.

8. RECORDS AND REPORTS

8.1 Records

It is helpful to keep a continuous record of inspection data, vibration, repairs and the associated cost. This record can be used to determine high-maintenance-cost machinery. A record of the repairs and the materials used in repairs permits evaluation of new materials and repair methods. Tabulation of case thickness measurements and observations during inspection provide data for determining corrosion rates, permitting new cases to be ordered in advance of expected case retirement or to be repaired when economically feasible. When ordering spares for main and auxiliary equipment it is usually essential that the equipment serial number and model number be specified. This will help the manufacturer rapidly identify the component, thereby improving delivery time.

8.2 Reports

Reports should be made to provide all concerned with adequate information on machinery condition, need for repairs or replacements, recommended materials, causes of failures, rates of metal loss, and service life.

APPENDICES

APPENDIX A
RECOMMENDED PREVENTIVE MAINTENANCE SCHEDUAL

A.1 Centrifugal Machines

There is no single established approach to an effective maintenance program for every centrifugal equipment installation. The importance of tailoring the maintenance program objectives to each unique equipment installation has already been emphasized. The following preventive maintenance schedule is not intended as a complete guide, but only to suggest how to devise a plan for the particular installation in question. The items selected and the schedule itself must be tailored to the installation and carried out with common sense and good judgment.

A.1.1 Daily maintenance

1) Check the lubricating oil and seal oil reservoirs for possible water accumulation by draining a small sample from the reservoir low-point drains.

2) Check the lubricating and seal system oil filters for excessive pressure differential.

3) Verify that the oil levels in seals and lubricating oil reservoirs are within a safe operating range.

4) Check the operation of all process cooler and separator traps and seal system sour oil traps by observing the liquid levels in sight glasses or blowing off trap bypass valves to drain funnels.

5) Review all supervisory and process instruments such as those indicating oil pressures and temperatures, vibration, process pressures, and temperatures to ascertain that no unexplained deviations have occurred.

6) Listen for noise level and pitch changes around equipment gears, and drivers.

7) Inspect visually for oil, gas, liquid or water leaks and loose parts.

8) Check the differential pressures across intake gas filters, intercoolers, aftercoolers, and interstage separators for excessive differential that could signal plugging or other deterioration.

9) Observe the level in the seal oil drain sight flows and the bearing oil drain sight flows for abnormal level changes and check regularly to establish that the connections have not become clogged.

A.1.2 Weekly maintenance

Verify the calibration and operation of all protective alarm and trip devices through actual test. Test lockout arrangements should be provided on each device to allow safe test with the compressor on stream.

A.1.3 Monthly maintenance

1) Make a vibration survey of each bearing housing, including shaft readings where possible. The data at each location should include unfiltered or total wave and rotational or filtered wave at rotating frequency components. If these two values do not agree, a thorough investigation, including a frequency search, should be made to determine the cause.

Any significant increase in vibration should be noted and corrected at the earliest possible moment to prevent permanent bearing or equipment damage.

(to be continued)

APPENDIX A (continued)

2) Test the performance of all intercoolers, aftercoolers, and oil coolers to evaluate their efficiency. The rate of deterioration will determine the cleaning schedule.

3) Lubricate the linkage, pins, and slide bars of all control valves and valve positioners or guide vane positioners.

4) Obtain oil samples from lubricating and seal oil reservoirs for analysis by the laboratory.

A.1.4 Major maintenance shutdown

1. Coupling inspections

a) Gear type

1) Dismantle, and remove all grease, taking note of condition of the grease. If significant separation has occurred, the lubricant supplier should be consulted for further grease recommendation. The coupling grease should always be checked within the first month of initial operation of a new unit to verify that the lubricant has not separated or otherwise deteriorated. This practice should be followed until a lubricant is selected. The amount of sludge build-up in continuous oil-lubricated couplings may indicate the need for better or additional oil filtration at the coupling spray nozzel. Check the spray nozzel pattern on reassembly.

2) Clean all hubs and sleeves thoroughly and inspect gear teeth for abnormal wear and broken or cracked teeth. The hub and sleeve teeth and hub keyway should be given a thorough magnetic particle or dye check inspection for evidence of cracks.

3) Repack and replace the proper type and mount of grease using new gaskets or orings, where applicable. Follow the coupling supplier's recommended bolt torque values and bolt tightening sequence.

b) Nonlubricated type

1) Inspect the flexible hinge member for cracked or damaged disks in the disk pack or diaphragm.

2) Inspect coupling hubs and spacers at all high stress points for cracks using the magnetic particle or dye check method.

2. Verify the alignment of all couplings

a) The cold offset alignment should be verified by actual thermal growth measurements at operating conditions. This procedure should be repeated whenever the process conditions are changed significantly. The cold offset may require changes due to foundation settling or shifting.

b) The ambient temperature and the location of the dial indicator driver or driven shaft must be recorded on all alignment records for future reference.

c) A 305-mm diameter face plate temporarily bolted to each coupling hub will assist greatly in improving angular alignment accuracy on small-diameter, high-speed couplings.

