"Electrifying Oil by Over-Filtration in Gas Turbines"

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Observations of the Problem:

A merchant plant, located in Texas consists of a series of combined cycle gas turbines generating a total of 1,000 MW in electrical capacity. The turbine generators cycle operation daily and have been in operation for about 4 years. After two years of service, erratic performance began in the fuel gas valves and IGV (Inlet Guide Vane) positioners. Inspection of the valves indicated a brown tar-like coating – varnish.

Valve problems in gas turbines are serious and costly. Valve problems can cause a unit to trip and are responsible for many unplanned outages and fail-to-start conditions. In response to this situation, many gas turbine OEM's now outfit their control valves with sensitive sensors that provide warnings before a trip occurs. Typically, a warning is activated if the valve is 3% off of response time and a unit trip occurs at 5%. In addition, OEM's have formed Trip Reduction Teams to diagnose unit trips across their fleets. Unit trips are very damaging to the turbine system from a maintenance perspective. Unit trips can be budgeted to cost upwards of \$35,000 just for wear and tear. This does not count the costs associated with not supplying customers with power which can be much higher. Although not all unit trips are caused by varnished valves, this was identified as a key contributor at the plant and solving this problem is of critical importance in order to effectively manage the operation of their production facility.



Figure 1&2: Varnish Coating on Inlet Guide Vane (IGV) Servo Valve

The plant paid special attention to their monthly oil analysis to identify the cause of this problem. The analysis indicated that the fluid was in acceptable condition and gave no clue as to why the varnish was occurring. After discussions with the OEM and oil manufacturer, the plant attempted to address the valve varnish problem by filtration. A ramped up filter inspection and change-out frequency was initiated in the hopes of

solving the valve varnish problems. This had no viable effect on varnish formation or buildup.

Most gas turbine operations use the same oil for four different functions: in the lube circuit, as seal oil to prevent gas from escaping from the generator, as a hydraulic fluid to energize valves and as lift oil during start-ups. Even though oil analysis did not indicate that the oil had reached the end of its life, the plant dumped their lubricant, charged their system with new fluid, changed all of the filters, and rebuilt all of the servos and actuators. Potential hot-spots in the system were also identified and insulated as can be seen in Figure 3. The plant has a 12 micron rated full flow oil filter setup on the lubricating oil system. This lubricating oil system feeds the turbine hydraulic oil system which has an absolute 2 micron rated filter. This 2 micron hydraulic filter was the source of the problem discussed in this paper. After the 2 micron filter, the oil flows through a 15 micron last chance filter and final (pencil) filter before it enters the servo assembly and energizes the IGV valve. Varnish deposits were observed to be forming downstream of the 15 micron "last chance" oil filter and forming deposits large enough to plug the final (pencil) filter inside the servo assemblies.



Figure 3: One potential source of heat from the fuel gas system was eliminated as a potential source of coking in the IGV hydraulic lines by insulating the lines in the proximity of the heated fuel gas lines.

Three months later, a problem developed with IGV servo tracking, prompting the plant to inspect the valve's last chance filter. Large, black, solid pieces, similar to shiny coal, had restricted the filter orifice stopping oil flow. These chunks had developed inside the outside-in flow filter. Needless to say, the original varnish problems in the IGV valve were not fixed, and other serious problems remain.



Fig. 4-5: Plugged IGV Valve Last Chance Filter

After significant research, the plant determined that these filter chunks are the result of spark discharges that occurred inside the filter. The potential energy for these sparks was actually developed upstream of the last chance filter, in the 2-micron filter. The potential energy was stored in the oil until it hit the jagged metal edges of the last chance filter where the energy was released in the form of a spark. This had the effect of cracking the hydrocarbon molecule and coking the oil.

Spark Discharges in Mechanical Filters

Oil and filter media are both dielectric and the friction generated as oil flows through a filter produces static electricity. The static electricity gathers on insulated surfaces and if enough energy is accumulated, a spark is released. The spark that is created can have an extremely high, localized temperature instantly cracking the hydrocarbon molecule. Spark discharges from mechanical filters are an alarmingly common occurrence. Sparks occurring in lubrication systems are a safety hazard and can quickly deteriorate the quality and life of the lubricant. Advances in mechanical filters have made them the tightest clearance zones within most lubricant systems, therefore the most susceptible to generate static electricity.

