On-Line Thermal Barrier Coating Monitoring for Real-Time Failure Protection and Life Maximization

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PUBLIC ABSTRACT

Under the sponsorship of the U. S. Department of Energy's National Energy Laboratory, Siemens Westinghouse Power Corporation proposes a four year program titled, "On-Line Thermal Barrier Coating (TBC) Monitor for Real-Time Failure Protection and Life Maximization," to develop, build and install the first generation of an on-line TBC monitoring system for use on land-based advanced gas turbines (AGT).

Federal deregulation in electric power generation has accelerated power plant owner's demand for improved reliability availability maintainability (RAM) of the land-based advanced gas turbines. As a result, firing temperatures have been increased substantially in the advanced turbine engines, and the TBCs have been developed for maximum protection and life of all critical engine components operating at these higher temperatures. Losing TBC protection can therefore accelerate the degradation of substrate components materials and eventually lead to a premature failure of critical component and costly unscheduled power outages. This program seeks to substantially improve the operating life of high cost gas turbine components using TBC; thereby, lowering the cost of maintenance leading to lower cost of electricity.

Siemens Westinghouse Power Corporation has teamed with Indigo Systems, a supplier of state-of-the-art infrared camera systems, and Wayne State University, a leading research organization in the field of infrared non-destructive examination (NDE), to complete the program.

EXECUTIVE SUMMARY

With On-line blade monitoring, Siemens Power Generation (PG), under the sponsorship of the U.S. Department of Energy, has developed an innovative way to continuously monitor row 1 blades in gas turbines. By using a high-speed infrared camera these blades can be kept under surveillance during operation of the gas turbine. The challenge comes when the blades are running they rotate at extremely high speeds and in a hostile environment of a fully operating turbine engine. This unique approach opens opportunities to real condition-based maintenance which can lead to significant cost savings for PG's customers.

The blades in the first two rows of a gas turbine are subjected to high thermal stresses. In order to optimize the life of the blades and to avoid the high costs involved in unscheduled replacement a team at Siemens in Orlando developed the idea of recording the radiation of the hot ceramic blade surface using a high-speed infrared camera. To do this a cooled optical probe, which reaches as far as the moving blade row, is installed in the gas turbine. The camera is attached to the optical probe and mounted outside of the turbine casing. Despite the high speed of rotation, the control software is capable of identifying and recording each individual blade. The images are evaluated automatically, and the entire system can be linked up to remote diagnostics centers.

This monitoring system makes it possible to replace the blades based on their actual condition. Blades will be replaced only when they are worn, such as when the thermal barrier coating is severely damaged. Taking into account the high costs of a row-1 or row 2 replacements, by implementing this new technology significant cost savings can be achieved.

During the month of October 2-12, 2004, Siemens Westinghouse Engineering successfully installed a commercial On-line TBC Blade Monitor in a W501FD gas turbine at Empire Stateline Electrical Company in Joplin Missouri. This is the first commercial full scale, high temperature, full pressure, blade monitoring system. Blade monitoring is accomplished by both near and mid- wave infrared (IR) high speed cameras. Two access ports were R5 design reviewed and installed to allow two vantage points for viewing the row 1 blades on the W501FD engine. A pair of IR lens trains were designed and built to install optics within the turbine cover. These optics are capable of withstanding the high temperature of the turbine casing with only a small amount of compressor discharge cooling. The cameras are operated via a control station in the engine test room. A TATM blade rotor synchronization system was developed to allow for specific blade(s) viewing. Custom software has been created to operate the camera(s) and select any combination of blade views and view periodicities. The software also operates filter functions, camera motion and skew. The entire camera system is contained in an environmental enclosure that is cooled with a small amount of compressed shop air. The enclosure is self contained and allows multiple adjustments to the optical system from the engine test room. The system has an expected life of 8,000 hours.

This commercial installation will monitor and evaluate the performance of row 1 TBC coated blades of both pressure and suction sides. The tests and demonstration will evaluate the mechanical design of the monitoring viewing ports, mechanical integrity of TBC monitoring system (camera performance, environmental enclosures and spectral filter) and integration and development of system supervisory system and TBC Lifing Model.

The anticipated benefits are listed below:

(1) Use of the on-line TBC monitor will significantly improve plant reliability and availability by extending critical component lives. Damaged TBC can be identified early and repaired before the component's catastrophic failure.
(2) Use of the on-line TBC monitor will significantly increase availability of peaking gas turbines by eliminating down time required for frequent borescope examination of TBC's.
(3) The on-line TBC monitor can be used on all existing and new gas turbines that use TBC to protect critical turbine parts. The fundamental concepts of the on-line TBC monitoring is equally applicable to smaller land, aero and marine based gas turbines. This opens future global market opportunities for the team to pursue.
(4) The financial payback of this technology comes in the form of reduced maintenance costs and having power plants available when they would not have been. All of today's advanced gas turbines can benefit from this monitor. We expect over 600 "F" and "G" class gas turbines to be in service over the next 12 years. The total estimated 12-year life-cycle maintenance cost savings for these 600+ units is expected to be over $600M.

ON-LINE TBC MONITORING – STATUS OF TASK 2

Task 2: Develop On-line TBC Monitor for Blades

PROGRAM PROPOSAL

Subtask 2.1 Determine Temperature-Dependent IR Characteristics of Blade Surface and GT Working Fluid

STATUS OF TASK 2, SUBTASK 2.1

This task has been completed and reported in previous technical reports.

Subtask Task 2.2 Develop IR Monitor for TBC Coated Blades

STATUS OF TASK 2, SUBTASK 2.2

This task has been completed and reported in previous technical reports

TASK 5: DEVELOP TBC REMAINING LIFE PREDICTION MODEL

PROGRAM PROPOSAL

SWPC will develop the supervisory software for the TBC diagnostic system utilizing a rule-based logic. The system will store all the processed data coming from the blade and vane temperature sensors. The data will be supplemented by key thermal data produced by the performance monitoring package. The sensor data will then run through a rule-based expert system to determine the probability of TBC coating failure.

