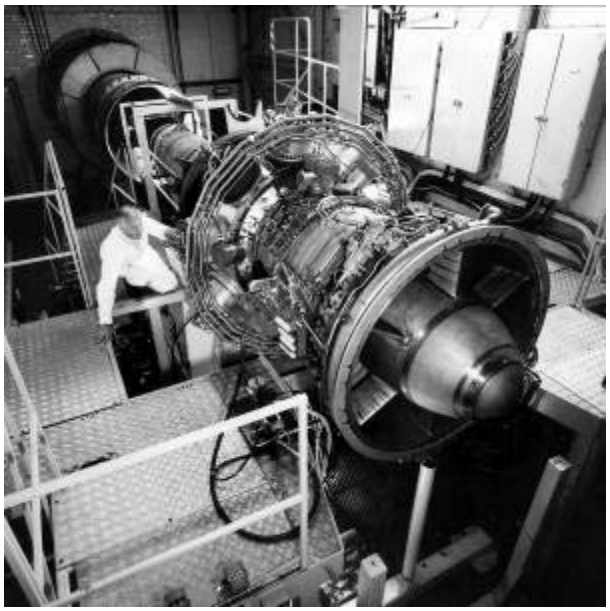
Gas Turbine Engine Performance

January 2005

EVALUATING THE IMPACT OF CYCLIC MAINTENANCE STRATEGIES



Demonstrating practical approaches for monitoring the impact of gas turbine washing strategies and tracking the resultant changes in performance and profitability

AMS™ Suite: Equipment Performance Monitor provides equipment performance monitoring of Gas Turbines, Steam Turbines, Compressors, Boilers, Pumps, Heat Exchangers and other process equipment in a secure web-based environment and allows users to;

- Run your process more efficiently.
- Improve your operating margins.
- Avoid unnecessary shutdowns.
- Improve your maintenance management decisions.

GAS TURBINE PERFORMANCE is subject to degradation over time. When gas turbine engines are run, they become fouled with airborne contaminants such as oil, pollen, soot, unburned fuel, soils and salt which encrust compressor components. Generally, axial flow compressor deterioration is the major cause of loss in gas turbine output and efficiency.

Fortunately, much can be done through proper operation and maintenance procedures to minimize fouling type losses. On-line compressor wash systems are available that are used to maintain compressor efficiency by washing the compressor while at load, before significant fouling has occurred. Offline systems are used to clean heavily fouled compressors.

The washing of gas turbine compressors is the most effective method of preventing fouling. Customer experience demonstrates that cleaning maximizes:

- Power output
- Fuel efficiency
- The life of machine components (e.g. bearings and blades)

COMPRESSOR WASHES

The process of cleaning (washing) the gas turbine is generally achieved by one of three main methods.

Engine Stripping

This is where the engine is taken off-line, stripped and hand cleaned. This method is by far the most costly, due to the associated labor costs and excessive downtime. As a result, this is very rarely used for performance recovery alone.

Shot Blasting

Abrasive contact, or blasting, using crushed nut shells, coke, peach stones or similar are fed into the inlet air stream whilst the engine is running to remove contaminants. Here the performance improvement tends to be short-lived with the added drawback of possible damage to the protective coatings on blades.

Regular Washes

This is by far the most practical solution, regularly restoring performance with a quick and simple operation.

- Online

Also known as ‘fired’ or ‘hot washing’ this is conducted whilst the engine is running.

- Offline

Also known as a ‘crank-soak’, this is where the washing is carried as the engine is being turned on the starter motor.

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THERMODYNAMIC PERFORMANCE of gas turbine engines is a function of the three main components; the air compressor, combustion firebox and the power turbine section – each of which contribute to the overall performance of the machine, converting fuel to power.

