Application Note

Monitoring strategy – Optimizing LNG gas turbine efficiency by performance monitoring

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ABSTRACT

Gas turbines are some of the most reliable machines, but just a few percentage points drop in performance can result in annual production losses of millions. Many case studies have shown that performance monitoring as an automatic monitoring strategy proves to be an important tool for optimising the production output.

Optimal operation and maintenance

The substantial worldwide market growth in LNG demand is driven by economic and environmental benefits as well as improved production technology. Gas turbines are widely used in the LNG industry as a result of this improved technology, and they boast exceptional reliability in relation to other prime movers. But the performance of these machines is strongly dependent on how well they are serviced. It is not unusual for their performance to drop a few percent points between overhauls, translating into production losses worth millions of dollars.

On-line and off-line (crank) washes are some of the important services for maximising gas turbine output, but there are many different policies in terms of procedures, recipes and scheduling of these washes. The effectiveness of these washes, or any other process-related service or modification of the gas turbines, is best determined by monitoring the performance of these machines. In fact a performance monitoring system that is part of an integrated condition monitoring strategy can do much more to increase overall production of the gas turbines and other process machines. It can also reduce the number of unexpected shutdowns and reduce overall maintenance costs by detecting faults early enough so service can be cost-effectively planned ahead of time.

Performance monitoring system

An integrated vibration and performance monitoring system was selected at an LNG plant that would not only maximise the output of a number of critical machines in the entire plant, but would also reduce the number of unplanned shutdowns. The same system would also reduce by one person the machine specialist manpower needed to safeguard the machines.

During the period of one year of using the system, a number of faults have been detected in a number of machines. However this article focuses on how the performance monitoring function of the system is used for detecting, diagnosing and trending gas turbine compressor fouling and turbine nozzle faults associated with the propane and mixed refrigerant compressor trains in the liquefaction cycle at an LNG plant.

Compressor fouling

The gas turbine compressor blades perform a number of tasks to prepare the incoming air before it is fired and expanded to rotate the power turbine to drive the gas compressor. The efficiency with which this task is performed depends upon the aerodynamic flow of the air over the blades, which is also influenced by the surface condition and profile of the blades. Even though the incoming air is filtered, dirt is still able to bypass and accumulate on the blade surfaces, or even erode them by impacts over time. Both of these effects will reduce the airflow and efficiency of the compressor, thus limiting the power output.

Machine manufacturers report that the efficiency of the gas turbines can be significantly improved by using recommended blade-washing techniques, but a loss of around 2.5 % in efficiency can still be expected between overhaul

intervals. Out of this 2.5% efficiency loss, it is reported that 1.5 % is recoverable by using more optimised washing techniques. This 1.5 % efficiency gain translates into an increase in production, and for many industries the reduced fuel consumption and lower emissions are an additional benefit.

Offline and online compressor wash

The offline wash is the most effective way to clean the gas turbine compressor blades. Unfortunately the machine must be stationary to do this, and this means production downtime.
An online wash, on the other hand, can be carried out without shutting down the machine, but this only cleans the first few compressor stages. Nevertheless this is important, since the first stage deposits not only reduce the efficiency but also the airflow and the compressor discharge pressure. The succeeding compressor stage blade deposits only reduce efficiency (not airflow or discharge pressure) but these stages are more effectively cleaned by offline washing.
The regularity of on-line and off-line washes is strongly dependent on the application and location, and is a trade-off between optimal operating efficiency in relation to downtime. The only way to determine the effectiveness of the compressor blade-washing program is not merely by visual examination using a boroscope, but by monitoring the performance of the machines.

