Operating experience, analytical procedure help OEM extend intervals between GT inspections

By **Barton M Pepperman** and **Diego L Caso, Jr,** Siemens Power Generation Inc

Editor's note: In the demanding world of deregulated power generation, plant staffs are continually challenged to reduce the cost of operation and to maximize revenue opportunity by increasing availability. One way to achieve both objectives is to extend the intervals between inspections—combustor, hot gas path (HGP), and major. This often is the subject of open discussion at user-group meetings.

OEMs generally agree that the time between inspections can be as much as doubled without adversely impacting reliability. But careful analysis is required to determine exactly what's possible for any given unit. The COMBINED CYCLE Journal asked Bart Pepperman and Diego Caso to explain how Siemens Power Generation approaches an interval-extension request and decides what components, materials, coatings, etc, require upgrading to meet user goals.

Keep in mind that the ensuing discussion only addresses inspection intervals for gas turbines (GTs). Extending GT intervals will, of course, impact inspection intervals associated with balance-of-plant equipment.

Inspection intervals for GTs are established based on operating time or start cycles. The former is in units of equivalent base hours (EBH), a number calculated from actual service hours at specific firing temperatures for each fuel burned. Equivalent starts (ES) are calculated from data on the number of actual and aborted starts and trips at specific loads, time to both start up and shut down, and instantaneous load changes. Recommended intervals for refurbishment and/or replacement of consumable components are based on EBH or ES limits, depending on the GT's mode of operation.

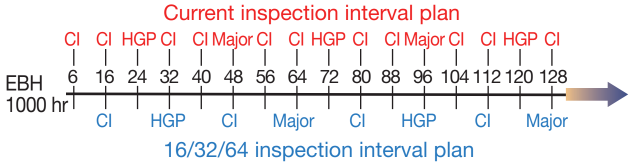
The procedure followed to eliminate some of the traditional planned maintenance outages and thereby provide the opportunity to reduce the life-cycle cost (LCC) of operating a unit is called the inspection-interval extension process (IIEP). Fig 1 illustrates an hours-based inspection-interval extension that takes a combustor inspection (CI) from 8 to 16k EBH, a HGP inspection from 24 to 32, and a major inspection from 48 to 64. The different types of inspections are defined at appropriate multiples to optimize LCC.

Bear in mind that the IIEP is not intended to be a clean-sheet redesign based on the latest analytical tools used to engineer advanced frame engines. Rather, the process is primarily an empirical one with the goals of minimizing program cost and reducing implementation time. As such, it relies on a review of service history and past performance to identify components impacted most by an extended inspection interval.

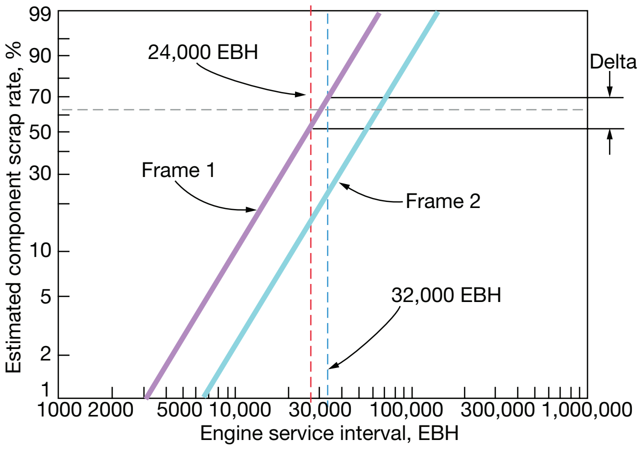
Any required design enhancements are based on field-proven advanced frame technology both to minimize the application risk and the time required for product development. Such design changes may, of course, involve additional analysis and testing in accordance with current standards. End result of an IIEP is a package of component upgrades and repairs that could be implemented during a planned outage and would accommodate the recommended extended inspection intervals from that point forward.

End-user benefit of implementing the recommendations of the IIEP is the opportunity for increased profitability. The following goals of the IIEP are consistent with that objective:

- Eliminate several CIs and some HGP inspections over the expected life of the GT, as suggested in Fig 1.
- Component life commensurate with the



1. Current interval is compared to extended interval for a hours-based unit



2. Weibull plot shows impact of extending service hours on scrap rate

3. Upgraded bond coating is alongside sample of the original bond coating

extended inspection intervals.

- No adverse impact on the performance or power output of the engine.
- No changes in current operating conditions.
- Minimal impact on site-specific emissions throughout startup and through the entire load range for any particular unit.
- GT reliability consistent with that prior to implementing the recommended upgrades.
- Availability improvement as a result of the extended inspection intervals.
- Minimal impact on outage duration.

Primary components of the IIEP

Empirical data analysis. Information sources on component condition and performance generally available to the analysis team include inspection reports, outage reports, and photo documentation of previous inspections. First step in the data-collection process is to develop a list of all potential resources—to estimate the time and cost of data acquisition and to ensure that significant data are not overlooked. Of great importance is obtaining a data sample of sufficient size to enable meaningful decision-making and of collecting the information in a manner that can be related to engine operating time and cycles.

Raw data must be properly organized to ensure accurate analysis. This requires compiling the information into a standard format with common terminology (the same things often are called by different names—for example, tip rub instead of light rub, or vice versa). In addition, *all* data must be entered, including that on hardware that is perfectly fine. This is necessary to determine rates of occurrence.

The analysis team also must distinguish between instances where data were not available versus instances where there was no component effect. Next, the database on component condition and performance can be expanded to include operational data as a function of hours and starts, limits, and disposition.