The compressor turns, driven by the turbine, compressing the inlet air as it spins. The mechanical energy required to drive the compressor is acquired from the total mechanical, rotational energy generated by the turbine section. This is the same energy source that drives the generator to create electricity or provide mechanical power. and in a similar vein. Reduced performance of the turbine compressor results in an increased energy requirement, in turn reducing the energy available for electricity production or mechanical power. When a machine is not base-loaded, this results in increased fuel consumption to meet process demands.

Therefore, the gas turbine compressor and performance play a key part in the operational profitability of the power generation cycle. Fig 1.1 shows the continuous monitoring of compressor performance attained and expected.

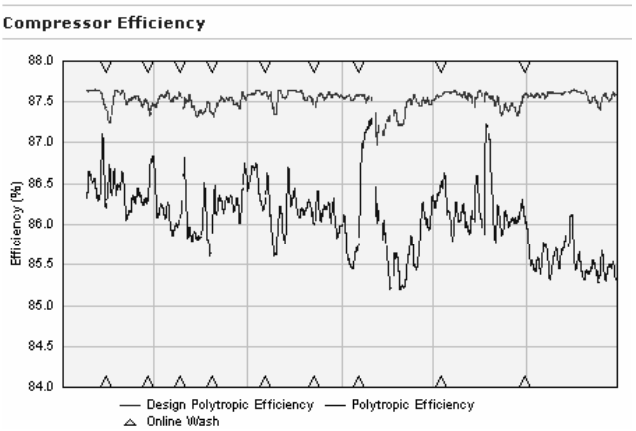
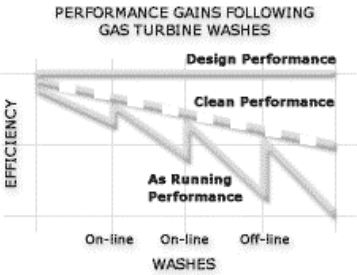


Fig 1.1 Compressor Polytropic Expected & Actual Efficiency

The efficiency values at actual and expected (design) conditions are measures of divergence from idea thermodynamic behavior. Polytropic efficiency looks at the actual work versus ideal work and includes effects for non-ideality of the compressed fluid (i.e. divergence from ideal gas behavior).

Typically in power plants, on-line washes are performed everyday (on continuously running turbines). This involves utilizing a built-in set of spray nozzles that inject heated distilled water and/or detergent into the compressor while at about 80% load. The washing continues for about 10 to 15 minutes. This recovers much of the deterioration that has accumulated over the previous 24 hours.



Online washes are usually supplemented by a periodic off-line wash, the frequency of which varies from maintenance strategy employed, anywhere between 2 weeks and 6 months.

This further permits recovery of compressor and turbine performance. It is important however to distinguish the difference between design and clean performance, as depicted above. As with any machine - the clean, or maximum achievable performance, will naturally degrade with time and should be continually monitored to evaluate machine and site capability.

PERFORMANCE MONITORING of gas turbines and their respective components is a function of operational and external variables such as ambient conditions. For example, gas turbine output is a strong function of ambient temperature. Turbines lose about 0.4% power for every 1°F rise in inlet temperature. Conversely a 1°F drop in temperature by evaporative cooling of the inlet raises the gas turbine power output by 0.4%. Machines operating in regions with large seasonal temperature variations can experience extreme swings of generation capacity, up to 40MW for larger machines. The effects of ambient conditions, both temperature and pressure, must be accounted for within performance calculations by normalizing results to ISO (International Standard Organization) standards.

In addition, the loading range of turbine operation will also impact upon expected engine performance according to the manufacturers design specifications. Typically, turbine performance will increase with operating load, until a peak capacity is reached.

From this point, increased loading will gradually reduce the thermal performance of the machine. To accurately evaluate the engine performance, the deviation between expected and actual performance must be evaluated, independent of all operating conditions.

NORMALIZED gas turbine and compressor performance, independent of operating load, present a deviation from expected performance as shown, right. Combined with the validation of raw data and removal / substitution of erroneous data by the employment of thermodynamic models, the true operating performance of the engine with respect to design (or expected) conditions is apparent.

