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Thermal History Paint case study

Nozzle Guide Vane Segment of small aircraft engine

The novel technology, Thermal History Paint, was successfully applied to measure the temperature of a jet engine component at over 375 locations with an estimated precision of ±5°C. The results compared well with thermocouple data and a summary of the project is provided in this short report.

Background

The Aerospace Research and Test Establishment - VZLÚ in Prague, Czech Republic together with the manufacturer of high-speed turbine machines for the aerospace, power and transport industries PBS Velka Bites developed a new design for a Nozzle Guide Vane Segment (NGVS) of a small jet engine. The purpose of the redesign was to overcome overheating of the components. A successful redesign extends the life of the components by avoiding burning of the trailing edges. The development included extensive testing using a dedicated test stand and was conducted as part of the ESPOSA[1] FP7 programme.

The design included the introduction of internal and film cooling to the components. To validate the design, temperature measurements were required across the surface of the components, particularly at the trailing edges. VZLÚ identified Thermal History Paint as an ideal solution to deliver the temperature information required. Sensor Coating Systems (SCS) worked with VZLÚ to successfully implement the unique technology on the NGVS.

"The SCS data delivered back to VZLÚ meets and even surpasses the initial VZLÚ requirements. The data extends very limited information from thermocouples and brings the complete view to the thermal process inside the cooled NGVS."

Tomáš Jelínek, VZLÚ

What is Thermal History Paint?

It is a new, more efficient and cost effective temperature sensing technology to replace current thermometry methods. The unique technology, patented by SCS, will be beneficial in all industrial sectors where temperature information is essential. The paint comprises luminescent sensor materials and a water based binder. When heated in operation, the luminescent properties of the sensor coating permanently change according to the temperature of exposure. After operation, an automated optical read-out device measures the luminescence to provide the maximum temperature of operation. The thermally activated changes occur over a wide temperature range so that a temperature profile can be measured without data gaps. The current operating range is 200-900°C with a precision of ±5-10°C. A development programme is underway to extend the range to 100-1200°C. For further information on the technology see references [1,2].

Figure 1. A measurement in action on the NGVS.

[1] *http://www.esposa-project.eu/en/efficient-systems-and-propulsion-for-small-aircraft-2.html*

Results on the Nozzle Guide Vane Segment

Thermal History Paint (THP) was applied by SCS to all the gas facing surfaces of the NGVS, which comprised three individual Nozzle Guide Vanes (NGVs). Also, four thermocouples were fitted, one at the leading edge of NGV 2 and one at the trailing edge of NGV 2, 3 and 4 (see Fig. 2). The component was installed and operated at VZLÚ in the engine test stand. Unfortunately an unrelated component failure caused the test to be stopped prematurely after approximately 6 minutes at constant load. After operation the segment was removed and there was no significant damage to the paint, as shown in Fig. 2. As expected, there were colour variations on the paint due to the temperature profile over the component. Hot spots can be identified visually, for example close to the hub the paint on the aerofoils appeared dark suggesting higher temperature.

Figure 2. A photograph of the (left) front and (right) back of the NGVS after operation.

Samples of the same material, painted alongside the NGVS, were used for calibration. The samples were individually heat treated for 6 minutes between 380°C and 905°C. After heat treatment, all samples were measured to generate the calibration dataset. To estimate the precision 25 measurements were recorded at 5 different locations on several samples. The standard deviation of the measurements was less than ±5°C. All the painted surfaces of the NGVS were measured in over 375 locations. The temperature profile was similar over the different NGVs. This profile showed good agreement with simulation data provided by VZLÚ. A summary of the results at two locations are provided in the following sub-sections.

Trailing edges

The measurements recorded at the trailing edges on the pressure side of the NGVs (see Fig. 3) are provided in Fig. 4. The results show that there was a similar trend along the trailing edges of the different NGVs. The temperature decreased from the hub to the shroud. However, there was a significant difference in temperature between the different NGVs.

This variation in temperature correlated to the readings from the thermocouples installed at the trailing edges on the suction side. A comparison of the results from the THP and the thermocouples (TCs) is shown in Table 1.

