STEAM TURBINE PERFORMANCE CONDITION MONITORING USING PLANT INSTRUMENTATION: CASE STUDY

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Summary: The overall internal condition of a steam turbine can be evaluated using the Valves-Wide-Open test. If steam temperatures and pressures along the turbine steam expansion path are measured, an assessment is possible of the condition of blading sections between available measuring points. The information available from such tests requires high accuracy in taking the performance data, meaning special tests that are expensive. Permanent plant controls and instrumentation systems have not been sufficiently refined to show the often relatively small changes that nevertheless indicate significant changes in steam path condition. This paper shows a case study that shows comparable results between high accuracy tests and the DCS on the unit.

Keywords: steam turbines, condition monitoring, performance monitoring

1 INTRODUCTION

Steam turbines continue to be the mainstay of baseload electric power production worldwide, whether supplied by fossil fired boilers or nuclear reactors. Many machines that their designers thought would have been retired continue in service, often with replacement of steam components with more recent designs of higher thermal efficiency. Long and reliable service is therefore required, and major components may operate for many years between inspections. (Vetter and Schwiemler, 1989).

The use of a range of condition monitoring techniques can help owners gain assurance of satisfactory internal condition and support maintenance decision-making (Roemer et al, 2000). Advanced off-line inspection methods, along with statistical evaluation of fleet material properties, are also developing tools (Fujiyama et al, 2004).

Many of the same techniques can be used in troubleshooting when a problem is suspected or evident from normal operational indications. Given the importance of these machines and the condition monitoring possibilities, relatively little has been published over the years on this topic, although some must have been shared within industry associations and conferences. The major text covering this topic is Cotton (1993). Sanders (2002) provides guidance on steam path audits: the evaluation and justification of restoration once a machine is opened, while Lo and Abdullah (2001) describe modelling.

This paper describes an application of one of the many types of thermal performance analysis method (Beebe, 1994). The principles described could well be adapted to other kinds of machine. The information should be useful to turbine owners in general when interpreting results from condition monitoring tests. In the case described here, sections of the desuperheater (temperature control device in the boiler steam piping) disintegrated, with metal pieces passing to the turbine. Fortuitously, this unit’s first major outage for inspection, maintenance and modification works in its 9 years of operation had been scheduled for soon after the changes were apparent. The effects on measured parameters are shown before and after the outage.

Useful consistency was obtained between the results from accurate tests and that from the plant’s instrumentation system, suggesting that where systems allow, that regular tests using permanent systems should be conducted. Specialist services in testing, monitoring, cycle modelling and performance analysis are available from at least one turbine manufacturer (Albert, 2000).

Internet-based monitoring and diagnostic systems have been applied in vibration analysis, and also developed using performance analysis for steam turbines (Orsagh et al, 2000). An internet search will soon show the several vendors that provide after-market on-line monitoring and evaluation systems.

Special pattern recognition software, such as described by Hansen and Oberdan, 1998, can be applied to detecting differences in data logged by plant instruments, and such systems can be expected to grow in capability and application. SmartSignal, AssetMAX are just two of those available. The case described here uses only the DCS provided with the plant.
2 THE PLANT

The turbine of this case study is one of two 500MW Hitachi sets installed in the early to mid 1990s at Loy Yang B Power Station in the Latrobe Valley of Victoria, Australia. This was the last station built by the then State Electricity Commission of Victoria (SECV), and the first to be privatised, initially partly and later fully. At the time of this event, it was owned by Edison Mission Energy. The boilers are of similar design to the four at the adjacent Loy Yang Power plant, and are tower type forced circulation with a separator vessel. They are much larger than a black coal boiler of equivalent output as the lignite fuel contains typically 63% water. The area has some 85 000Mt of such coal, near the surface, currently won in three open cut mines with a yearly output totaling some 70Mt.

The turbine is of the two casing type, with a combined High Pressure-Intermediate Pressure casing and a single double-flow Low Pressure casing. Blading is impulse, with the last stage blades 1016mm long. Steam conditions are the standard for the time and still the most common: 538°C main and reheat steam temperature, with main inlet pressure of 16.4 MPa. Steam is admitted through fine-holed strainers that are integral to the main stop valve assembly and intended to protect the blading from damage from any metal parts carried into the turbine.

The DCS is a Bailey Infi90 with the array of screen-based data displays and controls now usual in such plants. Uniformance PHD, Honeywell’s advanced process historian system for plant information, is used to record operating data at 2 second intervals and enable interrogation in the office.

