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VALIDATION OF A THERMAL HISTORY PAINT ON A TURBINE BLADE IN A HOT GAS RIG FACILITY

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1. ABSTRACT

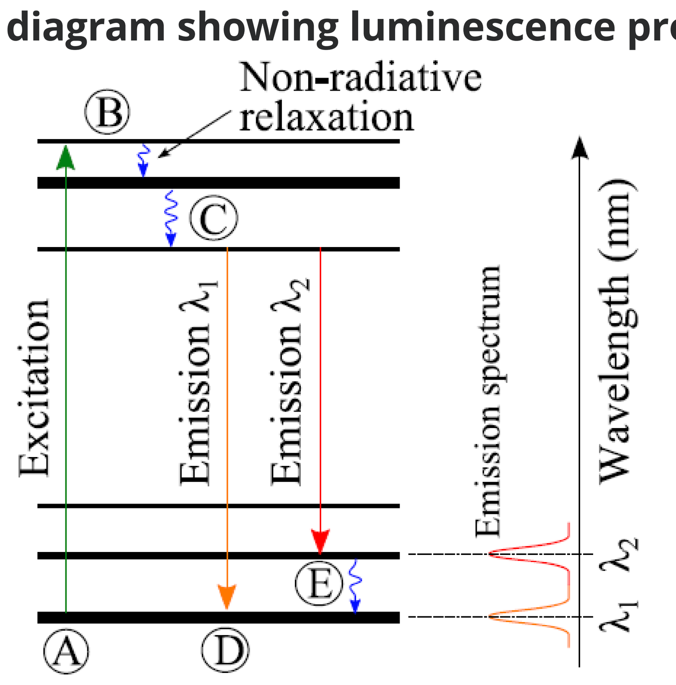
The drive to higher efficient engines and lower emissions is achieved by increasing firing temperatures. This is leading to sophisticated cooling designs and advanced high temperature materials. Validation on critical components require novel temperature measurements, where surface temperature measurements can make a difference. According to the Propulsion Instrumentation Working Group [1], over 80% of an aerofoil in all turbine blades needs to be measured for test monitoring and to verify durability. Design engineers require a high resolution thermal mapping technique.

A new thermal mapping technology was tested in realistic combustion conditions. Thermal History Paints [2] and Coatings [3,4] are novel temperature sensing technologies, able to reveal temperatures along surfaces of turbomachinery components. An internally cooled gas turbine vane, instrumented with 30 thermocouples, was tested for 45 minutes in hot gas test rig. The thermocouple data was used to conduct a post calibration procedure, and validation against FEM predictions [5]. All three data sets were in very good alignment, showing average variations of +/- 4°C.

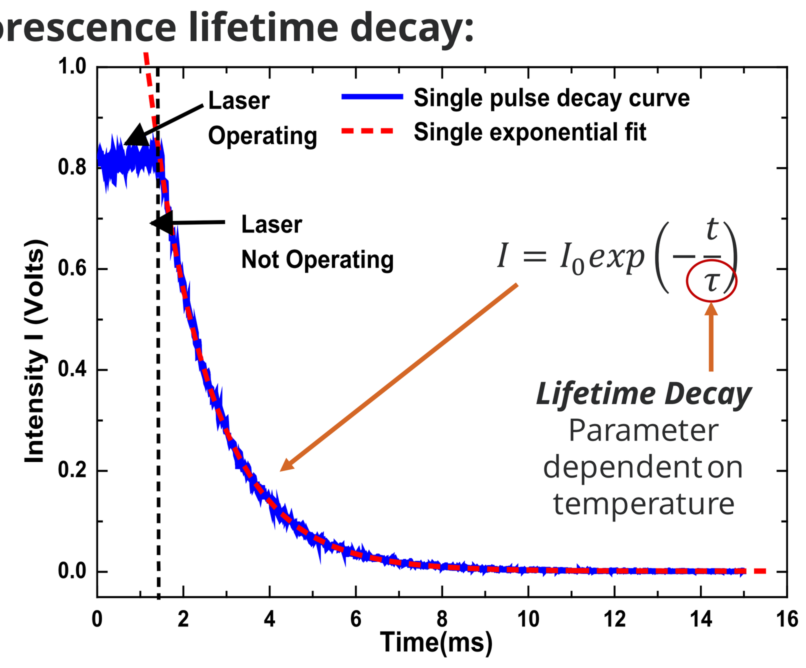
2. PRINCIPLE

Rare earth ions act as atomic level sensors. When irradiated with light, electrons promote to higher energy states. The relaxation happens via two competitive processes, radiative and non-radiative. Permanent changes in their internal structure due to heat exposure causes crystallisation and fixes temperature information. Lifetime Decay can be measured providing sensitive thermal profiles.