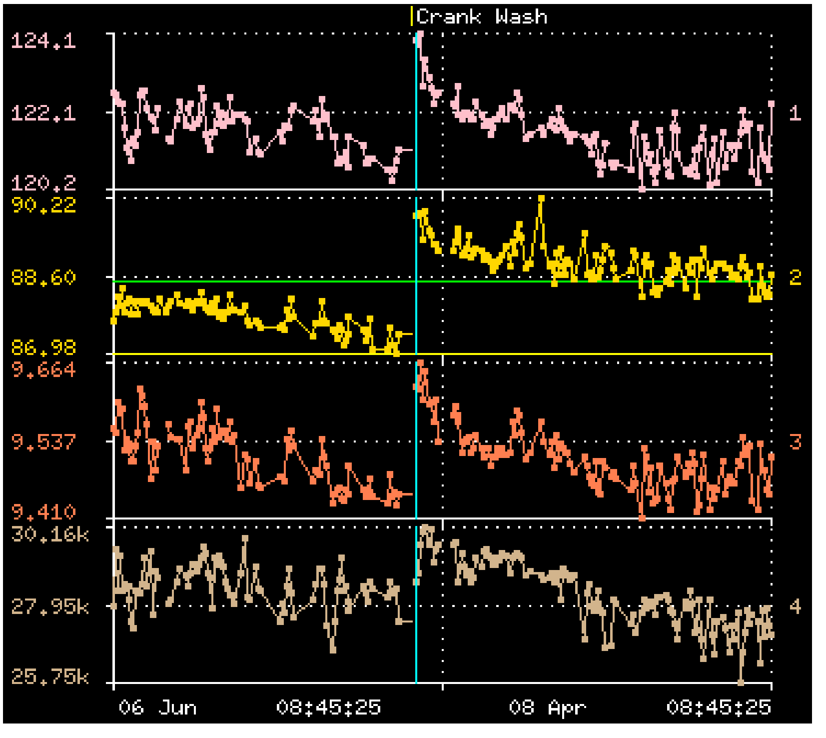

Figure 1. Performance trend for a gas turbine before and after an offline wash: 1. Corrected bell-mouth airflow (kg/s). 2. Isentropic compressor efficiency (%). 3. Corrected compressor discharge pressure (bar) . 4. Corrected power (MW).

Case 1: Offline washing makes a difference
A significant increase in gas turbine performance can be seen in Figure 1, after an off-line wash was performed:

- Increased compressor efficiency by 2.5%
- Increased compressor discharge pressure
- Increased airflow
- Increased power

On-line washes had not been done prior to the off-line wash, and therefore these are the expected results. This is followed by an expected downward trend of these parameters as the compressor blades begin to foul again.

Case 2: Rain showers reduced performance
At one installation it had been very humid for two weeks and this was followed by a period with heavy rain showers. On the day of the rain showers there was a very dramatic decrease in performance in many of the gas turbines. Immediately following the rain showers a newly commissioned gas turbine fully recovered the original compressor efficiency it had prior to the rain showers (not shown in the figures), but other

gas turbine trains gave indications that there was significant compressor blade fouling (reduced efficiency, airflow and discharge pressure).

An on-line wash was then carried out on those gas turbines which had not recovered after the rain showers. The results were disappointing and so several on-line washes were carried out in succession since it was not possible to stop the machines at that time to do an off-line wash. This only resulted in a partial recovery of most of the machines, evident by the diagram in Figure 2 for one of the machines. What had happened?

What went wrong with the efficiency?

As seen in Figure 2, the pressure drop across the inlet air filter started to increase dramatically during the two weeks of high humidity and then returned to a normal level immediately after the rain showers. The following is the sequence of events: The filters started to become saturated with water due to the high humidity. Maximum saturation was reached during the rain showers and the water precipitated into the gas turbine compressor bringing with it all the dirt that had accumulated during the months since the last filter change. The water evaporated during the compression process, leaving most of the dirt attached to the blades during this short time interval, thus lowering the efficiency to an extremely low level. The accumulation of dirt was so drastic that it was not possible to recover the efficiency after subsequent on-line washes for all the machines.