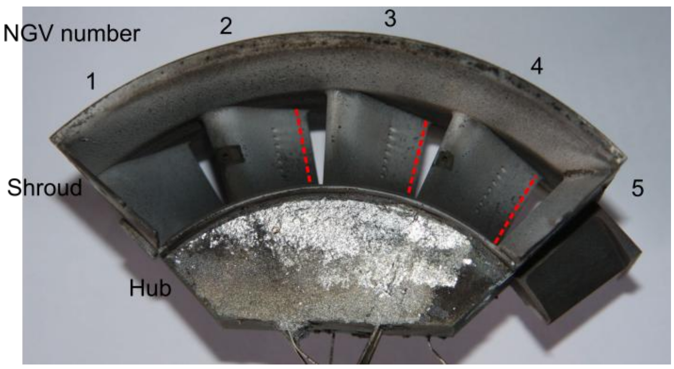

Figure 3. A photograph of the NGVS showing the locations of the measurements using THP on the trailing edges as red dashed lines.

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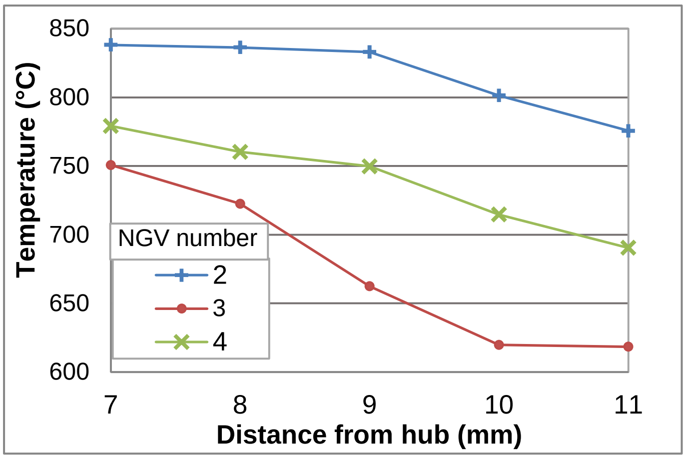

Figure 4. The temperature measurement results recorded at the locations shown in Fig. 3.

Table 1. The temperature measurements from THP compared to results from the closest located thermocouples.

NGV	THP reading	Closest thermocouple location
2	833°C	~800°C
3	662°C	~660°C
4	750°C	~740°C

Shroud

The downstream surface of the shroud was measured along four lines as shown in Fig. 5. The temperature readings from these four lines are shown in Fig. 6. All measurement lines follow a similar trend, the temperature increased on all measurement lines to a maximum at a rotational angle of 20-40°. This indicated that there was a band of higher temperature across the shroud surface. The temperature variation was greater closer to the NGVs (18mm line). The temperature variation over the surface can be more clearly visualised in the contour plot shown in Fig. 7.

All measurement lines follow a similar trend, except the line at 12mm between 80° and 95°. At this location there is a wide fluctuation in the temperature measurements in a short space. This fluctuation also appears as a discontinuity in the contours in Fig. 7. At this location, the measurements were made at a repair on the component, therefore, there was a different substrate material. The change in material, hence heat flow, may cause this fluctuation.

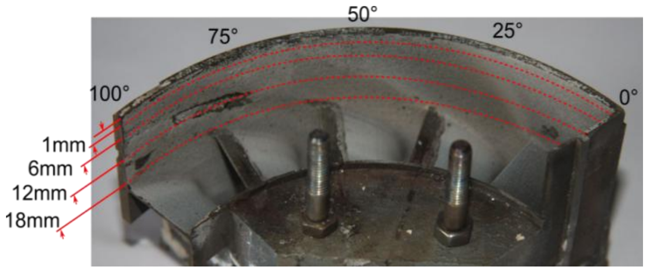

Figure 5. A photograph of the shroud with the four measurement lines labelled.

