

THE ENGINEERING EQUIPMENT AND MATERIALS USERS ASSOCIATION

Ageing rotating equipment

Guide for maintenance and operation

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ENGINEERING EQUIPMENT AND MATERIALS USERS' ASSOCIATION

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1. Introduction

Rotating mechanical equipment is increasingly being operated for longer periods, and so the question arises about whether it is safe to continue operation. If it is safe then what additional precautions are needed? Is it necessary to replace equipment if it has passed a certain age, or is it advisable to do so? This guide aims to answer these questions from a machinery user's point of view.

All rotating mechanical equipment needs some form of servicing/routine mechanical inspection if failure is to be avoided. This guide is also aimed at highlighting additional inspection work required. 'Condition based maintenance' can be used to monitor machine performance and operation. It is widely and successfully used to ensure that machines are only serviced when they actually need it, rather than on a time based interval, but servicing/inspection is still required. Inspection should identify any ongoing deterioration, and is the default way to identify the progress of all the deterioration modes. However, the scope of the inspection may need to be reviewed after a long time in service to make sure that long term deterioration is found.

In some cases, complete replacement of machinery or part of it is warranted, and this Publication discusses why this may be required. Such a replacement cannot be assumed to be the correct step as there are many examples of equipment successfully operating for over forty years with no particular deterioration present.

2. Scope

The scope of this Publication covers rotating mechanical equipment operated within the petrochemical, process and power industries. The types of equipment covered are those listed in Table 1, which is included within Section 3.4. Specifically covered equipment types include pumps, fans, compressors, generators, motors, gearboxes and certain types of turbine. Such equipment is designed to operate continuously for many years but there are some deterioration mechanisms that start to take place over a longer time frame – at least 5 to 10 years after the equipment is commissioned.

Users may determine that other types of equipment not listed here (or in Table 1) fall under the scope of this guidance. However, it is understood that the application of EEMUA 230 is done at the user's discretion.

The following assumptions have been made in the preparation of this Publication:

- A normal maintenance programme is being carried out;
- The maintenance programme includes inspections, scheduled either by time/running hours or by the condition of the machinery;
- Condition monitoring is being carried out including regular vibration monitoring as a minimum;
- Routine inspection/testing of machine protective systems (such as trips / trip valve operation / relief valves) is being carried out.

As well as additional inspections, replacement of part or the entire machine may be necessary or simply advisable. The guide aims to highlight where a review of upgrade and replacement options may be beneficial.

A large topic that is not covered in this document is the initial design of rotating mechanical equipment, which is assumed to be correct, or to have been dealt with during commissioning or in the first few years of operation.

This Publication does not describe repairs or reclamation necessary as a result of failures in service. Such failures may cause serious damage to the machine and may threaten its continued long term operation. Some topics are included in this guide that are not related to machine failures, e.g. the change in regulatory requirements and the changes in instrumented machine protection.

3. Guidance

3.1 Introduction

This Chapter is set out to firstly describe the various deterioration mechanisms that are relevant for process plant machinery and then the mitigation steps that may be taken for that particular deterioration mechanism. Clearly, some of the deterioration mechanisms will apply to many types of equipment, whereas others only apply to certain types of machine.

In some cases there may be reasons for equipment to be replaced completely and these are listed.

A list of the various types of process plant machinery is then given with a cross reference to the types of deterioration mechanisms that apply (see Table 1).

3.2 Mechanical deterioration mechanisms

From the Pressure Systems Safety Regulations 2000 Approved Code of Practice L122⁽¹⁾ paragraph 110, there are a number of mechanical deterioration mechanisms, which are described in this Section with specific application to rotating equipment. Specific mitigation steps are listed for each deterioration mechanism.

Clearly, a general mitigation is to put in place appropriate inspection to identify problems and allow for rectification.

Note: As routine inspection/repair is assumed to be taking place it is not specifically listed against the deterioration mechanisms described in this section.

3.2.1 External corrosion

External corrosion is typically due to atmospheric oxidation of the metallic components of the machine, and is applicable mostly to carbon steel operating near ambient temperatures (0°C - 80°C) where water can be present. It is made worse where the equipment is insulated as the insulation can trap moisture next to the surface of the casing.

Other factors that can increase the rate of external corrosion are the local atmospheric conditions, including:

- Steam leaks;
- Process leaks of acidic gases or liquids or corrosive materials such as salt/brine;
- Local ambient conditions (temperature, humidity and salt content of the air).

High temperature external corrosion may be an issue if the temperature exceeds 400°C for susceptible materials.

Machine casings are often of a standard design and also are designed for stiffness rather than for the pressure that is being contained. The result of this is that in most cases, the design maximum operating pressure is well above the actual service conditions, so it is unlikely that external corrosion will threaten the reliable operation of equipment.

The areas which are most susceptible to external corrosion and the anticipated effects are:

- Small bore branch connections in carbon steel
 - pin hole leaks;
- Low pressure carbon steel equipment housings (such as fans or ducts)
 - pin hole leaks;
 - potential for large areas of corrosion leading to structural failure
- Structural support steelwork;
 - potential for structural failure/support failure and major equipment damage.

Specific mitigation steps are:

- Correct specification, application and maintenance of protective systems such as paint;
- Avoidance of process/steam leaks;
- Correct specification, installation and maintenance of insulation to avoid water ingress;
- Correct specification, installation and maintenance of pipe supports/structural supports.

3.2.2 Internal corrosion

Internal corrosion requires a corrosive environment to be present inside the machine. For most applications, this requires free water to be present in the presence of acidic species. Where high internal temperatures (greater than 500°C) are present then dry oxidation can take place. In some cases corrosion is affected by the fluid flow to produce metal loss in high flow velocity regions.