Raw signals from both the blade and vane monitors will have to be preprocessed before the data is analyzed. Preprocessing will also be performed to eliminate spurious indications. Blade monitor signals will include high-speed radiance scans of the blades. Data will be processed into a meaningful form to demonstrate changes or excursions that require reporting to the control software. The decisions that guide in this selection will be made throughout the program.

The control software will interpret the reported trends or excursions and notify or alert the operator of the finding. Different types of preprocessing logic will be used to identify excursions or trends. Raw data signals will be processed as collected. Some preprocessing steps will include a continually updated running average with statistical significance for ongoing data collection. This will establish a baseline for comparison of each refreshed data set. Excursions from this baseline will be brought to the attention and disposition of the artificial intelligence (AI) system. Historical averages will be periodically stored for long-term trending and AI disposition. The system will report information in the following categories:

Temperature maps, Remaining life of TBC, Recommendations for optimizing specific parameters, and Emergency alert.

By continually monitoring the operating conditions, the remaining life for future operating conditions will also be forecasted. Using the advice given by the control system, an operator will have the ability to balance power output and TBC life expense rate. This will ultimately optimize power output and outage scheduling for maximum operator control. Other engine performance and parameter inputs will also be accessed by the advisory system as identified throughout the program. The system will also provide alarms for critical TBC loss situations. The alarms will notify operators only in the event of eminent damage or failure. The system will also provide alarm signals for connection to standard tripping control devices for the option of automatic tripping.

STATUS OF TASK 5

Temperature barrier coating on blades has a limited life time as illustrated in Figure1. The development of temperature barrier coating and related research is mainly focusing on the task to avoid TBC defects and to maximize the lifetime of TBC at specific conditions until the first defect appears. Limited work has been done to characterize the progression of TBC defects once defects exist. In the context of this program Siemens Westinghouse has used experimental setups to monitor TBC defect growth with the goal to model the defect growth analytically. An analytical model for defect growth was developed by Siemens CT in Munich, Germany. Siemens Corporate Research was involved in the experimental data acquisition and post processing for some of these experiments.

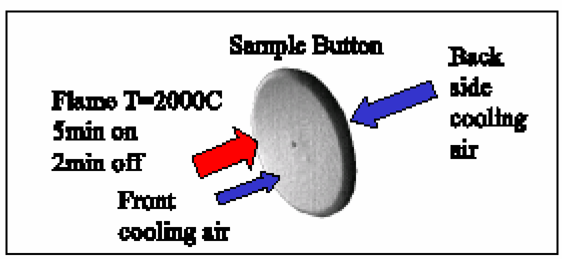


Figure 1

Data acquisition

Figure 2 illustrates one experimental setup, which was used to monitor TBC defect growth using TBC coated test buttons. In this particular experiment a flame was used to heat the test button. In addition cold air was used to cool the test button from the back side and from the front side. During the experiments a test button would be exposed to the heat from the flame for a time of approximately five minutes and then cool down for two minutes. The procedure was repeated for several hours until the end of the experiment. The test buttons were monitored by infrared cameras. A modified version of the Blade Inspector software was used to acquire four images at each heating/cooling cycle. A schematic graph of the button temperature as a function of time is given in Figure 2. In addition, several example images show the appearance of the test button at different stages during the heating and cooling cycle. It is essential for experiments with longer duration to limit the amount of data recoded. The Blade Inspector software was used to track the heating and cooling cycles and to adjust the camera integration time accordingly. A change of integration times required also a switch of corresponding non-uniformity correction files. The change of the integration time was necessary due to a significant change in radiance intensity between the heating and the cooling phase. The on-line unsynchronized tracking of the heating and cooling cycles by the Blade Inspector software allowed to save images a specific states in the cycle. Four states were selected. One image was saved at the end of the cooling phase.