(to be continued)

APPENDIX A (continued)

3. Clean and inspect all journal bearings

a) Remove and inspect each bearing for signs of babbitt damage.

b) Measure and record the bearing-to-shaft clearance following the manufacturer's recommended procedure. Replace any bearings found to have clearances exceeding the manufacturer's specifications.

c) Inspect the shoe-to-retainer contact point on all pivoted pad bearings for signs of fretting or excessive wear that could hamper the shoe pivot freedom.

d) Thermocouple or RTD detector lead wires embedded in shoes must be installed to allow complete freedom of shoe movement.

e) Inspect bearing seal rings, if used. Garter springs or other retainer springs should be replaced if weakened by worn spots.

4. Clean and inspect each thrust bearing assembly

Note:

Record an axial set-back measurement to locate the rotating element in the casing before disturbing the thrust bearing. Check the manufacturer's drawing for reference dimensions. Always keep forward and rear thrust assemblies and related shims separated. These assemblies must not be interchanged.

a) Inspect shoes for signs of loose or damaged babbitt.

b) Inspect hardened contact buttons on self-aligning bearing shoe backs and leveling plates for flat spots or fretting. Slight wear spots should be removed by light stoning to restore the button crown or leveling plate curvatures.

c) Check the thrust collar radial and face runout if a removable collar is used. Carefully follow the manufacturer's instructions for reassembly of the thrust collar if it is removed.

d) Readjust the thrust bearing clearance to the proper value.

Note:

Forward and rear thrust shims must be adjusted together to keep the rotating element axial position in its correct relationship with the casing.

5. Inspect all oil baffles for signs of rub, plugged drain-back holes, or chipped touch points. Reinstall with specified radial and axial clearances.

6. Remove the casing cover for an internal inspection if performance level or maintenance schedule dictates this step:

a) Properly clean and inspect all impellers or blading for erosion or corrosion. All highly stressed parts should be given a magnetic particle inspection or dye checked for cracks. Casing diffusers or stator blading should be cleaned and inspected to meet the same requirements as the rotating speed.

(to be continued)

APPENDIX A (continued)

b) Interstage seals should be replaced if damaged or eroded to such an extent as to allow clearances to exceed specified values.

c) Rotating elements should be checked for balance if increase in vibration has been noted. The cause of any such lack of balance should be investigate, such as loss of a nut or accumulation of sludge.

7. Lubrication and seal systems

a) Drain and clean each system reservoir. Use squeegees or synthetic sponges for internal cleaning. No rags of any type should be used, since lint may get into the lubricating and seal systems.

b) Centrifuge the oil before returning it to the reservoir or replace it with new oil. Replacement oil should be carefully strained to keep foreign material that may be present in the oil drums out of the system.

c) Clean or replace lubricating and seal oil supply filters.

d) Remove tube bundles from oil coolers and thoroughly clean the water and oil sides. Test tube bundle of the cooler hydrostatically to its rated pressure before reassembling the cooler.

e) Inspect all system controls and regulating valves for foreign material, sticking pistons or valve stems, and so on.

f) Inspect the lubricating and seal oil pumps for abnormal wear at pump element bearings, shaft seals, and couplings.

8. Process check valves

a) Remove and inspect each valve for wear at hinge pins, disk guide pins, disk return springs, and seals. All worn parts should be replaced.

9. Process expansion joints

a) Inspect the internal bellows surface for pitting and erosion that could lead to failure. If lined, inspect the liner.

b) Adjust pipe support hangers, if required, to position the expansion joint properly in its cold position.

10. Speed increasers

a) Inspect pinion and gear bearings for damage or wear and proper clearance. Carefully check the bottom of the gear base for metallic particles.

b) Check the gear tooth contact pattern. Check gear teeth for signs of abnormal tooth wear and unequal tooth loading.

c) Gear and pinion teeth should be subjected to thorough inspection by magnetic particle process or dye check.

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APPENDIX A (continued)

d) Clean all mesh spray nozzels and all internal oil supply passages. Make sure that the nozzles are properly secured on reassembly.

e) Inspect all splash pans for possible fatigue cracks or loose fasteners.

11. Instrumentation and protective devices

a) Check the calibration of all instruments used for monitoring operations or for obtaining maintenance data.
b) Check the calibration and functioning of all alarm and trip devices.

12. Main driver

a) Follow the recommended inspection and maintenance procedure, given in 6.2.7, 6.2.8 and manufacturer's instruction manual.

A.2 Reciprocating Machines

The manufacturer's manual should be followed at all times. The inspection and routine maintenance schedule listed next gives the minimum recommended time intervals between inspections. Many of the time intervals can be extended beyond those listed for a particular unit, depending on operating conditions and other related factors.