Process plant applications do not normally suffer from significant internal corrosion as the materials are selected to avoid deterioration. However, there can be exceptions, which include:

- **Gas turbine inlet internal corrosion** due to water/salty atmosphere/high temperatures;
- Small quantities of **water present in a gas compressor** drying out and then re-condensing. As the liquid re-condenses any acidic species in the gas will become highly concentrated and corrosive.
- Water carry over in an air **compressor/gas compressor intercooler** knock out system causing corrosion of carbon steel components. For an air compressor this can be made worse where the air inlet is in an industrial area such that acidic species can be concentrated in the condensate water.
- Fluid flow disturbing the **protective film on the metal surface** (e.g. oxide layer) resulting in material loss. An example of this is in a boiler feed water pump in high flow velocity regions (e.g. casing outlet nozzle) where gross local metal loss has been seen after 20 years in service.
- **Machine systems shut down** allowing internal condensation and standing water. This also applies to **bearing systems** where atmospheric breathing can cause internal water accumulation and subsequent corrosion.
- **Dissimilar metals corrosion**, e.g. aluminium labyrinth corrosion in a steel casing;
- Under deposit corrosion in a **wet gas centrifugal compressor**;
- **Cooling water pumps** internal corrosion following coating breakdown;

- **Induced draft fan impellers** on fans that do not run continuously have been found with corrosion to the impeller attachment bolting. This threatens impeller integrity due to air leaks at rotor seals causing local dew point corrosion to shafts and impellers. Gross failure of a large fan is likely to be a significant safety concern as the casing is unlikely to contain the failed parts, which will then be ejected from the machine.
- Corrosion in cooling water areas of **reciprocating compressor cylinders**. This is often made worse due to the low cooling water velocities within the cylinder cooling water channels, which leads to silt lay down and then under deposit corrosion.

Machine casings are often of a standard design and are designed for stiffness rather than for the pressure that is being contained. The result of this is that in many cases, the design maximum operating pressure is well above the actual service conditions, so it is unlikely that internal corrosion will threaten the reliable operation of equipment.

Specific mitigation steps are:

- Monitoring internal system pH;
- Preservation steps during periods of extended downtime;
- Repair/maintenance of internal coating;
- Dry instrument air/nitrogen purging of bearing housing systems;
- Use of purge mist lubrication systems for the bearing housing;
- Use of anti-condensation heaters;
- Correct cooling water treatment/chemistry;
- A maintenance regime that cleans out cooling water deposits regularly.

3.2.3 Stress Corrosion Cracking (SCC)

Stress Corrosion Cracking (SCC) can be caused by a number of different agents, such as sulphides, chlorides, nitrates and hydrogen. Correct initial selection of materials of construction should avoid problems with SCC during the life of the equipment. However, external effects can occur later in the life of the equipment, either with chlorides (typically from sea water salt spray or salt water estuary environments), hydrogen (from surface corrosion) or incorrect choice of lubricant, e.g. molybdenum disulphide incompatibility with a particular grade of fastener. High strength components are most susceptible and for machinery the issue is generally with studs and bolts. Machine holding down bolts or casing attachment bolts have both been subject to SCC and failure after many years of service.

Another known cause of SCC is following a machine failure. During a failure, if a rub occurs then an area of much higher hardness can be created through frictional heating and then quenching. This area of higher hardness may not show any other signs of distress but once put back into service the high hardness area can be subject to SCC.

Alternator end bells are highly stressed components and have been known to fail due to SCC.

Where there is a corrosive material being handled inside the machine (such as chlorine), an example has been seen where a split line leak has caused cracking of the split line bolting when an aggressive environment formed around the bolt.

SCC has been seen on steam turbine rotors where there are coincident conditions of a corrosive environment, a high stress level and a susceptible material composition.

Specific SCC mitigation steps are:

- Avoidance of external corrosion of bolting through correct lubrication or coating combined with inspection of static bolting if external corrosion or contamination are present;
- Careful inspection of parts and in the event of a failure checking for high hardness.

3.2.4 Fretting corrosion

Although not listed in the Pressure Systems Safety Regulations (PSSR), fretting corrosion is a problem that occurs on machinery where there is high load and relative movement between mating parts. The relative movement is typically very small (1-10 microns). The damage is caused by the removal of the oxide layer on the surface of the metal and then re-oxidation of the exposed material. Surface welding and tearing can also take place leading to further damage and also a reduction in the fatigue resistance of the part due to the surface damage.

In machine components fretting corrosion is most commonly seen at shaft fits where the interference fit is insufficient to avoid relative movement given the loads that are applied. Fretting corrosion is seen typically as a blackening of the surface and also a loss in surface material once the black deposit is removed.

In reciprocating compressors fretting has been observed between the crankshaft and the flywheel as well as between pressure packing cups within the piston rod packing. Fretting can also often be seen on the back of bearing shells.

In centrifugal compressors fretting can be seen on the back of journal pads and sometimes on shaft fits (such as coupling hubs).

In most cases fretting corrosion is either a cosmetic problem or else requires that the component is repaired by coating to recover the fretted surface back to its original dimension. In some highly loaded applications, fretting can initiate a fatigue crack, which can then cause machine failure, e.g. hyper compressor packing cup failures.

Specific fretting corrosion mitigation steps are:

- Correct pre-loading/fit between parts. If there is sufficient surface contact loading, then no relative movement occurs and fretting corrosion does not happen. This can be a function of both the machine design and correct maintenance;
- Silver plating one of the mating components.

3.2.5 Erosion

Erosion is where particles, droplets or vapour bubbles in the fluid flow remove material from the internal parts of the machine. The erosion can combine with corrosion (see previous Sections) to create an acceleration effect. Erosion is a particular problem with machinery due to the high fluid velocities that are often present. One other form of erosion that can occur in specific conditions is where