

Taking a Closer at Gas Turbines

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MORE AND MORE TURBINE OWNERS ARE USING SOFTWARE TO GUIDE LIFE MANAGEMENT DECISIONS FOR TURBINE HOT SECTION COMPONENTS.

Attracted to the high fuel efficiency and lower initial installed cost of advanced combustion turbines (CTs) compared to their predecessors, power producers have embraced these machines as a primary source of power generation. F-class CTs operate at significantly higher turbine inlet temperatures (exceeding 2400 F), thanks to OEM engineering improvements in blade cooling, materials, coatings, and design technology. As a result, CT owners enjoy improvements in efficiency and specific power compared to older models.

However, these advances in firing temperature have resulted in more complex designs that incorporate more temperature-limited parts and a range of protective coatings. In F-class turbines, all stages are at or near the temperature limit of the materials, and most sections require sophisticated cooling mechanisms. As a result, some turbine owners are finding that the hot section components of these systems – particularly expensive first-stage blades, or buckets – are not meeting durability targets.

The expected refurbishment interval for F-class CTs is about 24,000 equivalent operating hours. Yet, the few reported incidents discovered during inspections of F-class machines include complete consumption of coatings and base metal oxidation at the leading edge of buckets within 20,000 hours of operation. In as few as 12,000 hours of operation, trailing edge bleeding hole cracking due to thermal mechanical fatigue (TMF) has been reported, as well as cracking between the leading edge and mid-chord on both the pressure and suction side. Excessive damage may substantially reduce component reparability and subsequent planned service intervals.

When blades deteriorate beyond repair due to excessive base metal damage, turbine owners can incur replacement costs of \$2-3 million per row. If a blade breaks off during

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operation and causes extensive downstream damage, the replacement cost of the hot section components alone can exceed 25 percent of the cost of a new unit.

SAFEGUARDING TURBINE INVESTMENTS

Developing an effective life management system for the hot section of these F-class machines would be a major step toward preventing such major losses to CT owners. Given the short operating history of the newest CT models, significant scale-up in firing temperature, and limited operating experience with the advanced materials used in hot-section components, turbine owners need tools to help make life management decisions that balance failure risks and maintenance decisions with opportunity costs.

More specifically, in order to effectively manage O&M costs for key hot section components, operators of high-firing-temperature CTs need ways to accurately assess component condition, given their turbine's specific operating history. They need to know how they can optimize the life of expensive components through proper O&M, while minimizing the cost of lost generation due to downtime. Equipment insurers have expressed concern

that holders of extended service agreements covering these critical hot section components still need to be technically engaged with these critical maintenance decisions. This concern stems from the OEM's economic motivation to extend service life beyond their more conservative past practices based on replacement parts sales.

HOT SECTION LIFE MANAGEMENT PLATFORM

To this end, EPRI has developed a software program, called the Hot Section Life Management Platform (HSLMP), which enables CT operators to improve the reliability, availability, and maintainability of hot section components (Figure 1). Initially applied to first-stage blades of General Electric Frame 7FA+ and 9FA machines, the software helps operators optimize maintenance intervals, extend blade life, and contain and reduce lifetime costs. First-stage turbine blades are the model's first application because of their short life, high replacement cost, and exposure to high stress and temperature levels.

EPRI relied on data and guidance from Constellation Energy Group, Progress

Energy, Tennessee Valley Authority, KEMA, Florida Power & Light, and City Public Service of San Antonio in developing the HSLMP model. The database currently features 7FA and 9FA rotating components, although it is already planned to expand to include the stationary nozzles, and other machine types. To date, the turbine owners mentioned have been the immediate beneficiaries of the results, acting as part of the research and development team. Given the relative newness of the Frame 7F machines, the goal for these owners was to have viable results available by their first hot gas path inspections.

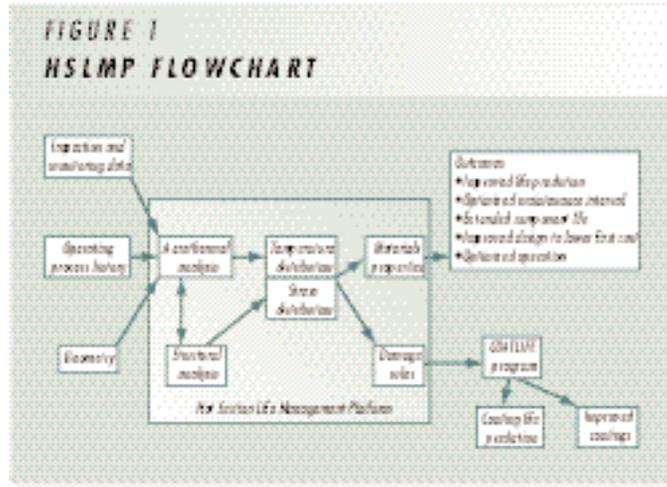
To use HSLMP, key component geometry, unit operating history and available inspection and monitoring data are input. To establish the initial database for any component, information on firing temperature, load and exhaust temperature are required at one-second intervals to characterize transient types of events, e.g.

