Advanced Turbine System Conceptual Design and Product Development

Topical Report for Non-Destructive Techniques for the Evaluation of Overlay and Thermal Barrier Coatings on Gas Turbine Components (Task 8.2.4.2)

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**Non-Destructive Techniques for the Evaluation of Overlay
and Thermal Barrier Coatings on Gas Turbine Components**

**Advanced Turbine Systems Program
Department of Energy**

Summary

There is currently no satisfactory non-destructive method for measuring the condition of overlay coatings applied on new or engine-run engine parts in gas turbines. The purpose of this program has been to evaluate the potential of various methods e.g. eddy-current and ultrasonic, for the non-destructive evaluation of overlay coatings in thermal barrier coatings systems and the results are described in this report. It is shown that a variant of the eddy-current method will give good correlations with metallographic measurements for determining the thickness of new coatings but neither eddy-current nor ultrasonic techniques gave a good measure of the extent of degradation of engine-run parts. There is however scope for improvement and some recommendations are made.

Introduction

There is currently no satisfactory method for the non-destructive examination (NDE) of coatings on gas turbine parts and determination of coating thickness, for example, has to be carried out by sectioning of the component and subsequent metallographic analysis. This method, which is both time-consuming and expensive, has nevertheless been used extensively for aero-engine parts to monitor coating quality and to gather statistical information for process control. For large components from utility size gas turbines costs are high and compared with aero-engines, only a limited number of parts can be examined so that the destructive method becomes less attractive both as an inspection technique and for obtaining process control data to measure part to part variations in coating thickness, for example.

During engine service protective coatings slowly degrade and this degradation process effectively controls the life of the part, particularly in situations where a thermal barrier coating (TBC) is used to protect against excessive metal temperatures. In this case growth of the oxide at the interface between the bond coat and the TBC leads to a build-up of stress in the TBC which can be relieved by a spalling of the ceramic layer and loss of the protection from the thermal barrier. In situations where the integrity of the TBC system is critical to the survival of the part, some non-destructive method of determining the degradation condition of the bond coat would clearly be advantageous.

In this report the results are described of recent progress in a program to develop non-destructive methods to measure coating quality and to monitor the condition of coatings in service. The work which has formed part of the Advanced Turbine Systems (ATS) Project funded by DOE, has involved the use of eddy-current (ET) and ultrasonic (US) methods developed by SouthWest Research Institute (SwRI) who have been responsible for development of the technique.

Experimental Results

(i) *Measurement of Coating Thickness*

The eddy-current technique depends on the principle that when a coil energized with an alternating current is placed on the component surface a localized electric current which is sensitive to the thickness both of the coating and the base material is generated in the conductive material. When a TBC is present the thickness of this non-conductive ceramic can be readily determined since the response from the underlying layer is simply a measure of the spacing between the probe and the bond coat. The thickness of the bond coat also affects the TBC response and can be readily observed.

In order to measure the thickness of the metallic bond coat and overlay, a more sophisticated approach involving a dual-beam eddy current technique, has to be used and this method, known

as Smart Eddy has been developed by SwRI. During a previous phase of the program the Smart Eddy system had been calibrated using standard samples with coatings of different thickness. The thickness was measured by the Smart Eddy system in each case and then the samples were sectioned and the thickness confirmed by metallography so that a set of calibration curves could be prepared, Figures 2 to 5. It can be seen that good correlations were obtained in each case between the eddy-current and the metallographic measurement.

These results encouraged the next stage of the work viz. the measurement of a coated component but preliminary data were clearly badly in error and this caused a re-evaluation of the approach. Consequently a somewhat different method was used which included moving to a four-frequency eddy-current device and a manual method of contacting the probe on the component surface. This allowed the probe to be maintained normal to the surface of the component which is the desirable configuration and which was not possible to achieve when the probe was placed in a "fixturing" device. The critical factor here is that when the probe is not normal to the surface a "lift-off" effect occurs which gives an error in the measurement.

Using manual contact with the component surface measurements were made with the four-frequency eddy-current unit and the results obtained are shown in Figure 6 along with the data obtained from metallographic determinations. The agreement is good and within 25 microns which is considered to be a reasonable correlation bearing in mind that variability in the metallographic measurements can be in this range. Thus, it appears that this modified procedure can give a good indication of the thickness of an overlay-type coating which could form the basis for a non-destructive procedure.

(ii) *Coating Degradation*

A TBC coating system will degrade during service as the underlying bond coat oxidizes and the growth of the oxide is accompanied by a loss of alloying elements from the coating so that a depleted zone is formed at the interface between the substrate and the coating. Thus the formation of this depleted zone is an indication of the overall degradation of the coating system since as oxide growth occurs, the growth strains must be accommodated by the ceramic layer and as these build up, the TBC will crack and spall. The ability to measure the rate of growth of this depleted zone would give an indication of the probable life of the TBC system. Two techniques were used to measure this depleted layer in engine run parts viz. eddy current and ultrasonic.

