ON-STREAM CLEANING OF TURBOMACHINERY

by

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INTRODUCTION

On-stream cleaning is regularly practiced on the axial compressors of gas turbines and on steam turbines. Many other turbo machines could be cleaned in service. In fact, the limiting factor is not the machine type, but the ingenuity of the operator. The purpose of this paper is to explain some of the principles involved in such cleaning.

"On-stream Cleaning" is defined as the periodic removal of accumulated deposits while the equipment continues in service. This definition excludes from the discussion the various techniques of preventing the deposit accumulation. It also excludes those cleaning methods which do not require dismantling, but do require that the machine is either idling or stopped.

The paper discussed the reasons for cleaning, fouling indicators and abrasive and solvent cleaning techniques. Details of turbine washing are used to illustrate the application of solvent cleaning.

WHY CLEAN?

There are at least three reasons for "on-stream" cleaning.

The first is to restore the system capability. If the unit is a driver, it's maximum horsepower will probably drop as it becomes dirty. Cleaning will restore this limit. If the machine is a dynamic compressor, the fouling may have reduced its head, and therefore, the maximum gas flow rate. Cleaning will restore the capacity limit.

The second reason is to increase the machine's efficiency. In most, but not all cases, fouling will increase the fuel or power required to do a certain task. The mechanism is that the deposit changes the flow contours. Removal of the deposits will restore the original profiles and the efficiency.

The third reason for cleaning is to prevent failures due to abnormal operating modes. Fouling on the rotor blades of steam turbines can cause thrust bearing failures. Deposits on steam turbine governor valves and trip and throttle valves are suspected of causing overspeed failures. Fouling in balance piston labyrinths and in balance lines has caused thrust bearing failures in centrifugal machines. Any rotor deposit can cause vibration due to unbalance if it is not laid down uniformly or if it sluffs off non-uniformly. There could be other similar effects which will cause failure of the unit.

FOULING INDICATORS

A prerequisite of a cleaning program is some kind of fouling detection system. Naturally, this system must cover the prime reason for cleaning. If the machine is a gas turbine, then the prime reason may be horsepower capability or it may be efficiency. On the other hand, on a back-pressure steam turbine, the prime reason may be either horsepower capability or thrust bearing protection. On a centrifugal compressor, the prime reason for cleaning may be to restore capacity, to improve efficiency or reduce thrust loading.

The selection of a fouling detection system will be strongly influenced by the safety and complexity of cleaning procedure. For example, the procedure may be to throw 10 pounds of rice into the suction of a gas turbine. Or, it may involve injecting a quart of water into a single-stage, mechanical-drive turbine, with a 30°F superheated inlet. In either case, the risk of damage and the manpower required is so low that no monitoring can be justified. The cleaning should be frequent and routine.

On the other hand, the cleaning may involve removing 300° of superheat from 200,000 pounds/hour of steam entering an eight-stage turbine. This is a much more complex case. If the turbine really is dirty, and is not washed, you may end up with a wreck. Alternatively, to wash, especially the first time, may result in misalignment due to piping stress, water slugging, loss of clearance due to differential contraction, vibration due to non-uniform deposit removal, or thrust bearing failure. This case obviously calls for a reliable indicator.

Fouling indicators which have been used include: (a) Gas turbine exhaust temperature; (b) Steam turbine steam chest pressure (single governor valve); (c) Steam turbine PI pressure (multi-valve); (d) b and c above modified to correct for steam flow; (e) The exponent n-1/n on a compressor or gas turbine where k is either known or is relatively constant; (f) The exponent n-1/n in one section of a machine relative to another section handling the same gas; (g) The pressure ratio in one section of a machine relative to another; (h) Thrust loading or thrust bearing metal temperature; and (i) Balance line to suction differential pressure.

CLEANING TECHNIQUES

There are two basic approaches to cleaning. These are abrasion and solvent cleaning.

Abrasion is the simplest of the two methods, but is usually the least effective. The more common abrasives are nut shells, sized about 1/64" or rice. The abrasive must have sufficient mass to achieve the momentum required to dislodge the dirt. However, high mass particles do not follow the gas stream. Also, they are hit by the leading edge of the moving wheels and blades. Consequently, the trailing edges are not abraded. The closer the dirt is to the point of injection, the less significant the asymmetrical distribution.