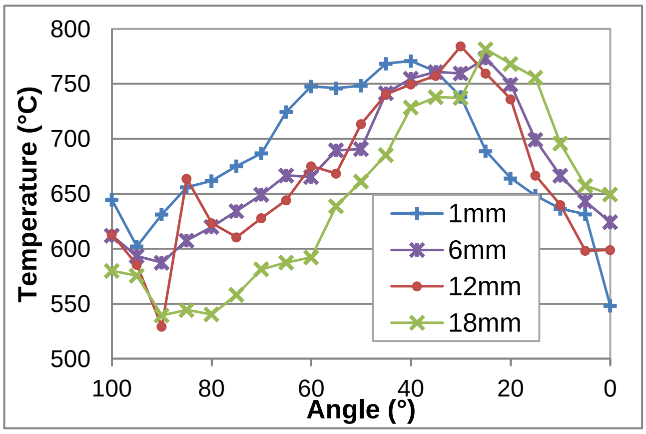

Figure 6. The measurement data recorded on the shroud surface shown in Fig. 5.

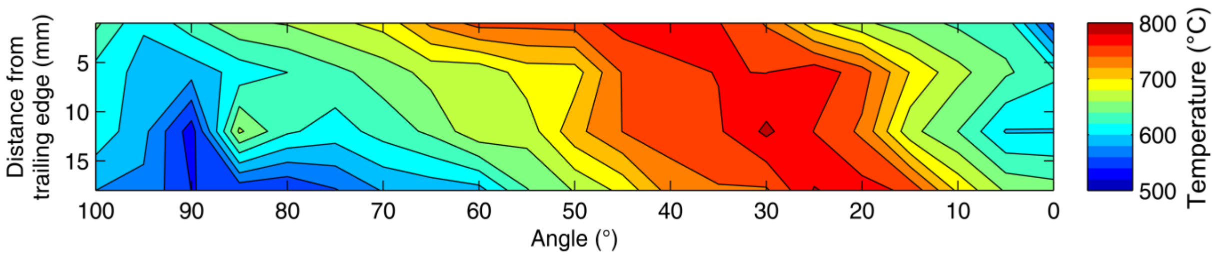

Figure 7. The temperature measurement results on the shroud surface shown in Fig. 5 represented as a contour plot. The contours are at every 20°C.

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Conclusions

- Thermal History Paint was applied to a Nozzle Guide Vane Segment for a small aerospace gas turbine.
- The paint survived testing without significant damage.
- Temperature measurements were recorded at over 375 locations.
- The results correlated well with simulation data and thermocouple readings.
- A dedicated calibration dataset was generated and indicated a precision of ±5°C on the measurements.

About Sensor Coating Systems

Sensor Coating Systems (SCS) Ltd. spun out of Southside Thermal Sciences (www.stscience.com) in 2012. SCS pioneers sensor technology based on luminescence materials for engineering applications in demanding environments. Its award winning technology enables accurate temperature detection, corrosion and erosion monitoring and life-time predictions and, in doing so, assists in optimising the operation of machinery, lowering fuel costs and maintaining material integrity. The main industrial sectors for application are the power generation industry, aero engines, automotive and machinery operating in extreme environments. SCS is internationally orientated and works with companies such as MAN Diesel & Turbo, Alstom and Snecma under collaborative agreements and also with reputed institutions such as the German Aerospace Centre. The technology has been also endorsed by a plurality of grant organisations in the UK and the US including INNOVATE UK and the British National Aerospace Technology Exploitation Programme (NATEP).

SCS received the British Engineering Excellence Award 2013. More recently the SCS technical team including co-workers received the prestigious John P Davies Award of the International Gas Turbine Institute (IGTI) of the American Society of Mechanical Engineers (ASME) in June 2014.

References

1. ‘Off-Line Temperature Profiling Utilizing Phosphorescent Thermal History Paints and Coatings’, J. P. Feist, S. K. Biswas, C.C. Pilgrim, P. Y. Sollazzo, S. Berthier, *Journal of Turbomachinery*, Vol. 137, Iss. 10, (2015), http://turbomachinery.asmedigitalcollection.asme.org/article.aspx?articleID=2237963
2. ‘Thermal barrier sensor coatings - sensing damage and ageing in critical components’, C. C. Pilgrim, P. Y. Sollazzo, S. Berthier, J. P. Feist, S. K. Biswas, J. R. Nicholls, *IET & ISA 60th International Instrumentation Symposium*, (2014) http://digital-library.theiet.org/content/conferences/10.1049/cp.2014.0558