(a) Eddy Current Measurements. Measurements were made at SwRI on engine run parts at frequencies of 0.5, 1.8, 4 and 6 MHz and subsequently the parts were sectioned and examined metallographically to determine the extent of alloy depletion beneath the TBC. The measurement locations are shown in Figure 7 which also gives the thickness of the depleted layers for various engines and it is clear that the amount of depletion varies considerably at the various locations in a given blade and from blade to blade. Where large amounts of depletion occurred (180 μm) at the leading edge, this was the result of loss of the TBC due to spalling and subsequent rapid

oxidation. Thus depletion measurements at the leading edge, or in other areas where serious degradation had occurred e.g. around cooling holes will be misleading and not representative of the conditions beneath a TBC.

Despite these reservations all the data obtained except leading edge have been plotted in Figure 8 as a function of the metallographic measurement and it clear that there is considerable variability. However from the distribution of the data it would appear that thicknesses of less than or greater than 80 μm could be detected. It appears that some further effort would be necessary to refine the measurement and in particular, to separate the effects of TBC thickness, coating thickness and curvature effects from the measurement of depletion.

(b) Ultrasonic Measurements. In this case the aim was to measure oxide thickness at the interface between the ceramic and the bond coat by measuring the amplitude of a signal reflected from the interface. Measurements were performed on engine run blades at SwRI using a 25MHz piezoelectric transducer with 1.25 mm diameter beam size on TBC coated vanes removed from various GT11N engines and compared with data from metallographic examinations, Figure 9. Samples were scanned in a raster pattern, and the amplitude of the reflected signal at the ceramic/bond coat interface was measured as a function of position. The results are shown in Figure 10 as a function of oxide thickness which had been previously measured at the same location. Surprisingly the data show a decrease in amplitude of the ultrasonic signal with increasing thickness which was an unexpected result. Previous work (2) on flat samples in the laboratory had shown an increase in amplitude as the oxide layer increased in thickness. In this case oxidation had been carried out in a laboratory furnace and in-service the pattern of degradation would be expected to be more variable around the airfoil. Consequently an attempt was made to analyze the data more locally i.e. adjacent to the location of the metallographic measurements. However there was no significant improvement in the correlation obtained. Clearly, further effort is required in order to develop a closer correlation with the local oxidation morphology.

Conclusions

1. The results suggest that a multi-beam eddy current technique could provide the basis for a non-destructive method for the measurement of the thickness of overlay coatings on gas turbine parts.
2. Results of the application of an eddy-current technique to monitor the degradation of overlay coatings by measurement of the depleted region at the coating-substrate interface suggest that the method has some potential for condition monitoring of coatings.
3. When an ultrasonic method was used to measure oxide thickness it was shown to be very sensitive to local variations in degradation when applied to a component and will require further development.

Recommendations for Further Work

1. Further work to demonstrate the four frequency eddy-current device for measurement of coating thickness in SV20 should be carried out. Preferably this should be in collaboration with a coating vendor.
2. The eddy-current technique should be applied to the measurement of thickness in SV34.
3. Further work to apply eddy-current methods to measure alloy depletion should be carried out in order to understand the reasons for variability.

References

- 1.0 G. Burkhardt et al., "Nondestructive Evaluation of High-Temperature Coatings for Industrial Gas Turbines", Superalloys 1996.
- 2.0 M. Cybulsky, "Non-Destructive Inspection of Turbine Blade/Vane Coatings", MWC-TR-9501, January 1995.

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Fig. 1: Locations on GT-11N blade where coating thickness measurements were made

Fig 2: Blade calibration fit, position C2

Fig 3: Blade calibration fit, position C3

Fig 4: Blade calibration fit, position X2

Fig 5: Blade calibration fit, position X3

Fig. 6: Calculated thickness on sample blade (via eddy current) versus metallographically measured

Location	Lakewood	Pascagoula	Midland 9	Midland 5
1	15	30	180	0 0
2	25	30	40	30 10
3	30	20	20	50 50
4	25	20	40	100 90
5	5	5	15	40 30
6	0	5	-	20 10
7	10	110	60	70 70
8	20	90	50	80 90
9	20	90	40	100 110
10	20	100	80	80 90
11	10	20	40	50 60

Fig. 7: Alloy epletion metallographically measured on engine run blades

Fig. 8: Graph showing alloy depletion measured metallographically vs predicted thickness measured by eddy current

ENGINE RUN ROW 1 VANES

Engine	Leading Edge (1)	Bridge SS (2)	Bridge PS(11)
Lakewood	6.57	5.82	6.87
Pascagoula	3.89	17.97	TBC Spalled
Midland 9	12.14	7.53	7.00
Midland 5	10.39	13.60	TBC Spalled
Midland 6	6.20	1.46	5.68
Midland 10	8.31	4.02	3.14

Fig.9: Oxide Measurements (μm) of Bridge Area and Leading Edge

Fig. 10: Ultrasonic signals from ceramic/bond coat interface on “engine run” vanes