Fig 2.1 shows two continuous performance curves, depicting the polytropic efficiency of the compressor alongside the thermal efficiency of the complete gas turbine engine. The compressor deviation mirrors the overall deviation, confirming that compressor degradation is the primary cause for overall machine thermal efficiency degradation.

Two regions of operation are apparent, as indicated by A and B, over which the frequency of online gas turbine compressor cleaning has been varied from a bi-weekly (A) to a monthly off-line wash (B).

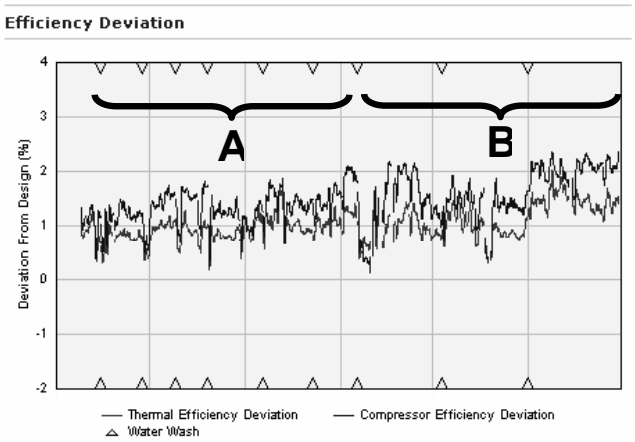


Fig 2.1 Compressor Polytropic Efficiency Deviation

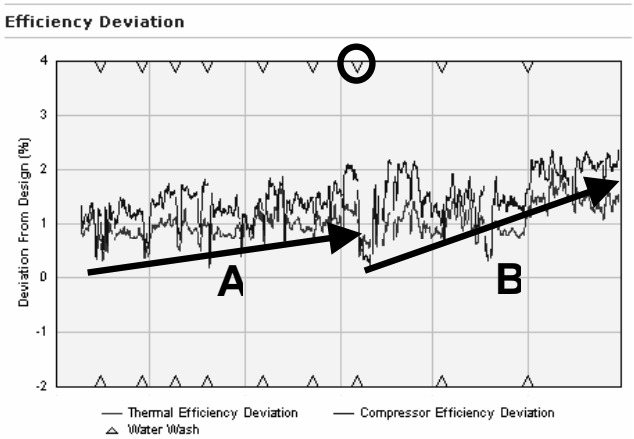


Fig 2.2 Illustrated Compressor & GT Degradation Rates

WATER WASHES depicted by the triangular indicators, mirrored at the top and bottom of Fig 2.2 show the regions of off-line wash frequency, separated by a manual clean of the engine during a scheduled outage period (circled).

By accurately evaluating performance at this level (<1% degradation in 3 months), the aggregate effect of compressor fouling upon both compressor and turbine performance can be seen to increase gradually, regardless of operating region.

The rate of degradation however shows a significant increase in gradient from bi-monthly region (A) to monthly region (B). In each region, the degradation rate approximation begins from the zero deviation value to illustrate the variation.

PROFITABILITY is key to all process industry operations and as such, within a pro-active, best-in-class maintenance strategy, the fiscal impact of asset performance is critical to evaluation.

Fig 2.3 shows the cumulative and operating cost of this 6MW engine with respect to increased fuel costs resulting from reduced performance.

During each 3-month period (A&B), the total thermal efficiency degradation of the gas turbine is shown to almost double in magnitude (1% and 2% respectively). For this 6MW machine, this translates to an additional operating loss of £2 GBP per hour.

When projected as an annual degradation rate, the resultant 12 month thermal efficiency level reduces to an equivalent £8 GBP per hour (4% below design). Over the first 12 months alone, the reduced performance would total £32K in controllable losses.