Energy level diagram showing luminescence process:

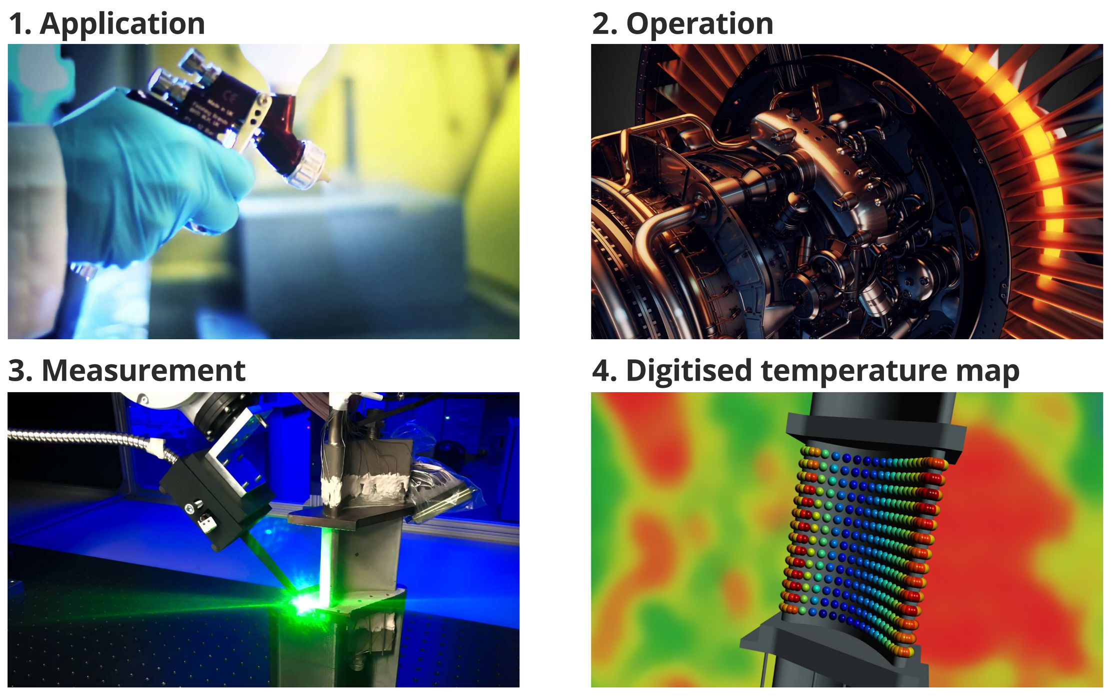


Phosphorescence lifetime decay:



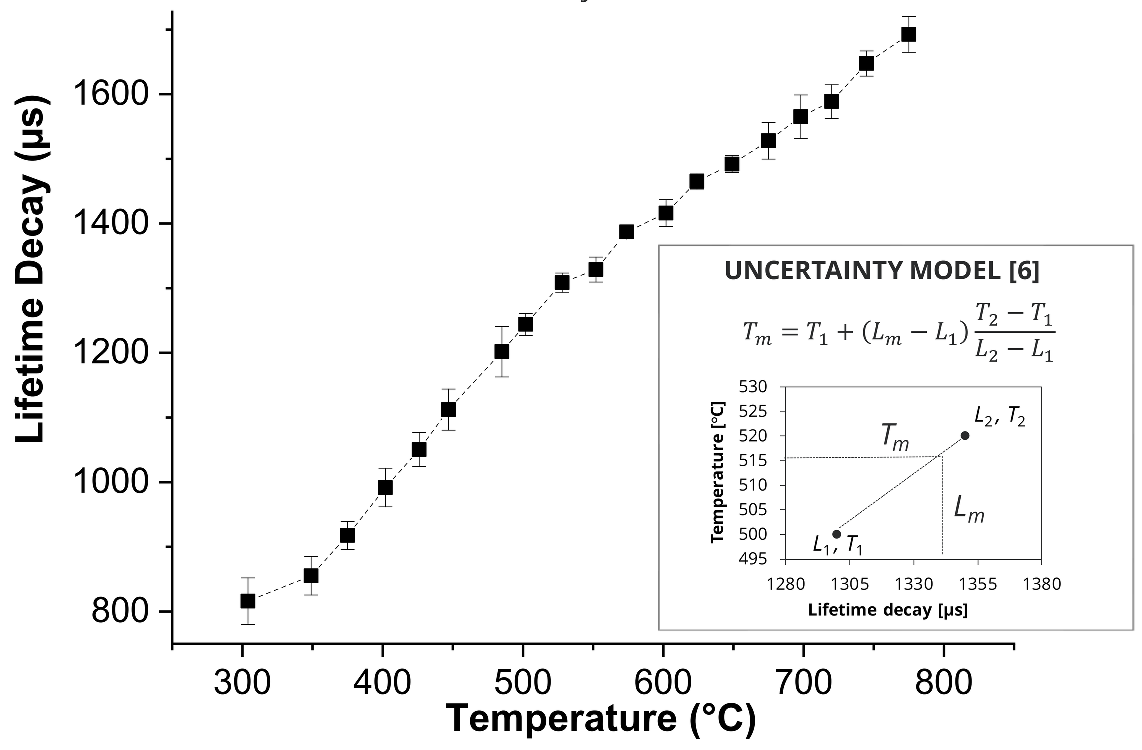
3. APPLICATION

Safe, REACH compliant, luminescent materials are manufactured, applied onto components surfaces. These operate in hash conditions and after operation, laser light excites the luminescent ions and allows single point life-time decay measurements along surfaces of turbomachinery components. The temperature information can be read-out by automated scanning system, and printed onto representative 3D models.

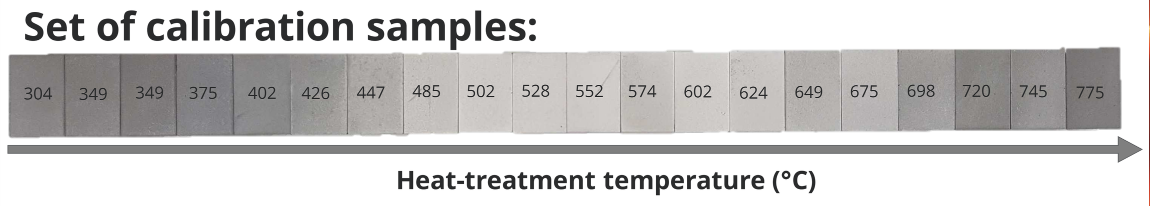


4. CALIBRATION

Heat treatments of 18 individual calibration samples from 300°C to 775°C, heat treated for the same time the vane was tested in the rig, 45 minutes. The calibration data shows an approximately linear trend with temperature. Error bars represent the standard deviation of measurements, multiplied by a factor of 5 for visualization. An Uncertainty Model [6] was developed specifically for calibration of Thermal History Paints.