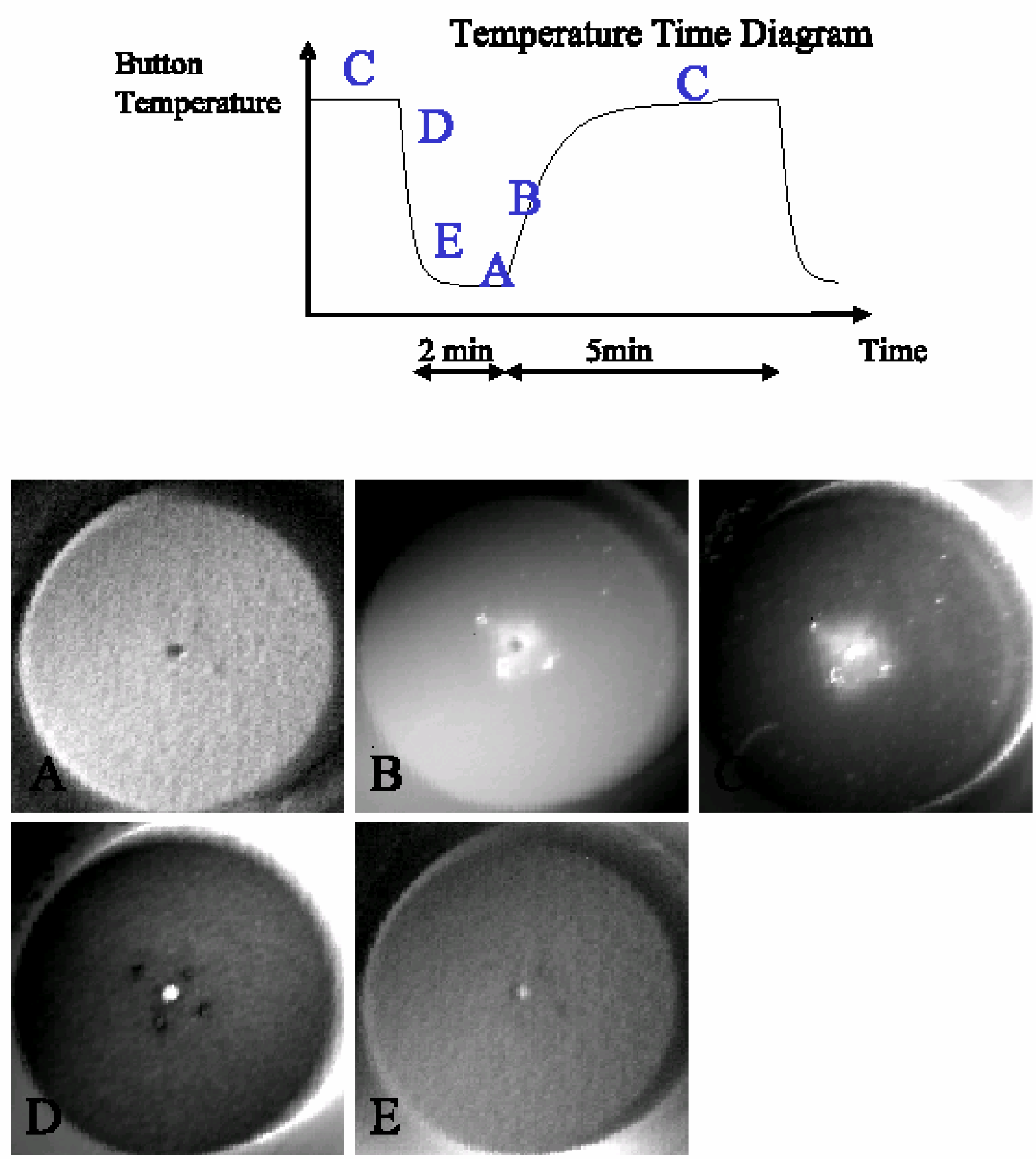


Figure 2

Figure 2: Top: TBC coated test button temperature-time diagram for one cycle, the letters in the graph correspond to images below the graph. Bottom: Thermal Signature of TBC Button during Test Cycle / NIR Sample (Siemens2) with indent, A: small defect in the center, B: delaminated TBC heats up faster and appears brighter, C: BC and delaminated TBC have similar brightness. D: high emittance from BC at beginning of cooling phase, E Emittance from BC and reflected light from flame

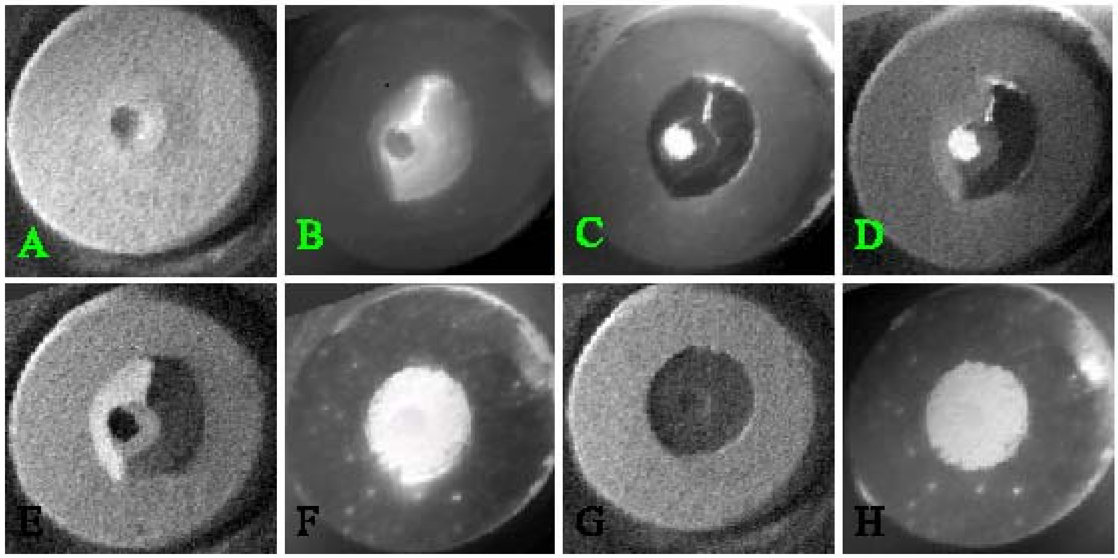


Figure 3

Figure 3: Sample: ID082010101 10mm Defect with indent A: Initial button, B: first heating phase, C, D: begin of cooling phase, buckling, cracks, and strong emittance from BC E: cooling phase, F: Spallation at third cycle heating phase, G: button during cooling phase, H: button several hours later in the heating phase A second image was recorded shortly after the flame started to heat the sample. A third image was recorded approximately three minutes after the start of the heating phase. An additional image was recorded immediately after the flame was turned away from the test button. The four described states in one cycle are marked with the letters A, B, C and D in Figure 2. An additional sample from the same experimental setup shows the very interesting significant variation of appearance in near infrared of the test button during the heating and cooling cycle. It appeared that the most information can be seen in near infrared images during the transition between the heating and cooling phase.

Measurement of TBC defect growth

The prediction of remaining life time and the modeling of TBC defect growth required experimental measurements of defect growth at various experimental conditions. More specific, a measurement of horizontal crack growth was required. Figure 4 shows an example of measured defect size as a function of time. A specific algorithm was developed by Siemens Corporate Research to extract the defect area. The algorithm can correct the angular view to avoid perspective distortions and takes advantage of intensity differences between defects and non-defect areas. The algorithm can operate on a user selected region of interest and extract the defect size over time. The numbers of pixels classified as defect are mapped to physical dimensions (Figure 5). The evaluation of experimental data indicated that the process of defect growth follows more a random and abrupt process and is less continuous. Most samples showed limited defect growth. If TBC defects growth appeared it appeared abrupt and happened within a small number of heating/ cooling cycles. It appeared that the defect growth can randomly stop as well. The experiments confirm that the underlying fraction mechanic is a very complex process and very sensitive to small changes.