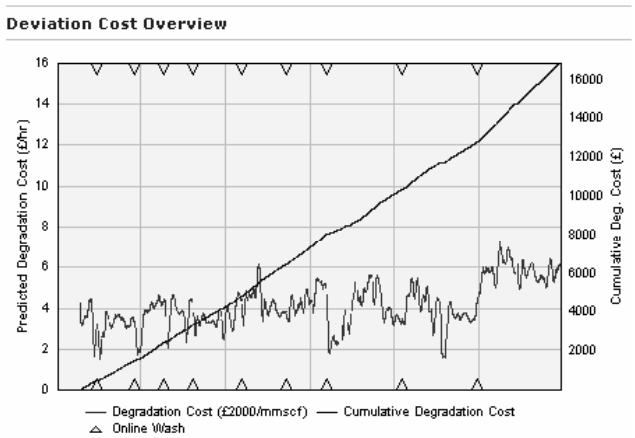


Fig 2.3 Operating & Cumulative GT Degradation Cost

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LOST PERFORMANCE and the requirement to drive effective gas turbine maintenance, is magnified for increased engine capacity.

ENGINE SIZE	1% / YEAR
6 MW	$ 32K
25 MW	$ 73K
50 MW	$ 205K
120 MW	$ 337K

Based upon the Journal of Turbo-machinery base-loaded GT manufacturer's performance data (2003) and an assumed MWhr value of $25 US.

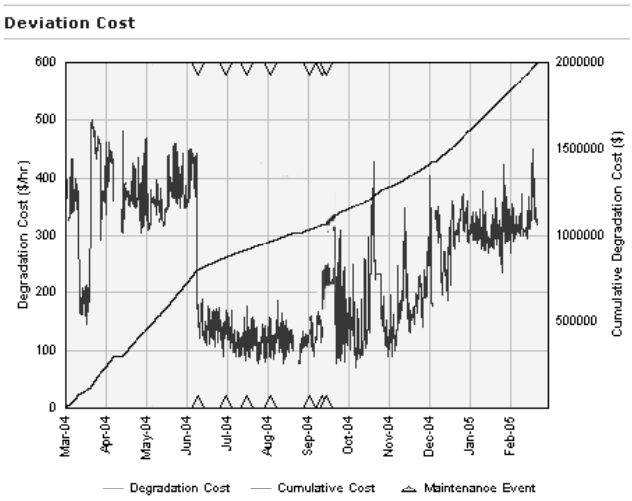
Shown right, is a 120MW, base loaded gas turbine during the trial installation of an on-line, automated, fired washing system. In addition to the daily 15 minute hot wash, a regular, off-line wash was conducted as a routine maintenance outage.

The introduction of the cleaning system initially proves huge benefits, estimated at over $250 US per hour (corresponding to a 3% thermal efficiency gain). During the 3 month cleaning system trial, the operating loss and turbine degradation rate can be seen to be significantly retarded.

Considering the residual deviation from design conditions (~$100/hr) as a function of machine age, the daily, on-line cleaning system arrests all effects of operating loss.

Further compounding the effectiveness of the gas turbine cleaning system is the resultant gradual and rapid deterioration of GT performance following the decommissioning of the trial system. Performance can be seen to decrease at a rate of US $2/hr per day, totaling a projected annual loss of over $3 Million US dollars for a single engine performance.

Machine featured is a base-loaded 120MW engine employed in power generation within a cogeneration application.



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AMS Performance Monitor by Emerson, is a web-based performance monitoring solution that requires no additional hardware or software.

Suitable for single machines and corporate fleets, AMS Performance Monitor is accessible for a fixed monthly fee, starting from $10 US per day.

AMS Performance Monitor assigns dedicated engineers to each installation to remotely analyze and assure quality of performance results, providing predictive expertise on critical assets.

For more information please contact:
Charles.Bennett@EmersonProcess.com

AMS Suite: Equipment Performance Monitor powers PlantWeb with predictive and proactive maintenance through performance monitoring of process and mechanical equipment to improve availability and performance.

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