start-up, partial load trip, shut-down etc. For subsequent life management, damage is tracked on a start/stop cycle basis, monitoring the same temperature and load parameters.

Aerothermal and structural analysis methods have been developed and built into the platform, so that temperature and stress distributions can be fully determined for both steady state and transient conditions under any specified operating scenario. Operating scenarios include start/stop, trip, and normal shutdown. This information is then combined with component materials properties and damage rules incorporated in the platform; these properties and rules have been independently established for the GTD 111 DS (directionally solidified) version of the blade material used in the first row of the 7FA+/9FA machines, as well as the GTD 111 EA (equi-axed) version used in lower rated machines. The software converts temperature and stress into accumulated damage due to creep, coating oxidation, and TMF – the three most common mechanisms that cause cracks in hot section components – on a cycle-by-cycle basis. The software then graphically represents to the operator the most recent operating history of the unit in terms of accumulated damage after each start-stop cycle.

HSLMP provides turbine operators with the following:

- A three-dimensional profile of first-row buckets, indicating temperatures and stresses under unit-specific operating conditions. Turbine operators can use this profile to predict where damage mechanisms will occur.
- The relative predicted TMF damage, or bucket cracks, for any given operating cycle or load profile. TMF is a function of the total strain range and peak temperature experienced during an operating cycle.
- Estimates on creep and coating degradation for a unit-specific operating history. Coating oxidation is the failure mode most sensitive to temperature and creep is governed by temperature and stress.



HSLMP can help evaluate proposed design improvements to buckets, including internal cooling strategies; the effects of tolerances, such as wall thickness and hole diameters; and the effects of alternative materials and coatings.

MODEL VALIDATION

The temperatures and stresses that the HSLMP predicts have been rigorously verified to ensure that the HSLMP software is able to produce accurate results upon which turbine owners can base life management decisions. Test results were in turn used to adjust and calibrate the software's algorithms.

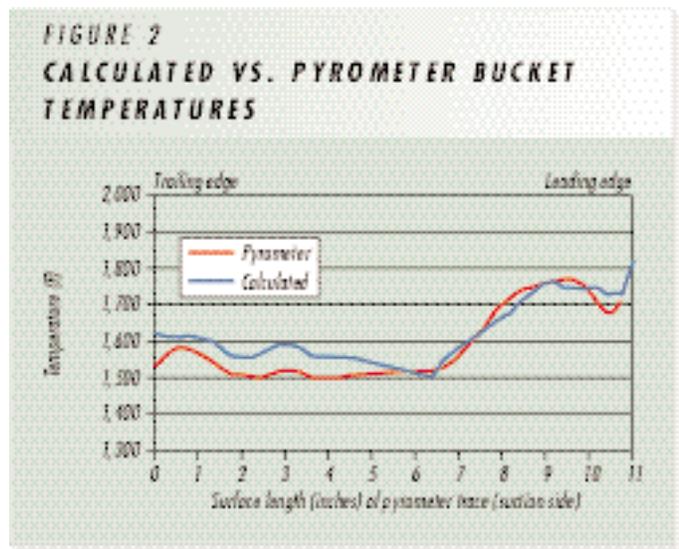
For example, to validate the accuracy of the aerothermal model, external surface temperatures predicted by HSLMP were compared and correlated with optical pyrometer measurements. The 9FA bucket temperature measurements were obtained at baseload and transient conditions; because the 7FA+ and 9FA buckets share such