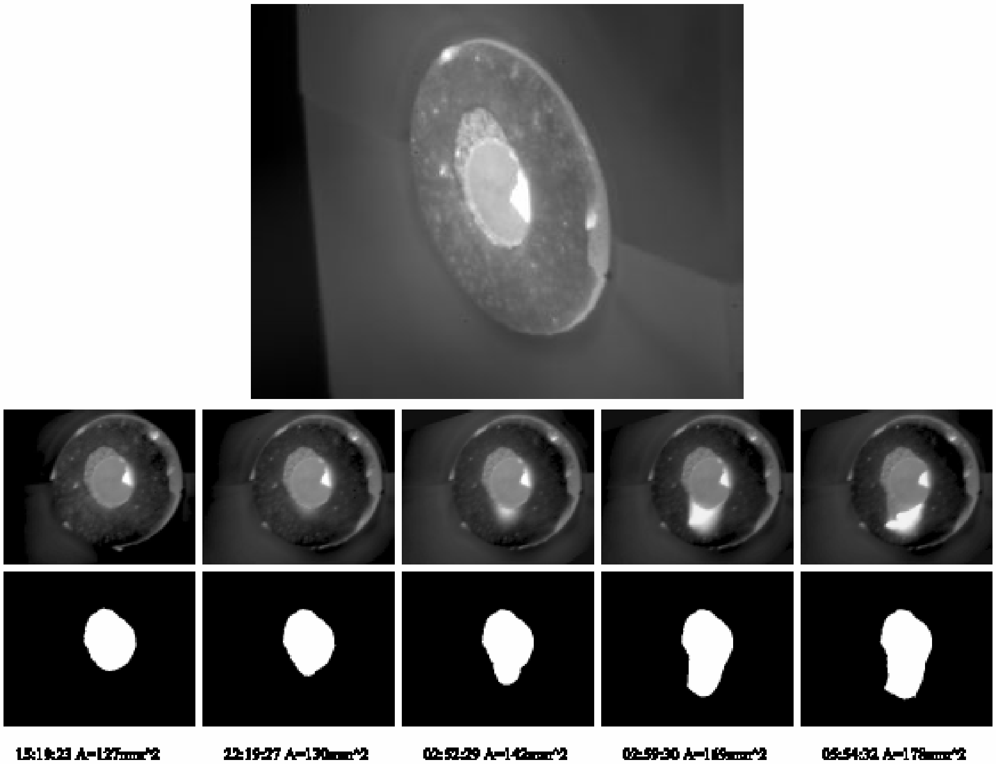


Figure 4 and 5: Segmentation of TBC defect area (horizontal crack growth),

ON-LINE TBC MONITORING – STATUS OF TASK 6

TASK 6: FIELD TRIALS

PROGRAM PROPOSAL

Subtask 6.1 Field trials for blade monitor.

In the final task of the program, the packaged system will be installed on an AGT at one of Siemens Westinghouse's long-term-program (LTP) sites to assess its performance under real plant conditions. A specific turbine engine type and the site for the field trials will be identified during the development process. The engine will be modified as needed for sensor penetrations and installations. Siemens Westinghouse design engineering will be heavily involved with all aspects of the engine changes. Standard engineering practices will assure safe and effective sensor installation.

STATUS OF TASK 6

The results of On-Line TBC Monitoring will significantly improve plant reliability and availability by extending critical component lives. Damaged TBC's can be identified early and repaired before the component's catastrophic failure, and thus will significantly increase availability of peaking gas turbines by eliminating down time required for frequent borascope examination of TBC's. The on-line TBC monitor can be used on all existing and new gas turbines that use TBC to protect critical turbine parts for all applications, to include the use of synthesis gas in Integrated Gasification Combined Cycle operations. The fundamental concepts of the on-line TBC monitoring are equally applicable to smaller land, aero and marine based gas turbines. This opens future global market opportunities.

Figure 6

New row 1 blades and used row 1 blades are shown in figure 6, Monitoring of TBC loss is important to avoid unscheduled engine failure or engine damage. It is necessary to replace coated blades due to the limited lifetime of the TBC.

The installations of the viewing port were installed per drawing # 2346J30 (option 3A). This view looking with flow on the right side of the engine would view the about 90% of the Airfoil height of the leading edge and pressure side of the blade. Figure 7
The installations of the viewing port were installed per drawing # 2346J37 (option 4). This particular viewing port intentionally looks down at the platform and lower airfoil. Figure 8

View 3A

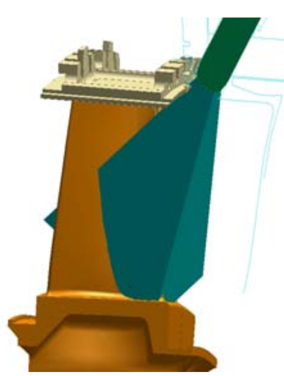


Figure 7

View 4

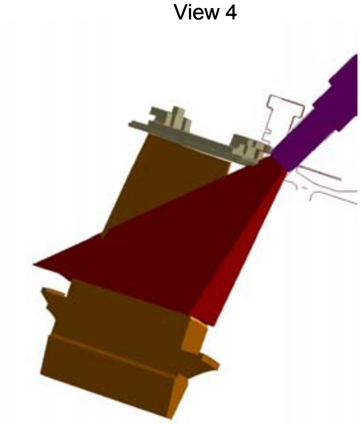


Figure 8

The program models and drawing targeted the viewing and penetration into the turbine and focusing on the primary locations of the leading edge, platform, pressure and suction side of the turbine blades.