The units run on base load at a capacity factor of 90% plus.

3 VALVES WIDE OPEN TEST

The overall internal condition of a steam turbine can be evaluated using the Valves-Wide-Open test (ASME 1985; Beebe, 2003). These tests do not require a test measurement of steam flow, which reduces the complexity and hence cost. The inlet area for steam entry is set at a repeatable opening, with wide open control valves being the only certain setting. The steam supply conditions and other operational settings are set as close as possible to nominated datum values for a steady run of typically an hour.

It may be necessary to run such tests at lower than normal steam inlet pressure if the turbine’s steam swallowing capacity at rated pressure is greater than the boiler can supply (Beebe, 2005). This is less necessary with recent turbine designs that tend to have less excess capacity than older designs. Because of this excess capacity on older machines, changes in turbine condition can go un-noticed as boiler output gradually increases to maintain the usual unit output.

The power output of the generator is measured accurately, and corrected to find what the output would have been if all terminal conditions had been the datum values: resulting in the parameter of Corrected VWO Output. The corrections used are the manufacturer’s data (“thermal kit”), or obtained from computer cycle modelling or specially conducted tests (Beebe, 2005). The generator is therefore being used as a transducer of the mechanical output of the turbine.

If steam temperatures and pressures along the turbine steam expansion path are measured at available points, an assessment is possible of the condition of blading sections between them. To be of most value, the information available from such tests requires high accuracy in taking the performance data, and similar precautions as used for the plant acceptance tests are usual. The accurate tests are too costly to be done frequently.

Permanent plant transducers can be sufficiently stable and the controls and instrumentation systems refined enough for condition monitoring of such plant as boiler heat exchange surfaces. However to date they have not been refined enough to show the often relatively small changes that nevertheless indicate significant changes in steam path condition (Beebe, 2003). The case described in the paper is in a plant equipped with a modern DCS (Digital Control System), and shows that useful results can be obtained by regularly conducting VWO tests using DCS data. Plant calibration of key instruments at intervals of 1 or 2 years has revealed little drift.


At this plant, accurate VWO tests are run each 2 years, and prior to a planned steam path inspection and afterwards. The tests are conducted by the Process Engineering and Environment Section of a specialist company, HRL Technology Ltd, following the same test procedures as used in the SECV days. These tests provide in-situ calibration of critical temperature and pressure instruments. Output is measured by the Electrical Tests Group of SILCAR Ltd to acceptance level standards. On this unit, acceptance tests were run in July 1993 to establish the unit’s heat rate.

4 OTHER USEFUL PARAMETERS OF CONDITION

From the available temperature and pressure tapping points, other useful parameters of stage condition can be obtained, even though these points are in steam extraction lines and therefore not exactly indicative of stage exit conditions. Repeatability is however usually sufficient. Along with the above, the main parameters relevant here and the 95% confidence limits applicable to some as assessed by HRL Technology are:
• VWO output: ±0.5% points
• Steam strainer pressure drop
• Enthalpy Drop efficiency of HP blading (ratio of actual enthalpy drop to that at constant entropy): ± 0.4% points
• Enthalpy Drop efficiency of IP blading: ± 0.2% points (not further discussed here)
• Pressure ratios between stages
• Heat Rate and main steam flow (not further discussed here).

On turbine designs such as these which have a combined HP-IP casing, leakage occurs from the HP inlet to the IP inlet through the central gland: the so-called N2 packing. This leakage cannot be measured directly, but can be estimated repeatably by running special tests. The value did not change significantly over the period following the acceptance tests.

5 TEST RESULTS

During the accurate tests, data is also collected via the DCS, and transferred into the plant’s PHD Historian database. The same calculations are performed off line on the office computer, which also runs a steam tables package (from Chemicalogic Corporation).

Figure I shows the VWO results from initial acceptance tests for both the accurate and DCS methods from acceptance tests until after the machine outage where repairs were made. The data points are shown joined together, but the trend between tests is not necessarily linear, and is certainly not so over the outage period.

A slight decline in performance from new was evident, and is not unusual (Kearney et al, 2004).