The abrasive must also be sufficiently tough to resist breakage on impact. This is a problem with rice, since it shatters readily. Again, the closer the injection to the deposit, the less significant the toughness.

Another problem with abrasives is what happens to them after they have done the cleaning. In a simple cycle gas turbine, they will probably be burnt. However, on a regenerative unit they can deposit in the regenerator. Some regenerator burnouts have been attributed to this. In steam system, they would probably plug up traps throughout the system.

During discussions about abrasive cleaning, the possibility of causing labyrinth damage is always raised. In fact, these apprehensions have proven groundless. We do not know why this is so. It could be that the particles are too big to enter the clearance space. On a centrifugal compressor, a typical radial clearance on the interstage shaft labyrinth is 0.008 inches, as compared with a particle size of 0.060 inches. The eye labyrinth has a much larger clearance, but a particle would have to make an unguided 180° turn to reach it. It is unlikely that it would do so.

How are the abrasives introduced into the machine? With air compressors, the abrasive can be thrown into the open suction. If the suction or point of injection is pressurized, the abrasives can be introduced using a blow pot. An eductor should be used to put the abrasive leaving the blow pot into a fluidized state before introducing it to the main gas stream. A good starting point for the injection rate is 0.1 weight per cent of gas flow.

SOLVENT CLEANING

Solvent cleaning is a much more delicate technique than the brute force of abrasion. In reality, there will almost always be some abrasive action involved. The idea is to dissolve the deposit in a solvent. The solution must then be removed from the system before the solute is re-deposited. Each solvent cleaning application presents different problems.

Water Washing Steam Turbines

The cleaning of water-soluble deposits from steam turbines is a classic example of solvent cleaning and the complex auxiliary considerations. Since the solvent is water, the intent must be to bring water into contact with the deposits. In this case, the working fluid is steam and water will only remain in equilibrium with it if the temperature is at saturation for the pressure at that point. Water must be added not only to provide the solvent, but to cool the fluid to saturation. We would assume sufficient water must be added to make the inlet steam 1% wet. Therefore, the water injection rate could be as high as 25% of the initial steam mass flow. It is the injection of such large quantities of liquid that creates the potential problems.

The potential problems of water washing steam turbines are:

1. Misalignment due to piping stress as the temperature is reduced.

2. Water slugging.

3. Loss of clearance due to differential contraction between rotor and stator.

4. Vibration due to non-uniform deposit removal.

5. Thrust failure due to almost complete plugging of one stage.

6. Damage to blading if it hits water retained in the exhaust casing.

On most machines, the misalignment due to pipe stress will not be significant. After all, we are only disposing of the superheat, whereas during run up, the machine is exposed to a temperature change at least two times as large. However, if piping strains are a problem on startup, one must make sure all sliding supports are free before attempting to wash. We have had no problems other than an increase (doubling) of axial vibration due to misalignment.

We try to avoid water slugging by two measures. We always use a venturi nozzle for desuperheating. Also, we insist that the piping fall continuously between the desuperheater and the machine inlet. Even if the water is not broken up into droplets in the desuperheater, it will pass inoccuously through the turbine as a constant stream.

To prevent loss of clearance, we always limit the rate of temperature change to 180°F per hour. The greatest hazard would be failure of the injection pumps when at maximum injection rate. Such a failure would produce a very high rate of change of temperature and would most likely result in an axial rub. To guard this, we try to use boiler feedwater, since these pumps are the most reliable in the plant.

We attempt to reduce the chances of non-uniform deposit removal by halting the increase of injection rate whenever deposit is actually being removed. This condition is detected by measuring the conductivity of the exhaust condensate.

It is alleged that thrust bearing failures have occurred because of stage plugging when an upstream wheel has sluffed its deposit before a downstream one. If this is so, the halting of injection increases when material is being removed would prevent it.

One of the criterion we use to check a turbine design before purchase is "Can all the condensate be removed from the exhaust?" Some turbine designs are such that the blading is within about 1" of the bottom of the casing. Others don't have a casing drain at the lowest point. Others have a ½ inch or ¾ inch casing drain. All these designs are suspect unless the condensate can drain freely out of the exhaust.