This phenomenon has been duplicated in a lab with several different kinds of filters. In a lab environment, many scientific tests can be performed that cannot be performed in operating equipment in the field. Following are some of the scientific findings that have been published on spark discharges generated by mechanical filters:

- The temperature of the sparks being generated through mechanical filters can be upwards of 20,000 degrees Celsius.
- Analysis has found H₂ gases, confirming that hydrocarbon molecules crack upon each spark discharge.
- Sparks will produce metallic ions and water.
- Oil consists of 9-12% air, 21% of which is oxygen. Even in a flooded oil environment, there is a still enough oxygen present to release a spark.
- Mechanical filters can produce free radicals leading to auto-oxidation.

- The higher the flow rate and the finer the filter, the more frequent the spark discharges.
- Static electricity will accumulate on any insulating material, such as filters.
- "Grounded" filters produce more sparks than normal filters. The electric charge will not occur on grounded filters, but the potential of the oil becomes higher than compared to normal insulated filters.
- Sparks have a higher potential for being released at sharp edges, compared to other surfaces.
- Even though the potential energy of a spark discharge occurs inside a mechanical filter, it is not always released in the same place.

Detecting Spark Discharges

Most occurrences that happen inside a lubrication system are not visible with the eye, making root cause analysis challenging. Spark discharges are the same. It is extremely difficult to observe sparks actually being discharged. Fortunately, spark discharges can be detected by a couple of other means. When sufficient amounts of static electricity are accumulated on filters to produce a spark inside the filter, the high temperature leaves burn-holes on the filter media. These are often times arranged systematically in rows as is shown in Figure 6. Close inspection of the filter core may also reveal the remnants of oxidized oil, as shown in Figure 7.



Figure 6: Single fingerprints are aligned on the filter core.¹



Figure 7: Flakes of coked oil found on the surface of filter core.¹

Magnification of the filter media will show several burned holes and is an excellent method to detect spark discharging in filters. An example of this is shown in Figure 8.



Figure 8: Magnification of filter media shows burned holes.¹

Another potential way to detect spark discharges is by hearing them. They make a loud "popping" or "cracking" sound. In the case of a gas turbine, many times a loud popping sound can be heard in the lube oil skid beside the full-flow filter as the oil is being pumped out of the reservoir. Sometimes turbine users only observe this phenomenon during start-ups or shut-downs when the oil pump is operating but the oil is below operating temperature. In this case, the increase in viscosity due to the lower temperature will increase the amount of friction, increasing the frequency of spark discharges.

Occasionally, it is possible to see these sparks. This has been observed in a gas turbine reservoir where there is a tank opening beside the lube circuit return line and the oil has been filtered on the way back to the reservoir. In this case, static electricity was developed in the filters and the potential energy stored in the oil until the sharp edge of the return line pipe released the spark.

What about the Original Varnish Problem?

As discussed in detail in this article, the system's mechanical filters were contributing to the IGV valve varnish problem, not helping it. The plant is investigating insulating the 2 micron hydraulic oil filters instead of grounding the filters to lower the amount of potential energy that can be generated. In addition, the plant is using Kleentek electrostatic oil cleaners to solve the varnish problem.

Conclusion

Valve stiction can be responsible for costly unit trips in gas turbines. Valve stiction is caused by oxidation by-products creating a varnish-type coating. A common strategy for fixing this problem is relying on mechanical filters, and sometimes switching to finer filters. When the plant investigated their IGV valve varnish problem, another serious contributing problem was identified. The valve's last chance filter became plugged with coal-like chunks. Investigation revealed that this occurred due to a spark discharge created by the system's 2 micron hydraulic oil filters. Friction generated from the oil passing through the fine filters created static electricity which discharged a spark after accumulating on the filter surface. Published scientific studies have discovered much information on this event, including the temperature of the spark discharge can be as high as 20,000 degree Celsius.

Although spark discharges have been visually observed in the field, it is uncommon. One method of detecting spark discharges are by hearing "popping" or "cracking" sounds close to filters. Another method is by visually examining cut open filters for signs of burned holes.

References:

- 1. Images used with the permission of Dr. A. Sasaki.
- Sasaki, A.; (2000) "Production of Free Radicals and Oil Auto-Oxidation Due to Spark Discharges of Static Electricity"; Proceedings of the 48th National Conference on Fluid Power, NFPA