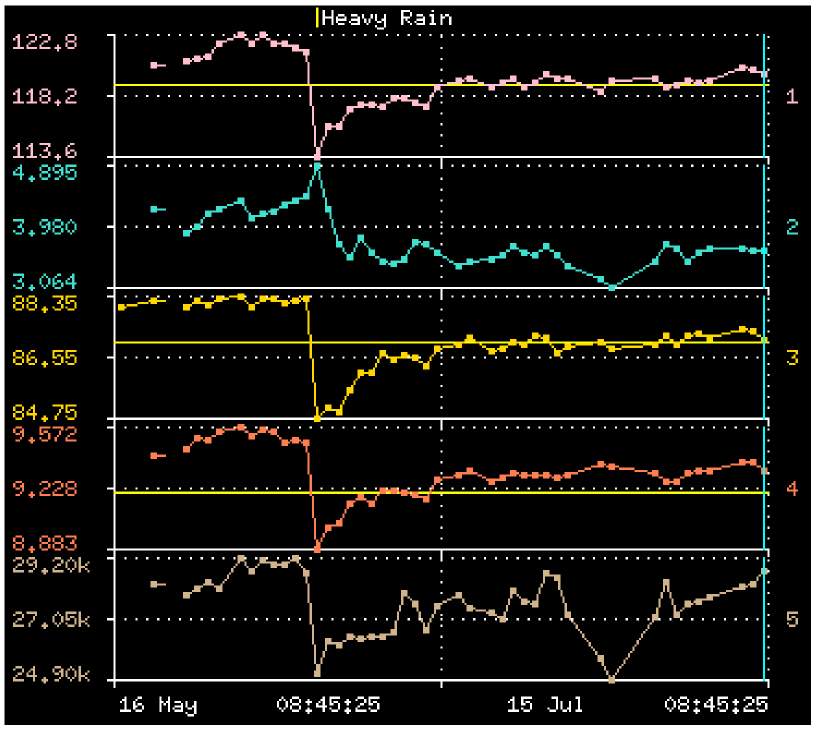

Figure 2. Performance trend for a gas turbine before and after an offline wash.: 1. Corrected bell-mouth airflow (kg/s). 2. Isentropic compressor efficiency (%). 3. Corrected compressor discharge pressure (bar) . 4. Corrected power (MW).

How to avoid this problem happening again

Obviously we can’t control the weather, but there are many things that can be done to minimise the risk that it poses for gas turbine operation. For example, in the case mentioned previously a weather protective enclosure could justify its investment in this and similar applications. But regardless of the type of physical modification done to a gas turbine to preserve or enhance its production capacity or reliability, a means is still needed to determine its effectiveness.

This is done by automatic and continuous performance monitoring and not only for commissioning of machines, establishing baselines or doing analysis/diagnostic work. Many believe that after a washing program has been established (with or without performance monitoring to optimise it), these washes can be scheduled at time-based intervals. Not only is performance monitoring needed for tracking the effectiveness of the

washing program under varying operation conditions, but it is also needed to monitor for unexpected events, such as rain showers, dust storms or other sudden changes that can influence the process.

Once an automatic performance monitoring solution is in place, it is important to monitor the correct parameters. In the example of the rain showers, it is very important to monitor the pressure differential across the inlet filter and its trend at all times. If there is a relatively high pressure-drop in combination with rain, fog or high humidity, there is a danger that the event described above can repeat itself. Change the filters before they become too dirty, perform on-line washes as often as possible during and directly after the event and, if possible, perform an off-line wash after any such event.

Case 3: Compressor efficiency is OK, but what happened to the power?

Two identical gas turbines are used in a low pressure and high pressure propane compression cycle, but the performances for the machines differ a lot. As seen in Figures 3-5, the machines have similar airflow, compressor discharge pressure and compressor efficiency, but GT A is performing slightly better except for its power output (Figure 6). How is this possible? By looking at the turbine isentropic efficiency (Figure 7), GT A is around 5% less than GT B. It was later determined that the second stage nozzle positions on GT A were incorrect, which was most prevalent during

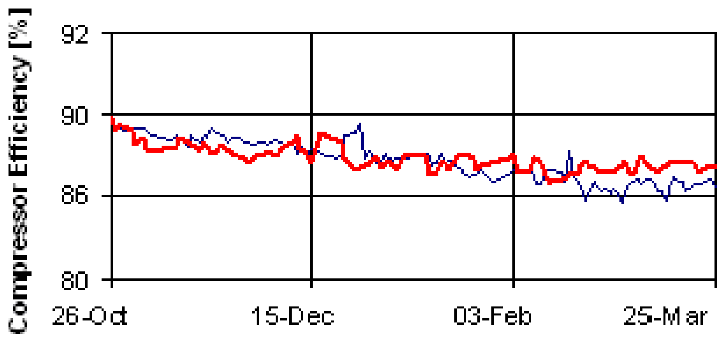

Figure. 3. Isentropic compressor efficiency of GT A (red) and GT B (blue).