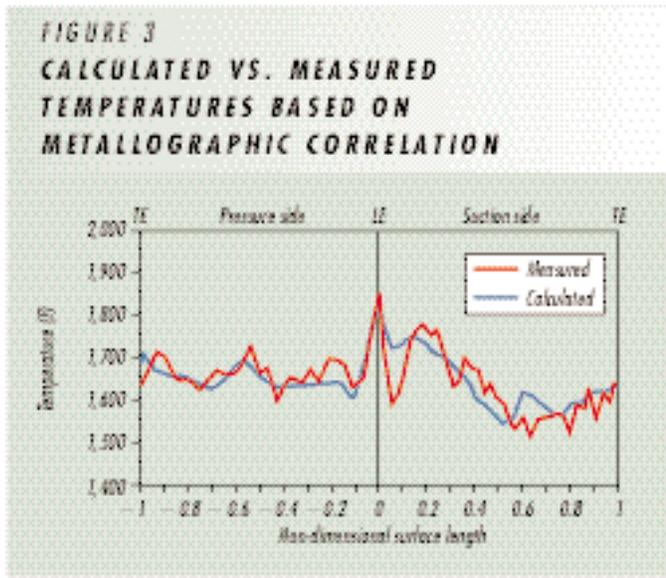
similar designs, these data were then used to verify the aerothermal models for 7FA+ buckets. The results of calculated aerothermal analyses using the HSLMP coincide closely with temperature measurements using optical pyrometry (Figure 2).

Engineers further validated the model's ability to accurately predict blade temperature via independently reported correlations with metallurgical evidence. The percentage of beta-phase in the aluminum-enriched coating of the buckets

was used to estimate local blade temperatures at 60 percent height of the airfoil. The amount of beta-phase in the aluminum layer, which characterizes the transformation of the material's microstructure when exposed to thermal cycling, had been conclusively correlated with temperatures prior to the test. As shown in Figure 3, actual measurements correlated well with the HSLMP predictions.

Model damage predictions via determination of temperature distributions were also compared with damage exhibited on field-operated components. Leading edge coating spallation predicted at 1850 F (1000 C) and heavy oxidation at the tip at 2000 F (1100 C) were confirmed in a 9FA model after 18,000 operating hours and in a 7FA after 21,000 hours (Figure 4).





Model results obtained from the structural analysis used to delineate stress and strain distribution were confirmed by direct comparison of model-predicted damage with damage exhibited on field-operated components, both

calculated parameters across these validation approaches indicates that the fundamental techniques the HSLMP uses are sound. As a result, turbine owners can use the software to improve life prediction of buckets and refine maintenance intervals to maximally extend component life while minimizing costs and downtime. In addition to using the data that the platform generates to improve engineering designs, advanced repair techniques such as laser welding can also be evaluated with the software.

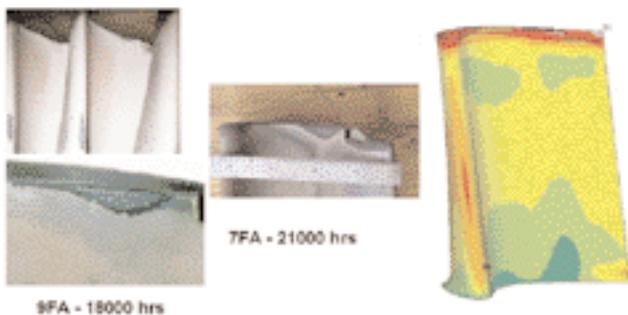


Figure 4. The damage areas that the HSLMP predicted, based on areas of high temperature, corresponded closely to actual observed damage in an operating 9FA and 7FA turbine.

in terms of the location and the extent of the damage. Calculated results matched the locations of actual damage observed in 9FA field units with an operating history of 17,000 hours with 104 starts and 30 trips.

HSLMP EXTENSIBILITY

By inputting data on operating history, component geometry, and materials properties, along with refined damage rules for these materials, it is anticipated that the HSLMP methodology can be extended to other 7FA+/9FA rows, other GE turbine models, and machines from other manufacturers. Future provisions to accept field inspection data will factor in specific component conditions in damage projections. To aid this process, EPRI recently published a comprehensive handbook of available material property data for superalloys used in CT buckets (EPRI report 1004652, July 2001). Future revisions will include property data for single crystal components, as these high-tech materials enter the market.

In addition, the temperature and stress distributions derived from the HSLMP can be used as input to a stand-alone COATLIFE model – an EPRI software product developed by the Southwest Research Institute that predicts coating life of advanced metallic coatings. In this way, the HSLMP and COATLIFE software can be used in conjunction with model coatings to accurately estimate coating life consumption in terms of oxidation and TMF damage, as well as determine optimal maintenance and recoating intervals. To date, remaining life can be estimated for aluminides, GT29, GT33, GT29+, GT33+ and PWA 286 coatings under a variety of operating conditions. Such analyses can ultimately be used to develop improved coatings for advanced gas turbines. Additional information on CT damage analysis and related operations issues can be found at www.epricenter.com. 

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