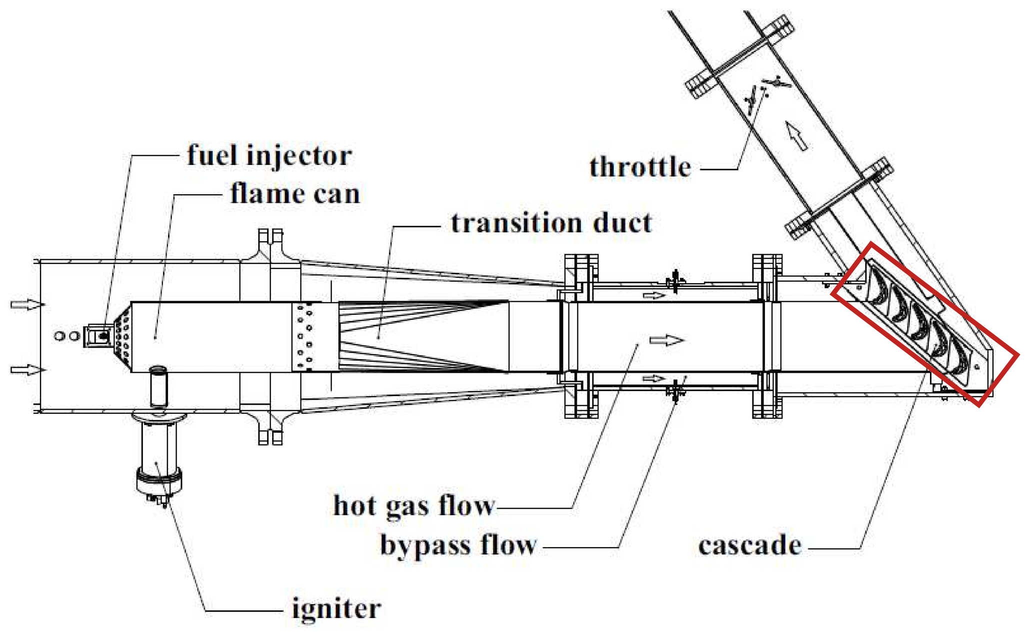


Set of calibration samples:

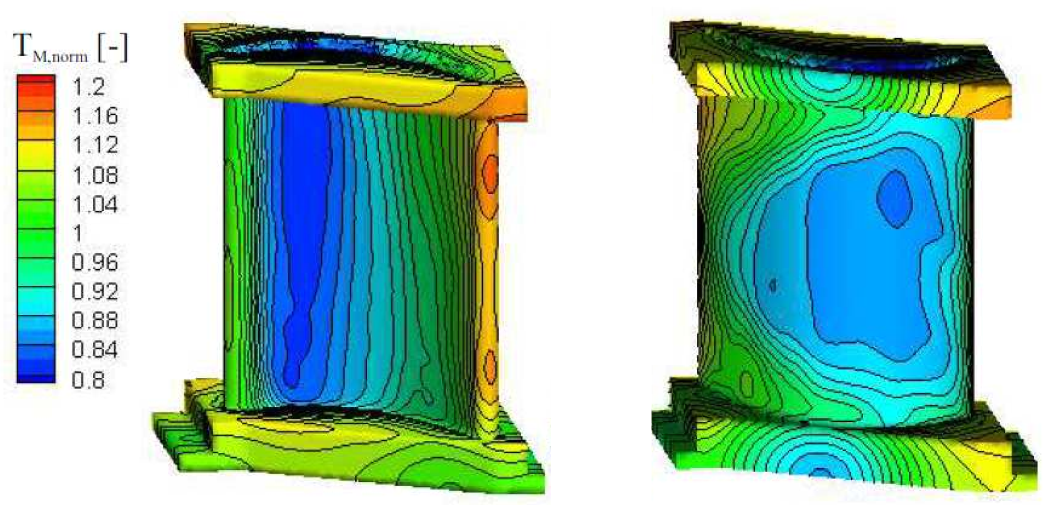


5. HOT GAS BENCH

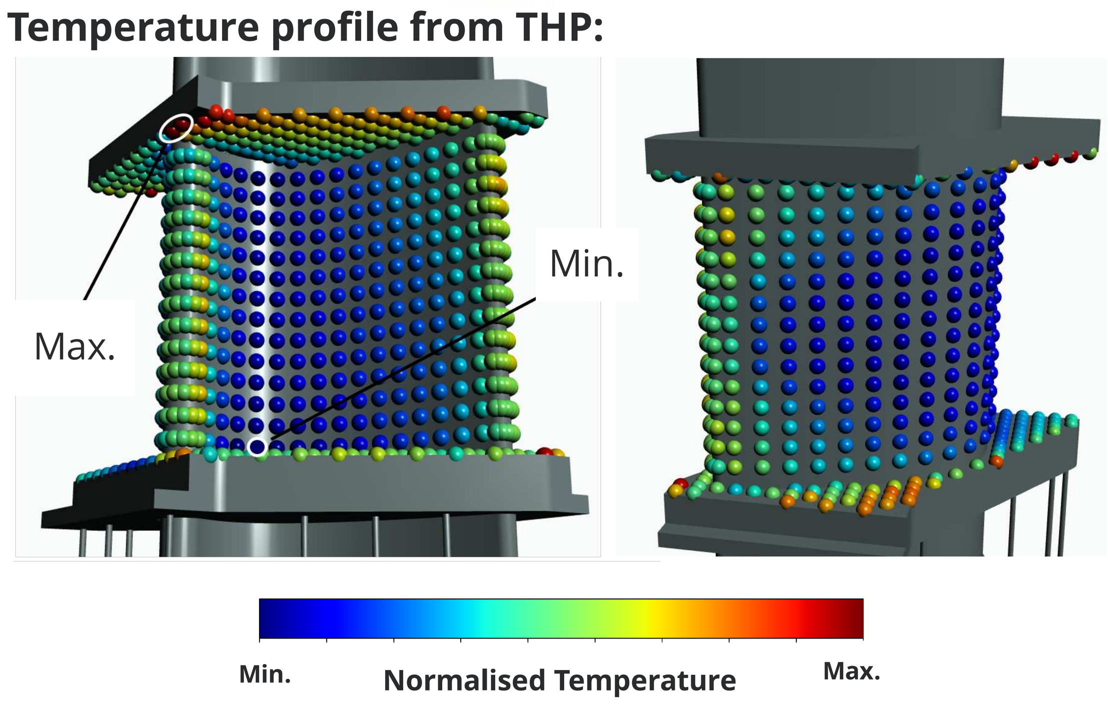
The vane was tested in a hot gas rig facility at Aachen University. FEM analysis was performed from the thermocouple data, showing similar trends to Thermal History Paints in hot spots in the trailing edge and cooler areas in the suction side.



Temperature profile from FEM prediction [5]:

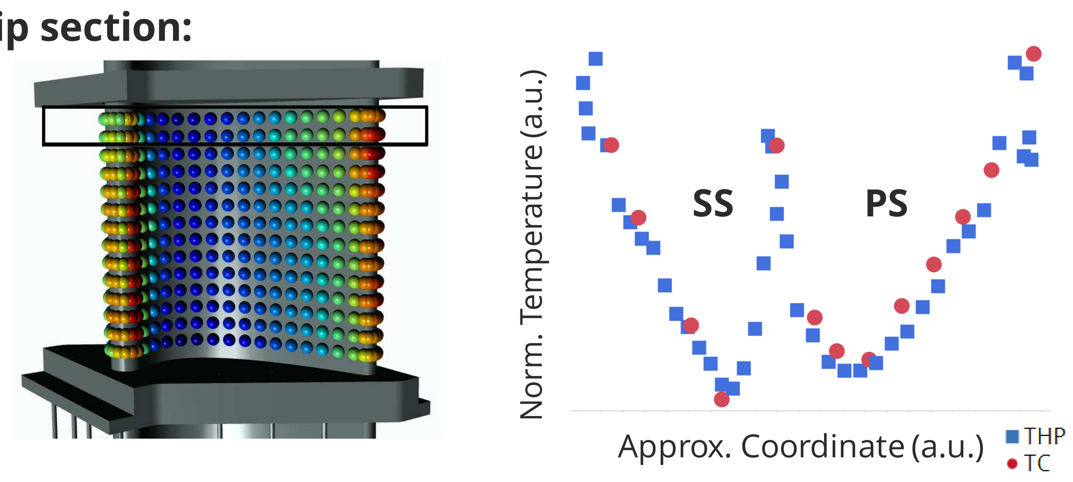


Temperature profile from THP:

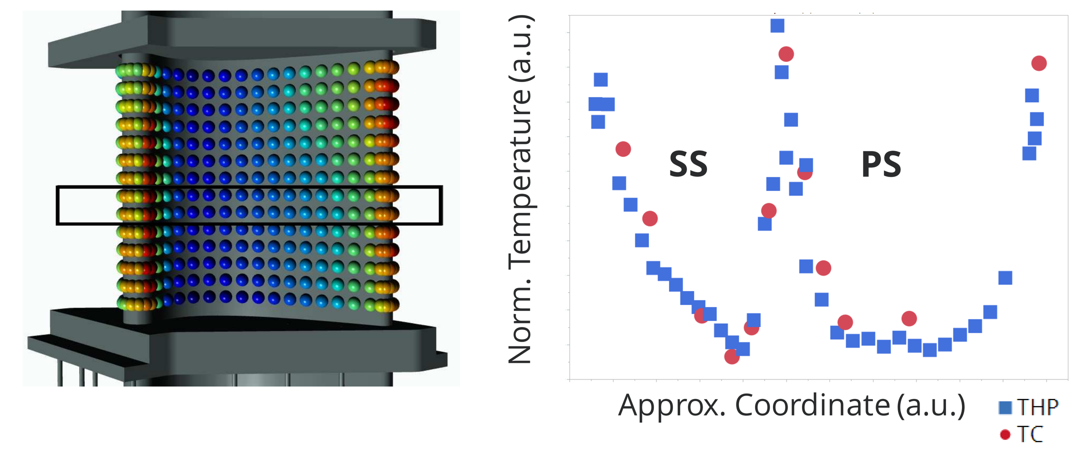


6. RESULTS

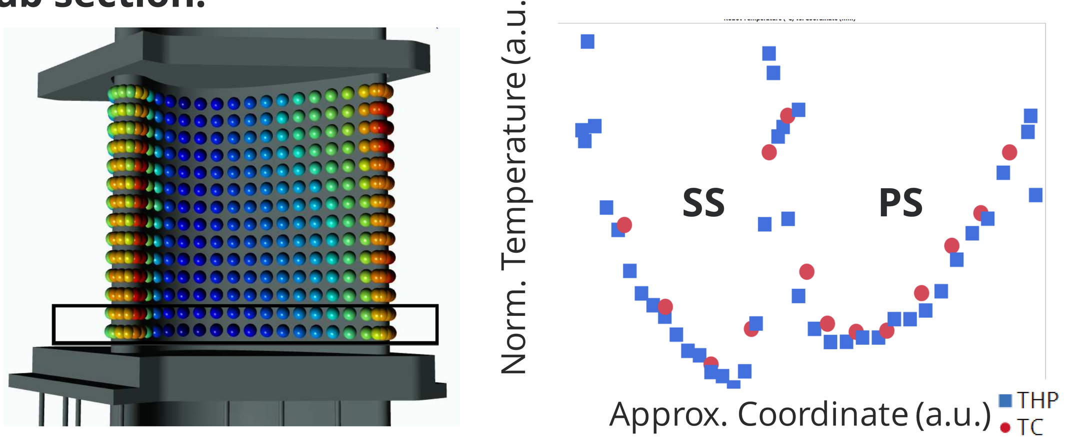
Tip section:



Mid section:

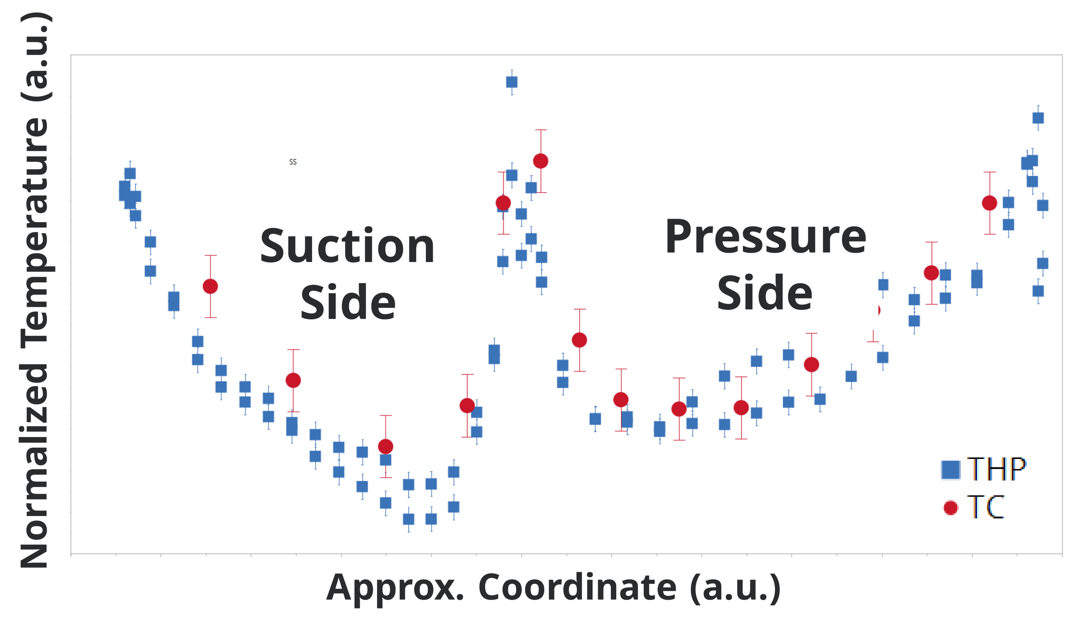


Hub section:

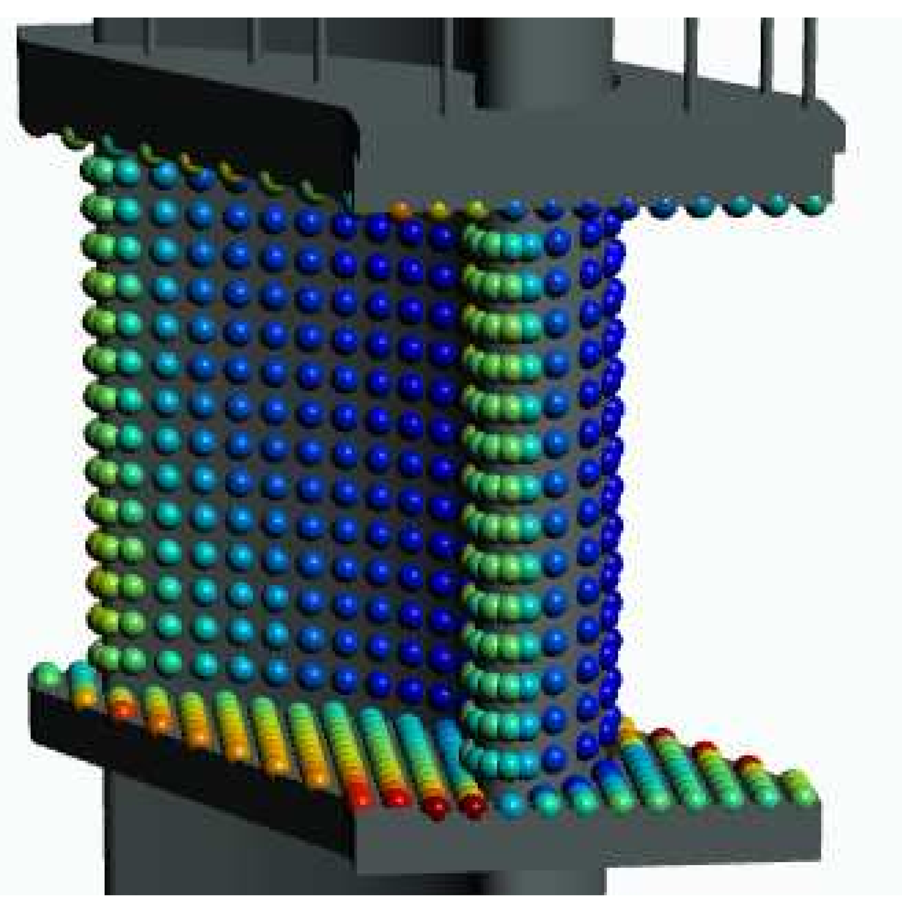


7. CONCLUSION

Over 1,000 temperature measurements were acquired on Thermal History Paints. Results show very good agreement with thermocouple and FEM analysis, from previous publications. An accurate temperature profile was recorded. This new temperature measurement technique was validated.



Validated high density thermal profile:



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