We consider that a stage is washed adequately when the condensate conductivity falls to half its peak level. When this point is reached, the water injection rate is again increased. The wash is considered completed when the inlet steam is saturated and the exhaust conductivity is down to 200 micromhos.

After the wash is completed, the inlet temperature is raised to normal at a maximum rate of change of 180° per hour.

Initiation of the normal steam flow path, bypassing the desuperheater, is the last hazard. We have found that water builds up in the line upstream of the valve, even when the bypass is left open. We now always leave the main valve cracked open to prevent the water buildup.

Over the past 13 years, we have successfully completed about 30 turbine washings. These involved six different machines, located in four plants. Based on this, we conclude that on-load washing is safe provided reasonable care is exercised. We have, however, observed that deposit soluabilities vary considerably between subsequent washes on the same machine. This same variability has been observed on two machines supplied by steam from the same source for the same time period. Some machines can be successfully cleaned without making the inlet saturated but most have required a wet inlet.

During our earliest washes, we believed that condensate was essential as the superheating medium. We reasoned that any other water would leave salts behind during the temperature increasing phase. Five of the machines have now been washed using boiler feed water, without any observable problems or deterioration of the cleaning.

Also during our earliest washes we noted an apparent accelerated fouling rate during the first few days after a wash. We have no reasonable explanation of this phenomenon. It levels out quickly and does not appear to affect either the maximum mass flow or the efficiency. Currently, we merely warn the operators to disregard it if it is observed.

In spite of the above hazards, steam turbine washing is an ideal application of solvent cleaning. If the inlet steam is under 1400 psig, is initially superheated, and the turbine is under load, the exhaust will always be wetter than the inlet. Therefore, wherever the water is injected, the washing will occur first on the downstream blades. Further, as the washing proceeds, the solution passing through parts of the turbine already cleaned is always more dilute than where the deposit is going into solution. There is no chance that dissolved material will be redeposited. The water soluble deposits in these machines are usually highly soluble and washing is rapid. All the deposit removed remains in solution in the condensate and can be removed from the discharge end by draining.

Other Solvent Cleaning Applications

Other machines are not as ideally suited to solvent washing as turbines. In compressors, for example, the tendency is for the solvent to evaporate as it passes through the machine. In addition, the solvency of most solvents is much below that of water for sodium chloride. The problem is to find a solvent that will attack the deposit, and will transport it out of the machine. In addition, the solution must either be withdrawable from the discharge system or must be acceptable in the product. The solvent may be a two-component system if the deposits are at the cold end—a light one to do the actual dissolving and a heavy one to prevent deposition as the former evaporates. When the deposits are at the discharge, a light solvent can be used, provided it is subjected as close as possible to the deposits, in large droplets, and a high rate. These three criteria help to prevent premature solvent evaporation.

We had an example of premature evaporation recently. Dilute caustic soda was inadvertently admitted into a centrifugal compressor. The water evaporated leaving a solid deposit between the second and third wheels. We did not want to use water as the solvent for two reasons. The machine was equipped with aluminum labyrinths and we were afraid the wet caustic would destroy this metal. Further, since the discharge temperature was 300°, it seemed unlikely that enough water could be added to carry the solution out of the discharge. We found that a liquid hydrocarbon with a final boiling point of about 450°F would move the deposit. Using this as a wash, the deposit was moved to between the fifth and sixth wheels. However, even with injection into the stage drain before the fifth wheel, it was not possible to move it out of the discharge. Finally, we gave in, shutdown, and washed "off line" with mildly acidic water.

As with turbine washing, there must be a way of removing the solution from the discharge casing. If the discharge flange points down, this will not present a problem. However, if it points up, and especially if the discharge velocity is low, an adequate sized casing drain is essential.

SUMMARY

Most rotary machines can be cleaned in service. Steam turbines and axial compressors are two examples of machines which are commonly cleaned on the run. Cleaning techniques include abrasion and solvent cleaning. Provided reasonable care is taken to avoid potential problems on line cleaning techniques are safe.