The objective and prominent blade failures occurring in the field are:

1. TBC loss caused by:
    - Erosion of TBC Coating
    - Plugged cooling holes
    - FOD Damage
2. TBC spalling caused by:
    - Sintering at over temperature (cooling hole plugs)
3. Delamination of APS coating caused by manufacturing defects
4. Cracks cause by strain accumulation, usually a design flaw

DESIGN REVIEW:

Siemens Westinghouse R-5 Design Review Requirements for Installation

The work to be discussed in this R5 review involves the DOE funded program entitled “TBC On Line Monitoring” system. The intent is to develop a system for real time viewing and, recording, of a Thermal Barrier Coated gas turbine component experiencing the onset of TBC spallation. The overall program involves continuously viewing a row 1 turbine blade surface via an infrared camera system. In order to “see” the target area one or more line of sight “viewing tubes” will be installed in a 501FD CT.

As the title suggests the intent of the effort is to provide a method for observing and gaining an understanding, in real time, of the initiation and process of TBC spallation from the 501FD row 1 turbine blade surfaces. The plan calls for taking continuous, real time, and photographic images of the blade surface under normal engine operating conditions. Thus, in order to “see” the appropriate surfaces it will be necessary to install special tubes that provide line-of-sight viewing of the targeted blade surfaces. The program requires that the system be applied at one (1), as yet undetermined, host site. Operational specifications require that the system be capable of continuous operation, under base load conditions, for at least 8000 hours and thereafter be replaced with standard components at the first opportunity.

Since this program is to be run in conjunction with other DOE funded programs it was decided to first install the system in the Berlin test facility to support the other projects. Thus we will have the opportunity to verify the basic OLM System concept in advance of the site installation.
As shown in figure 9, the original D’Spec indicated four(4) potential viewing paths. Up to and including the R3 view #1 and #3Awere both under consideration with #1 being the first choice. However, due to technical issues associated with view #1 the design effort has focused exclusively on views #3A an #4(a variation of #3A).

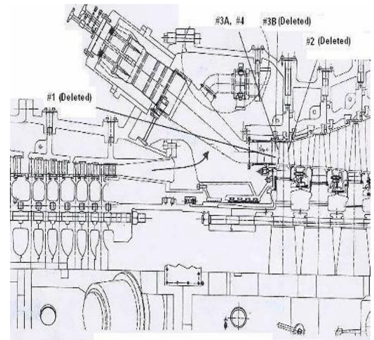


Figure 9

The basic design employees a tube within a tube configuration. The outer tube provides for the overall structural integrity and the internal "lens" tube provides for viewing access to the row 1 blade. The "lens" tube will be used with and without optical lenses installed. The optical lenses are expected to provide for magnification as well as well as the ability to view a much expanded field of view.

The main issues associated with installing the tubes include determining the optimum path for the tubes so as to see the maximum target area while minimizing interferences between the viewing tube and engine components and piping etc. The viewing tube assembly (common to view #3A and #4) is designed to meet all existing mechanical design criteria. It is believed that Views 3A and #4 have no particular issues associated with them and, in fact, #3A has essentially been done before by MHI at FP&L (501F prototype) without any known problems associated with that radiation pyrometer installation as seen in figure 9.

INFRARED CAMERA EXPERIMENTS

Experiments have validated two mechanical design drawing, 3D models and design reviews profiling the penetration and viewing of the turbine to row 1 blades. The criticality ranking of all blade regions, accessibility of blade surfaces, and propensity for degradation for blade surfaces were reviewed and analyzed to determine critical surfaces to be monitored. Testing and analysis, at the Siemens Gas Turbine Manufacturing facility in Berlin, Germany have validated 2 high-speed infrared cameras from Indigo Systems. The validated infrared cameras operated in the infrared spectrum from 0.9 - 5µm. The infrared cameras demonstrated high –speed shutter integration of (3µs) images of an operatingW501 gas turbine at base load condition while view row 1 blades. The row 1 tip speed works out to be 387.422m/sec. This means that for a nominal integration time of 3uS, the blade tip would travel 1.16mm, or about 0.046 inches. This equals about 867 miles per hour. The blade monitor when implemented in phase 2 will provide a radiance profile map of functioning first row turbine blades.

SYSTEM TEST INSTALLATION

The on-line blade TBC monitoring system was installed at two gas turbine engines during the four year program. The system was first installed on a stationary gas turbine at the Siemens gas turbine test center in Berlin, Germany. The system was installed a second time on a customer site (Empire Stateline) in Joplin, MO. Figure 10 shows various images of blades on row 1 from an operating W501FD test bed engine in Berlin, Germany. All images show blades with a leading edge in the front. Cooling holes on the leading edge are clearly visible. A black horizontal line corresponds to the platform gap. Some of the sample blades show a TBC defects on the leading edge. Images of blades from the test installation in Joplin, MO have a similar appearance.

The test installations have shown that several aspects can effect image quality. The alignment between the lens tube and the optical axis of the camera enclosure can drift. This can cause lens shading effects which can significantly reduce the irradiance intensity at the FPA sensor. Image quality degrades also with higher engine load. At higher load, images tend to be more blurry. Vibrations of the camera enclosure, shaft and blade vibrations as well as drift of the optical alignment can cause changes of the relative viewpoint from image to image. The monitoring system can be blind for several hours after engine startup. At this point no all effects are completely understood. The first images of blades acquired during engine runtime of the operatingW501FD test bed engine in Berlin, Germany indicated also that an image based TBC defect detection can be more complicated compared to the image data from TBC coated test button samples with defects.

FIELD TRIAL RESULTS:

Prototype Short Term:

The On-line TBC Blade Monitoring Team was successful in capturing the first infrared images from row 1 blades in the operating W501FD test bed engine in Berlin, under base load. This is the first known example of viewing blades during full turbine operation.

