

UNIVERSITY TURBINE SYSTEMS RESEARCH (UTSR) 2024 GAS TURBINE INDUSTRIAL FELLOWSHIP PROGRAM

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Program Report

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I. Background

The combustion department of Siemens Energy is working on a new series of product which is an update and optimization of current gas turbine SGT-9000HL 50Hz/60Hz. The transition [Figure 1] is an important section to conduct the compression function for gas turbine. To overcome the high temperatures produced when burning hydrogen gas (around 2,000°C), a thick ceramic coating is required inside the transition (2400 μm total). The thermal barrier coating, primarily formed by melted ceramic particles applied through plasma or flame torch, is applied to the inner surface of the transition using a robotic arm. The thermal barrier coating team is working to increase the combustion temperature from 1550°C to 1650°C to improve efficiency. As the temperature increases, the ceramic particle composition must also change, along with adjustments to the coating layer thickness and the path of the robotic arm.



Figure 1: The transition and robotic arm before coating

II. Assigned Challenge

A significant problem the TBC team encountered is the need to frequently adjust the robotic path and test different ceramic particle combinations in varying percentages. However, the current method of evaluating the thickness of the coating is both imprecise and time-consuming. One method uses an eddy current thickness detector on designated holes of a Mylar layer [Figure 2]. This method takes about an hour to gather all the data points and provides only a rough estimate of how the coating forms, which cannot be used for formal data analysis.

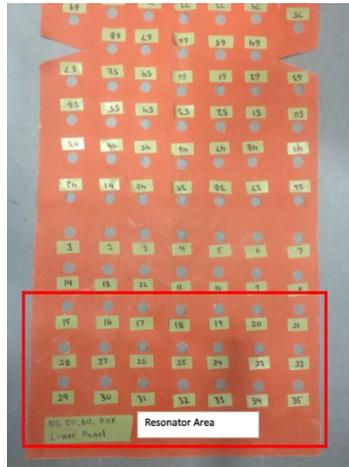


Figure 2: The Mylar points fabric

The other method involves using a 3D laser scanner [Figures 3, 4] to create a profile of the transition's inner surface after coating and comparing it with the profile before coating to determine the exact thickness. However, the 3D scanning process is not always reliable. There is a high likelihood of misalignment between profiles, requiring the entire scan to be redone. Additionally, alignment errors and thickness measurement inaccuracies can occur when the scan is imported into CAD software for visualization.

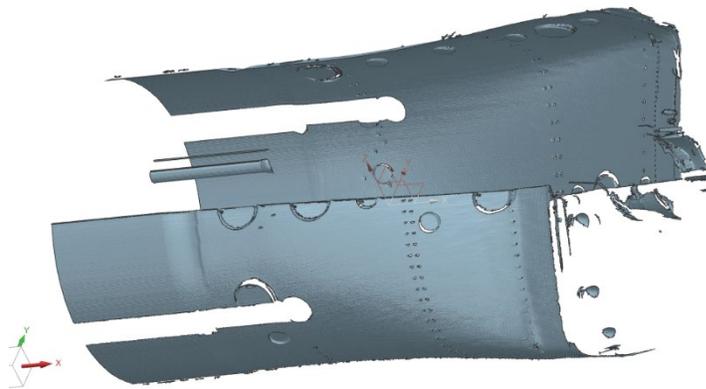


Figure 3: The 3D scanned facet profile

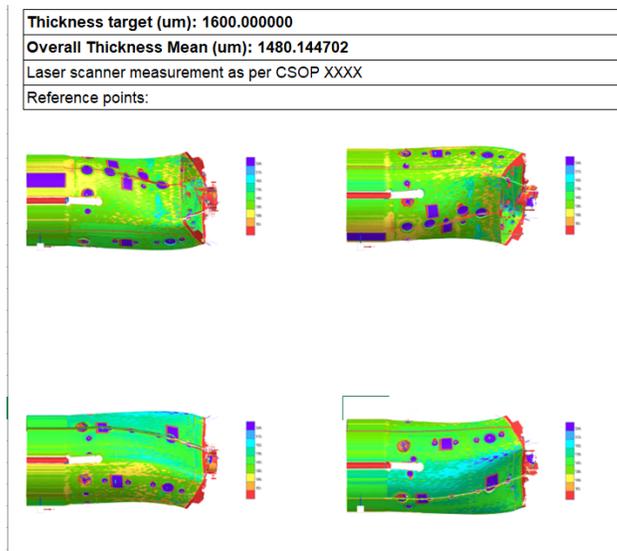


Figure 4: The evaluated thickness profile after processing

To solve the problem mentioned above, the author was tasked with developing and designing a system that can achieve two main objectives:

1. Quickly measure the coating thickness to reduce evaluation time, ensuring that production is not significantly delayed.
2. Easy installation and removal, so that the measurement process does not obstruct the normal production of parts in the same booth.

The data collected by the system must be precise, with an uncertainty of less than 0.5 mm. Additionally, it should gather enough data points to generate a clear and detailed thickness profile of the coating. This system would streamline the evaluation process and enhance production efficiency without compromising measurement accuracy.

III. System Development

To address the measurement challenges, the author designed and implemented a dual sensor system [Figure 5, 6]. The system comprises two different types of sensors:

Keyence CL P070: A highly precise sensor for small regions.