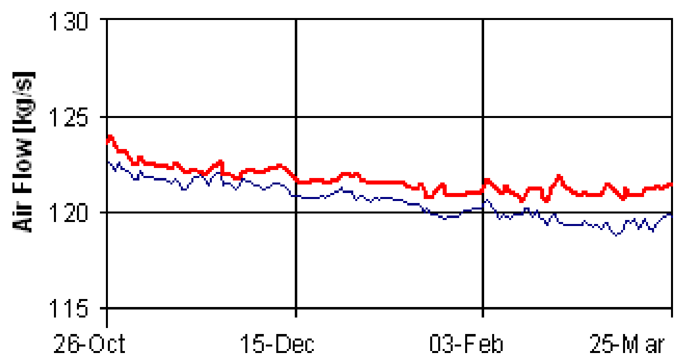

Figure 4. Bell-mouth airflow of GT A (red) and GT B (blue).

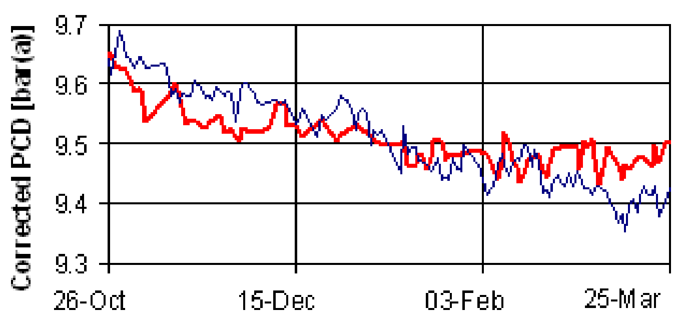

Figure 5. Corrected compressor discharge pressure of GT A (red) and GT B (blue).

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the warm summer months. The lesson to be learned here is to monitor all the appropriate performance parameters, not only the efficiency.

Conclusion

Process industries such as the LNG industry can save $millions in lost production by improving the performance of their machines by only a couple of percent. Compressor washing is one method to improve this, but its effectiveness is dependent on many factors. The most reliable technique to determine this is by accurate performance monitoring of the machines based on a standardized thermodynamic model, where the algorithms and corrections are widely accepted and time proven. The performance monitoring system should not be considered a temporary analysis tool that is used only from time to time, but as an automatic 24 hours/day, seven days a week monitoring strategy, just as in the case of vibration monitoring. Unexpected process changes can and do occur that make time-based solutions impractical. An appropriate machine condition monitoring system solution is needed to do this, and this is not the same system or strategy used for machine control and safety. An accurate thermodynamic model is required together with real gas properties, an extensive database, diagnostic and analysis tools and a versatile alarm strategy.

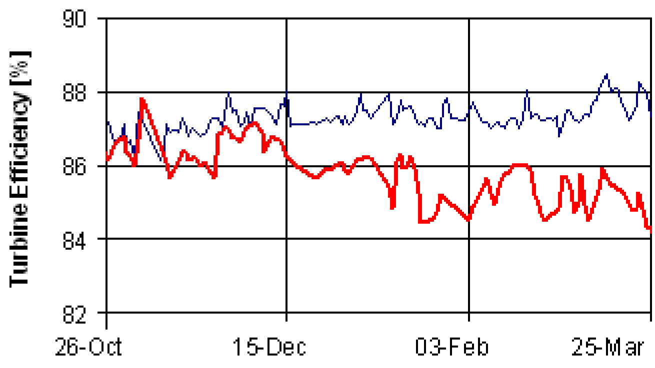

Figure 6. Turbine isentropic efficiency of GT A (red) and GT B (blue).

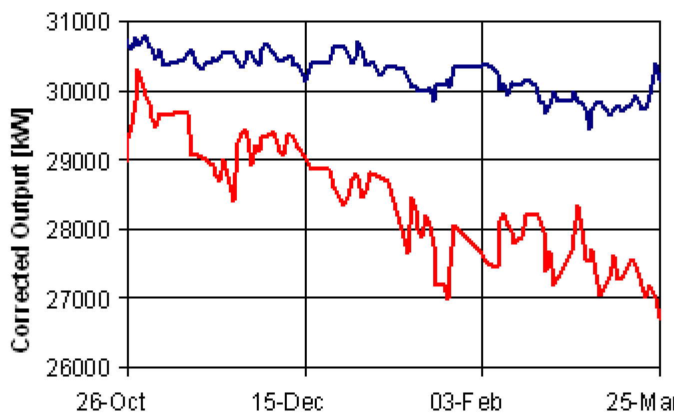

Figure 7. Corrected power of GT A (red) and GT B (blue).

But just as important as the system, a specialist is necessary to assess needs, implement the system and train personnel, since performance monitoring is a very specialised field.

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