Attached are image frames taken from high speed movies of blades moving at full speed in a operating gas turbine engine environment. These images were taken from one of two viewing ports installed for this purpose. This particular viewing port intentionally looks down at the platform and lower airfoil. The other port looks higher to about 90% of the Airfoil height. Image 1A is a still; white light photograph of a new blade from the perspective of the On-Line Monitor and image 1B is the corresponding view from the On-line Monitor's IR camera during engine operation. Images 2 & 3 are also from the On-Line monitor during engine operation. Image 2 shows clear TBC spallation at the leading edge. Image 3 shows a debond forming in the platform.

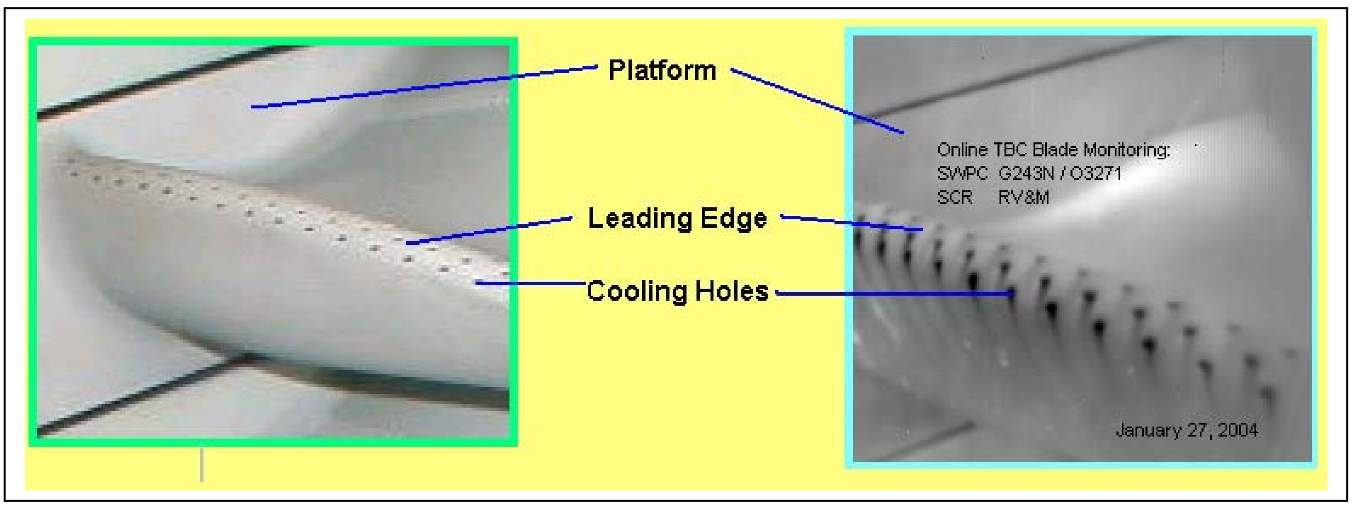
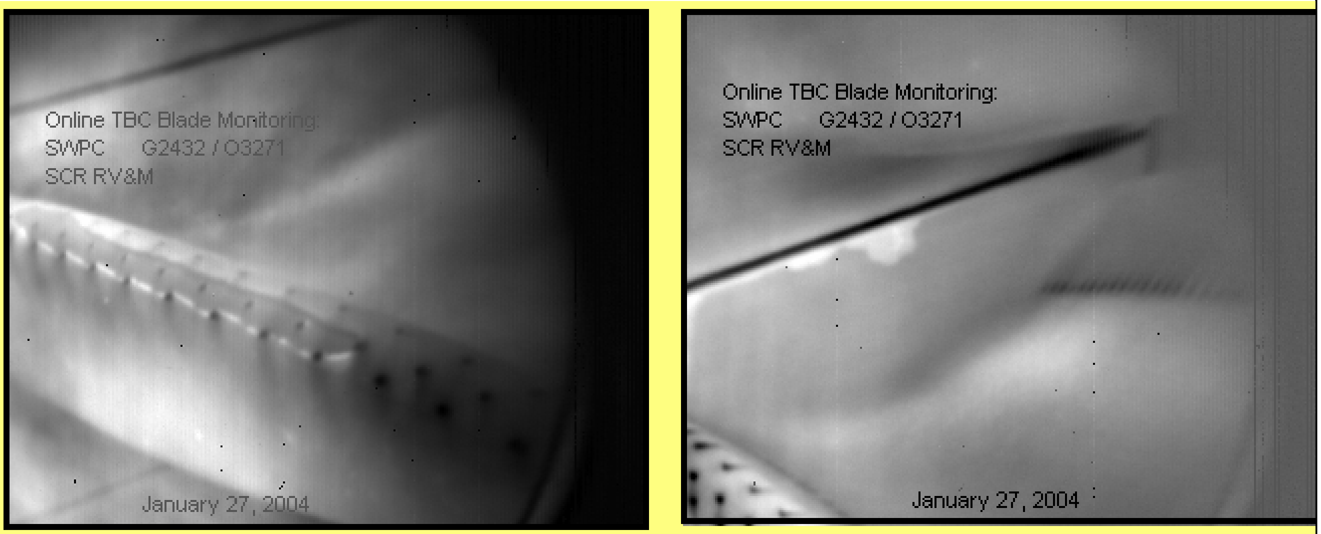


Image 1

This is a major milestone in our $5.12M, 75% DOE co-funded, R&D project. Next steps will be the introduction of remote monitoring and control capabilities via WIN_TS in the Berlin Test Facility (test for future Power Diagnostics applications) as well as the instrumentation of an LTP engine, most likely at Hines Energy Center.



Reference Blade used by Berlin Test Bed showing removal of Leading Edge TBC for identification purposes.

Platform debond. Image clearly shows spalled area and debonding of TBC on the blade platform.