A.2.1 Daily maintenance instructions

1) Inspect the engine's fuel gas scrubber to see that it is functioning properly.

2) Check the crankcase oil level; it should be at the full mark on the oil level gage. Add oil if necessary.

3) Fill each lubricator compartment with the proper grade of lubricating oil. This should be done each shift or every 8 hours.

4) If appropriate, examine the fuel-injection valves. If solid-type push rods are used, check the tappet clearances periodically. Check the clearance against those recorded after the cylinders were balanced.

5) Check both engine and turbine speed periodically.

6) Check lube oil pressure periodically. See manufacturer's operation data for correct value.

7) Turn the handle on the oil filter two or three complete revolutions every 8 hours if a scraper-type oil filter is supplied.

8) Suction and discharge pressures and temperatures should be checked periodically. The operator should occasionally measure the compressor cylinder valve cover temperature; an increase in this temperature usually indicates a leaky valve.

9) If equipment is multistage, check the suction and discharge pressures and temperatures of all stages as well as the compressor valve cover temperatures occasionally. An increase in these temperatures usually indicates a valve leak.

10) Check the temperature of the lubricating oil entering the cooler. See manufacturer's operation data for correct value.

(to be continued)

APPENDIX A (continued)

11) Check exhaust temperatures periodically. Compare them with temperatures that were previously recorded. Higher exhaust temperature in a cylinder usually indicates carbon deposits in the cylinder parts.

12) Check cooling-water flows and temperatures. See manufacturer's operation data for correct value.

13) Check traps or separators, or both, to be sure that they are functioning.

A.2.2 Monthly maintenance

1) Remove and clean spark plugs if necessary. Check the gap clearance and reset as required.
2) Check out safety shutdown switches and controls to be sure they are functioning correctly.
3) Check compression pressures. Low compression can be caused by sticking piston rings.
4) Inspect and service your particular ignition device as described in the manufacturer's instructions.
5) Check lubricator reduction gears; oil if necessary.
6) On motor-driven units, inspect the brush holders. They move freely; clean if necessary.
7) Change oil and filter in small engines (see manufacturer's recommendations).

A.2.3 Every three months maintenance

1) On large engines, examine air starting valves and air check valves for wear. Check to see that they are operating correctly. In low altitudes where humidity is high and the starting air is likely to be moist, more frequent check is advisable.

2) Inspect the fuel-injection valves and seats. If the valves are leaking due to worn valves or seats, it will be necessary to grind the valves and replace the seats. Correct seating of the valves and properly adjusted tappet clearances are necessary to keep the power cylinders balanced.

3) Clean the turbocharger blower wheel on engines so equipped. The time between cleanings will the different for each installation since the amount of dirt, soot, and oil vapors entering the engine air filter will vary.

A.2.4 Every six months maintenance

1) On large engines, examine the internal drive chains for correct tension. If there is excessive slack in the chains due to wear, adjust the tension as required.

2) Check the ignition device for sings of wear.

3) On large motor-driven compressor units, remove the oil filter cover or housing and clean the filter elements and case.

A.2.5 Every year maintenance

1) Inspect heat exchangers for fouling or leakage, or both.
2) Examine the cylinders as follows:

a) Check piston rings and cylinder bore for excessive wear.
b) Inspect the pressure and oil wiper piston rod packings; clean or replace as required.
c) Check piston rings for wear and damage.
d) Examine the valve seats, discs, springs, and stop plates; replace worn or damaged parts.
e) Examine water jackets for scale and corrosion; clean if necessary.
f) Replace any damaged gaskets.

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APPENDIX A (continued)

3) Check unloaders and unloader controls, if used, for correct operation.

A.2.6 Every three years maintenance

Check all the main bearings and the crankshaft for correct alignment. If bearing clearances are excessive, replace the bearing liners.

A.2.7 Other periodic check-ups

1) Examine the equipment valves. The frequency of inspection depends on the type of equipment service. Keeping the valve seats in good condition is important. Reface the seats when necessary, making sure that the proper lift is maintained. Replace cracked, broken, or warped discs. Check the valve springs against a new one; they must have the same tension.

2) Check the foundation bolts for tightness.

3) Check the gas regulators in the engine's fuel gas line to see that they are maintaining correct gas pressure. The required gas pressure will vary with the Btu value of the gas.

4) Clean the lubricator reservoir with a suitable solvent as requird.

5) Check the accuracy of the equipment gages. If service is severe, a check should be made each week.

6) Examine the air intake filter for excessive dirt and other foreign materials; clean when necessary. Excessive pressure drop across the filter evidence that cleaning is necessary.

7) Drain any condensation from the starting air system. The frequency of draining will depend on the location of the installation.

8) Check the cooling water if it has been treated for use in a closed cooling system. Balance the concentration of treating chemicals as required.