Analysis includes a comparison of data to acceptance criteria defined in applicable service documents and/or design manuals. The Weibull plot often is used to facilitate analysis; other plot types include survivability, bar, and scatter. To illustrate: Fig 2 illustrates that by extending an interval from 24k EBH to 32 would increase the estimated component scrap rate from 51% to 70% on Frame 1 and from 15% to 22% on Frame 2. This type of empirical data analysis provides the basis for evaluating LCC for each consumable component.

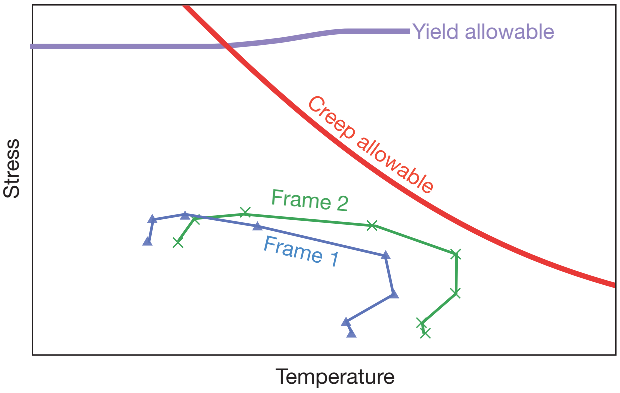
Life-cycle cost analysis. With regard to individual components, LCC is the sum of replacement and repair costs at each outage interval. Repairs are categorized by severity (replace/scrap, major, medium, and minor). Increasing an inspection interval changes the severity of the component repair and impacts the component scrap rate. The LCC analysis captures these changes in repair and replacement costs and compares them to cost criteria to determine if a design upgrade is necessary.

Risk assessment. A technical risk assessment is required on each component of concern, as determined by the IIEP. It evaluates application, performance, and combustion/emissions risks related to implementation of a product upgrade. Any risks considered "high" or "medium" require mitigation actions to lower the risk level. Example: Use a field-proven design improvement from an advanced frame or conduct additional technical analysis to demonstrate a lowering of the risk level. Any risks deemed "low" usually do not require mitigation actions.

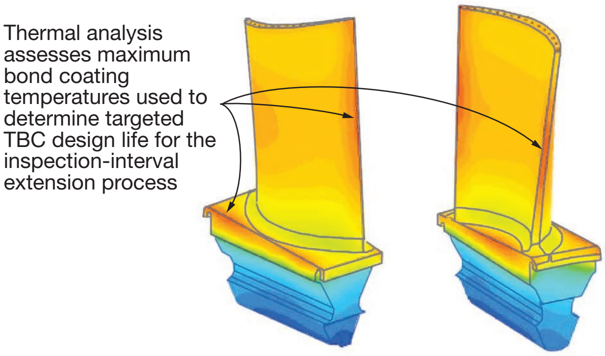
Technology analysis has two elements to consider: (1) Identification of available advanced-frame technology that can be transferred to a mature frame, and (2) the cost and schedule impacts associated with implementing an available technology solution and whether they are consistent with customer requirements.

For example, use of advanced coatings or advanced-coating application processes should be considered for a mature frame when a relatively minimal effort is required in the way of design, analysis, supplier qualifications, and tooling to achieve a potentially significant benefit with regard to component life.

By way of example, Fig 3 offers a side-by-side comparison of an upgraded bond coating from an advanced frame to the original bond coating on the mature frame being evaluated. The benefit is an obvious one. Another example of technology infusion from advanced frames is a material upgrade to improve creep life or oxidation properties.



4. Creep analysis results for extended inspection interval show design margin



5. Thermal analysis is an important method for assessing coating life

Peer reviews provide a method for identifying available technology options and are a critical step in the IIEP. They require participation by frame and component owners as well as representatives from key engineering disciplines—design, service, repair, materials, and manufacturing.

Regarding the assessments of cost and schedule impacts associated with the second component of technology analysis noted above, consider that advanced frame R&D programs may have technology that would benefit the IIEP. However, the particular technology may not yet have been qualified or may not be available in time to support the IIEP. In such a case, the advanced technology may be identified but not applied until the schedule and supply chain can support its implementation on mature frames.

6. Robotic coating application helps improve component design life

An engineering analysis is conducted when a component design upgrade is necessary to meet IIEP requirements. The depth of analysis depends on the type of design enhancement needed; procedures must follow those prescribed in the component design manual. Also, analysis must be consistent with the requirements established for advanced frames. It may include creep rupture (Fig 4), LCF, HCF, thermal (Fig 5) and modal depending on the type of design change and type of inspection interval extension (hours- or starts-based).

Manufacturing analysis involves consideration of casting, forging, welding, brazing, and machining changes required in support of a component design upgrade effort. Tooling and fixture requirements also must be determined. Since the end product is a marketable upgrade package, the process would require manufacturing source qualification for any new processes or designs.

The process must consider sourcing and leadtime as it relates to customer needs, as well as to the manufacturing risk-mitigation strategy. Advanced manufacturing processes, such as the robotic coating application shown in Fig 6, can help to significantly improve component refurbishment and design-life intervals.

Verification testing is influenced by the extent of the design change to a given component. Verification often requires one or more of the following: combustion system rig testing, frequency testing, flow testing (where additional cooling holes or cooling schemes have been modified), and metallurgical testing. After approval for commercial service, borescope inspections may be required at predetermined intervals.

Validation requirements depend on the level of risk that the IIEP introduces into unit operation. For example, significant design changes would warrant validation while minor design changes—such as coating enhancements—may be considered acceptable without validation. Operating experience with other frames influences requirements. Typically, validation takes place outside of the R&D program scope because of the amount of time it takes to validate a sophisticated product. CCJ