Image 2

Description of System:

Blade monitoring is accomplished by both near and mid- wave infrared (IR) high speed cameras. Two access ports were R5 design reviewed and installed to allow two vantage points for viewing the row 1 blades on the W501FD engine. A pair of IR lens trains were designed and built to install optics within the turbine cover. These optics are capable of withstanding the high temperature of the turbine casing with only a small amount of compressor discharge cooling. The cameras are operated via a control station in the engine test room. A TATM blade rotor synchronization system was developed to allow for specific blade(s) viewing. Custom software has been created to operate the camera(s) and select any combination of blade views and view periodicities. The software also operates filter functions, camera motion and skew. The entire camera system is contained in an environmental enclosure that is cooled with a small amount of compressed shop air. The enclosure is self contained and allows multiple adjustments to the optical system from the engine test room. The system has an expected life of 8,000 hours.

Future Plan:

DOE funded program objective: The next step for the On-Line TBC monitor is to conduct long term tests of the blade monitoring system on an LTP site (planned: first half of FY 04-05). In the meantime, with the experiences from the Berlin Test Bed, we will intensify our work on the artificial intelligence parts of the Overall Supervisory System, which already includes the camera control system and advanced image processing functions. This overall system will organize several sub-systems and report to operations. Specifically, it will recognize debond or spallation events, size the feature, report it to the TBC lifing algorithm, predict growth rate, and estimate remaining life given operating parameters. The Overall Supervisory System will be operated remotely and is able to interact with the existing Power Diagnostics data acquisition infrastructure.

LONG TERM DEMONSTRATION:

Field Installation and Testing

The on-line blade TBC monitoring system was installed at two gas turbine engines during the four year program. The system was first installed on a stationary gas turbine at the Siemens gas turbine test center in Berlin, Germany. The system was installed a second time on a customer site (Empire Stateline) in Joplin, MO. Figure 10 shows various images of blades on row 1 from an operating W501FD test bed engine in Berlin, Germany. All images show blades with a leading edge in the front. Cooling holes on the leading edge are clearly visible. A black horizontal line corresponds to the platform gap. Some of the sample blades show a TBC defects on the leading edge. Images of blades from the test installation in Joplin, MO have a similar appearance. The test installations have shown that several aspects can effect image quality. The alignment between the lens tube and the optical axis of the camera enclosure can drift. This can cause lens shading effects which can significantly reduce the irradiance intensity at the FPA sensor. Image quality degrades also with higher engine load. At higher load, images tend to be more blurry. Vibrations of the camera enclosure, shaft and blade vibrations as well as drift of the optical alignment can cause changes of the relative viewpoint from image to image. The monitoring system can be blind for several hours after engine startup. At this point not all effects are completely understood. The first images of blades acquired during engine runtime of the operatingW501FD test bed engine in Berlin, Germany indicated also that an image based TBC defect detection can be more complicated compared to the image data from TBC coated test button samples with defects.

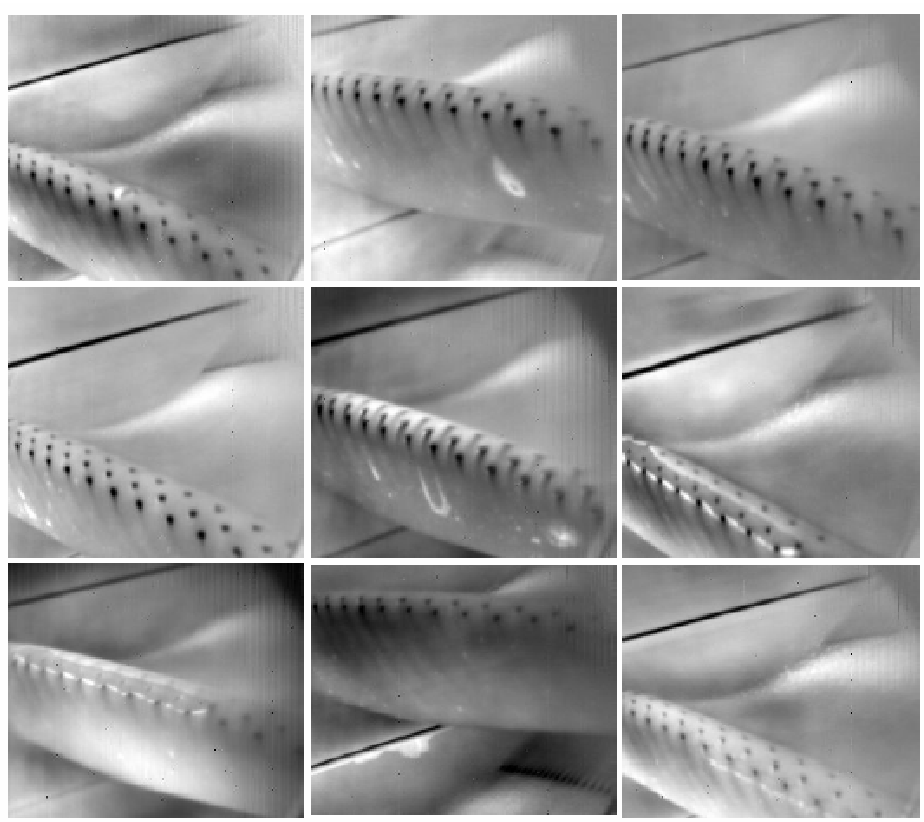


Figure 10: First infrared images from row 1 blades in the operating W501FD test bed Engine in Berlin, Germany

Online Monitor Blade monitoring at Empire State Line has now operated for over 4000 hrs giving real-time information of the turbine blades in the form of an image of the blade features such as cooling hole blockage, platform gap leakage, thin film cooling effect and TBC defects are visible. Figure 11 shows various images of blades on row 1 and row 2 from an operating commercial W501FD engine at Empire District Electrical Co., Joplin Missouri .The system currently has potential to map relative temperature and flow visualization. Planned improvements outside of this effort should allow absolute temperature measurements. This monitoring system continues sending images via WinTS to the Power Diagnostics Center in Orlando. The design and development for On-Line Monitoring for additional gas turbine engines also included NGF, GM and V94.3A engines.