Despite the further decline later, the other tests up to the fourth series do not show a large change given the confidence limits above. Some decline could be due to deposits on blading in certain sections of base-loaded turbines, as these are common with baseloaded turbines. They are often removed by forced steam cooling, as used on planned offloading to reduce the time to when the machine can be brought to standstill to prevent damage (the oil system can be stopped when the inner metal temperature reaches 185°C on these machines) and allow access (Beebe 1978).

After the initial decrease in 1999, operators noticed that the control valves needed to be fully opened to achieve 500MW output and the DCS tests were run more often. Although the parameter values vary in magnitude from the accurate ones, and also show some scatter, a consistent trend is apparent. With much condition monitoring, it is sufficient for the data to be repeatable, rather than of absolute accuracy, and the DCS approach can be applied to both steam and gas turbines (Girbig, 2001).

![Figure I: VWO Output: upper points, accurate tests; lower points, DCS results. (Foreshortened vertical axis)](image_url)
6 OTHER PARAMETERS: PRESSURES

The pressure drop across the steam strainers was not measured directly, but calculated from the difference between the main inlet pressure and the pressure after the control (i.e. governor) valves. The drop (in the order of 440kPa) is relatively small in comparison with the line pressure, and a better method is to install a differential pressure transducer across points as near to the strainers as available. The pressure drops here did not vary significantly during the period, although the strainers were found at the outage to have significant blocking and damage (Figure II).

Figure II: Main steam strainer showing blockage from metal pieces carried over from boiler damage

The First Stage Pressure (FSP) is measured immediately after the inlet nozzlebox. When corrected to standard inlet pressure, it is an indicator of changes downstream. It increased over the period, indicating increased restriction downstream. Figure III shows the corrected values from the accurate tests, along with the corrected pressure after the control valves, which showed a small increase of 0.37%.

FSP showed an overall decline of 5% from the acceptance tests. This also indicates a decrease in inlet steam flow. Figure IV shows the blockage found in part of the first stage nozzles by metal pieces that had gone through the strainer.

Figure III: Corrected pressures after control valves and first stage. (Foreshortened vertical axis)
Pressure drops that are relatively small compared to the line pressures are best measured with a differential pressure transducer. Even one of commercial accuracy can give more accurate results than by taking the difference between two separate high accuracy readings.

Corrected pressures all use the inlet steam pressure as their basis. If that reading is in error, all the corrected pressures will be also in error, so the Pressure Ratios across sections are a useful cross-check. Here the Ratios from After Control Valves to FSP, and FSP to HP exhaust were virtually unchanged throughout, which does not give confidence in the parameter!

7 OTHER PARAMETERS: ENTHALPY DROP EFFICIENCY

The Enthalpy Drop Efficiency can only readily be found in the superheated steam regions. It is the ratio of the actual enthalpy drop between two points and the ideal (isentropic) drop, and a decrease indicates damage or deposits. Steam properties are needed, using the measured temperature and pressure at a point. Figure V shows these parameters calculated from both the accurate tests and DCS data at the same test. Different tables of steam properties were sued, which could account for some of the difference (Kearney et al, 2004)

Although the ASME method requires inlet conditions to be taken at turbine inlet, some prefer to use the conditions at entry to the blading (Kearney et al, 2004) particularly where blades have been retrofitted. The data here uses turbine inlet conditions.

A comparable trend is evident, except for the test prior to the repair outage. The inlet steam temperature shown by the DCS of 544°C must have been in error, as the accurate test value was 534°C. The error was confirmed further by the HP inner metal temperature (DCS) that was close to the usual for previous tests at lower indicated DCS steam temperatures. This shows the value of logging all data during tests, as useful correlations may be found, even with unknown calibration.

![Graph showing HP enthalpy drop efficiency over time](image-url)
Reported experience shows that there is a high degree of variability in calculated enthalpy drop efficiencies, particularly in HP section efficiency (Milton and Dempsey, 1995). This is confirmed in Figure VI, which also gives the above data, with the addition of the monthly DCS tests conducted following the repair outage. It is evident that the scatter is too wide to show up anything but large changes.

The outage was extended to 57 days because of the unforeseen boiler and turbine repairs. The blading was fixed temporarily to last four years until a planned HP-IP casing replacement.

8 CONCLUSION

Useful steam turbine condition information can be obtained from Valves Wide Open tests on plants equipped with a DCS, but should be supplemented with regular accurate tests. As at this plant, DCS tests are conducted each month, and it is suggested that other plants could well try. The use of plant instruments for other parameters should be tried, but wide scatter should be expected.

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10 REFERENCES


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