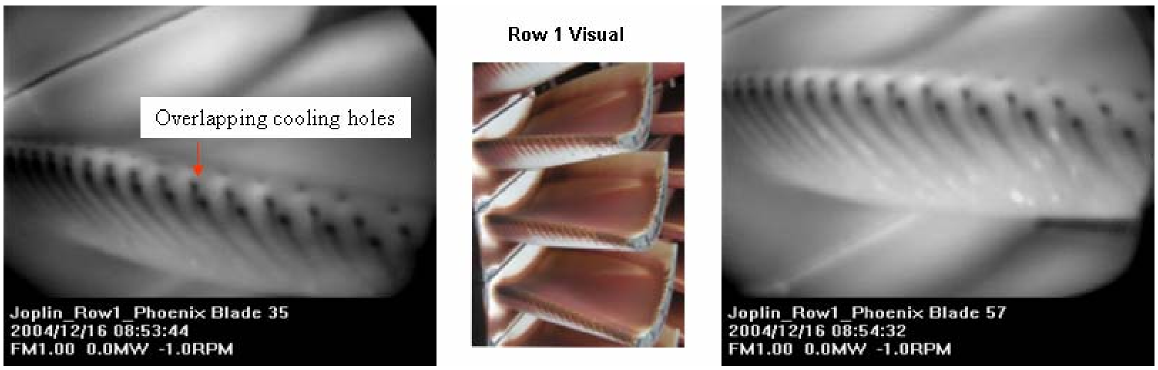


Figure 11: First infrared images from row 1 and row 2 blades in the operating commercial W501FD engine at Empire District Electrical Co., Joplin Missouri.

BENEFITS OF THE ON-LINE MONITOR PROGRAM

1. Increased Production Capacity Through Higher Equipment Availability. Early failure detection and minimized unplanned downtime. Reduced duration of major outages

2. Reduced Maintenance Costs

    Less overall maintenance effort by putting more emphasis on a conditioned based maintenance approach and elimination of time base maintenance activities

    Reduced cost-intensive corrective maintenance by avoiding unexpected failures which usually can be associated with overtime work and more expensive spare parts

    Improved planning and personnel utilization

3. Reduced Capital Costs

    Reduced spare parts inventory due to elimination of catastrophic failure and maximizing reparability

    Extended equipment life

4. Reduction of Risk

    Real time evaluation of new coatings/ designs

    Improved safety by preventing sudden equipment failure

CONCLUSION

The On-line TBC monitoring program has taken an aggressive approach to develop and install a real-time monitor for both blades and vanes. The program continues to meet and/or exceed the milestone and budgetary requirements. As reported, Siemens Westinghouse engineers have detailed a procedure to penetrate and install a spectral relay-imaging instrument to measurement the radiance, in real-time, row 1 blades. The radiance is relayed through the imaging tube and onto the focal plane array of the high-speed infrared camera operating with a spectral response of .9 – 5.0 microns. The emittance of clean TBC in the short infrared is very reflective, with longer infrared near black body emittance. The contrast in short wave provides the greatest contrast between the TBC coating and bond coat interface. This contrast provides radiance change information to monitor the progressive growth and spallation between these two interfaces. Additional tests next quarter (YR05) will determine the remaining life probability for the On-line numerical model. The On-line TBC Vane Monitor continues with the final down-selection, thus being the Acoustic Wave-Guides. Tests have indicated this sensor can be installed with minimal sensors and wires, very sensitive to TBC loss, and independent of geometry.

Key Milestone Update

Current program milestones are on or ahead of schedule.

PROGRAM STATUS

Achievements from 10/01/01 – 09/30/04

- DOW Proof-of-Concept Testing, November 2001
- 3D Model Scoping penetration location and direction, 3 of 4 models complete
- Westinghouse Plasma Center HHFTR Modification, Completion May 2002
- Spectroscopy measurements of GT working fluids, DOW Test, November 2001
- Purchase of NIR Infrared Data Acquisition system and rental agreement of Infrared camera head
- Siemens Westinghouse Power Corporation Program review, Completion March 28, 2002
- Select Infrared Hardware, Milestone completion April 2002
- Siemens Westinghouse Power Corporation Program review, Completion May 28, 2002
- Siemens Westinghouse Power Corporation Program review, Completion September 27, 2002
- R5 Design Review for Radial Penetration, Completion January 2003
- On-Line TBC Monitor system installation in working gas turbine, January 2004 (Berlin, Germany)
- Successfully installed an on-line TBC Blade Monitor in a W501FD gas turbine at Empire State Line Electrical Company in Joplin Missouri.

Milestone Completion, 2002

- Develop Proof of Concept of Infrared Sensor, Complete 12/10/2001
- Select/Develop infrared sensors - The final selection for the core of the blade monitor, the focal plane array, Complete 3/12/02
- Conduct lab prototype experiments on selected vane sensors - The vane sensor elements and concept will be evaluated in a lab environment, Complete 8/30/2002
- Assess computer controls and software needs - This effort will complete the statement of computer and software needs anticipated to input, update and archive the data generated by both the blade and vane monitors. Complete 8/30/2002
- Modify current high heat flux test rig - The High-Heat Facility rig test will be retrofit for Blade monitor simulation. Complete 6/6/2002

Milestone Completion, 2003

- Modification of high temperature test rig and TBC Lifing tests, Complete 12/01/03
- Installation of On-line Monitor View Ports for Row 1 blades, Complete 11/01/03

Milestone Completion, 2004

- First infrared images from row 1 blades in the operating W501FD test bed engine in

Berlin, under base load, 01/27/04 (Berlin, Germany)

- Identify available blade test facility, Completed 09/01/04
- Complete AI supervisory software/hardware integration into the system operating software, completed 05/31/04
- Complete implementation of TBC remaining life prediction software, completed 06/30/04
- Successfully installed an on-line TBC Blade Monitor in a W501FD gas turbine at Empire Stateline Electrical Company in Joplin Missouri

Presentations & Publications

None