Sharp GP2Y0A51SK0F: A coarse sensor for broader regions.

The system was installed on the robot arm, capturing measurements during the coating process. It ensured continuous calibration between sensors and allowed for the collection of both coarse and fine measurements, improving the overall accuracy of thickness evaluation. The data was exported as CSV files for easy analysis and timestamp-based visualization.

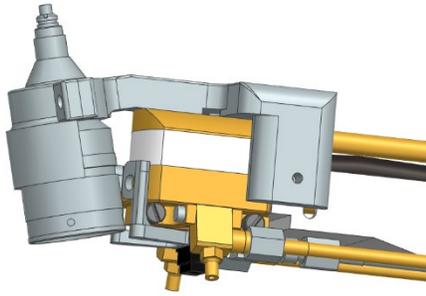


Figure 5: The fixture part of the CAD model of dual sensor system (without wires)

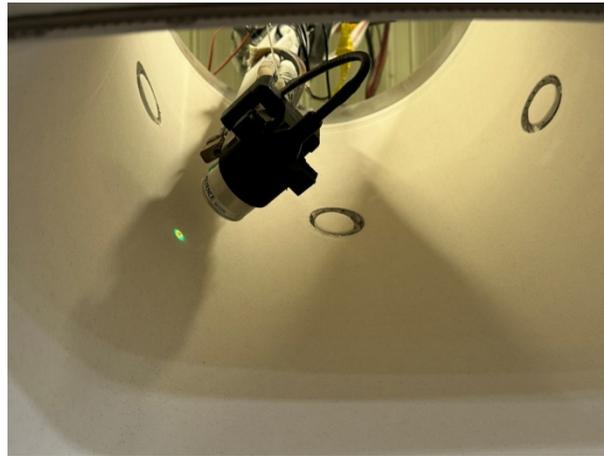


Figure 6: The working dual sensor system on the robotic arm

IV. Assembly and Setup Instructions



Figure 7: The whole setup of dual sensor system

The dual sensor system [Figure 7] was designed with ease of setup in mind. The system can be installed and calibrated within minutes, following the instructions provided in the documentation (a 20 pages operation instruction with detailed photos):

3D-printed clamps hold the sensors in place on the robot arm.

A combination of screws, nuts, and copper supports ensures stability. Details can be found in the Bill of Materials [Appendix A].

Sensors are attached using a 3mm hex screwdriver for secure fastening.

Cables are secured using zip ties along the length of the robot arm to prevent wear and ensure efficient movement during operation.

Keyence CL-3000 controller software is used to control the sensors, while the data is saved periodically to avoid large file sizes and simplify data processing. Arduino Uno PCB board is also used to acquired and save data.

V. Challenges Encountered

Throughout the development of the dual sensor system, several challenges were addressed:

1. **Out-of-Range Measurements:** The sensors occasionally operated outside their intended range, resulting in lost data. This issue can be mitigated by using two sensors positioned symmetrically to each other, allowing them to cross-validate and calculate each other's data, thereby reducing the likelihood of out-of-range errors.
2. **Sensor Noise:** The coarse sensor introduced noise, requiring multiple iterations and fine-tuning to achieve reliable results. This issue was largely resolved by applying a floating average filter, which successfully eliminated 90% of the noise.
3. **Data Calibration:** Since the sensors operate on different scales, careful calibration was necessary to align their outputs accurately, particularly when calculating the difference between their readings during robot arm movement. To address this, a calibration step using a known reference value can be added before each operation to ensure consistency and accuracy throughout the measurement process.

VI. Sample Data Acquired

The system was tested at different frequencies (e.g., ACE 1.4 at 60Hz and ACE 1.3 at 50Hz), providing real-time measurement data that was used to analyze the coating's thickness and uniformity. Key findings from the data indicated areas where the coating process could be optimized to improve the quality and consistency of the thermal barrier coating [Figure 8,9,10]. The manufacturing process engineer already use some of the data as a reference to improve the robot arm coating path and give very positive feedback. The required surface distance varies in different parts, so the index line differs in each figure.

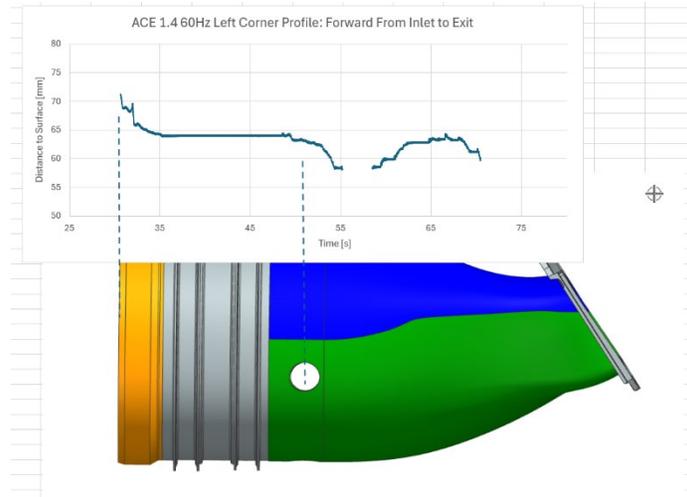


Figure 8: ACE 1.4 60 Hz left panel

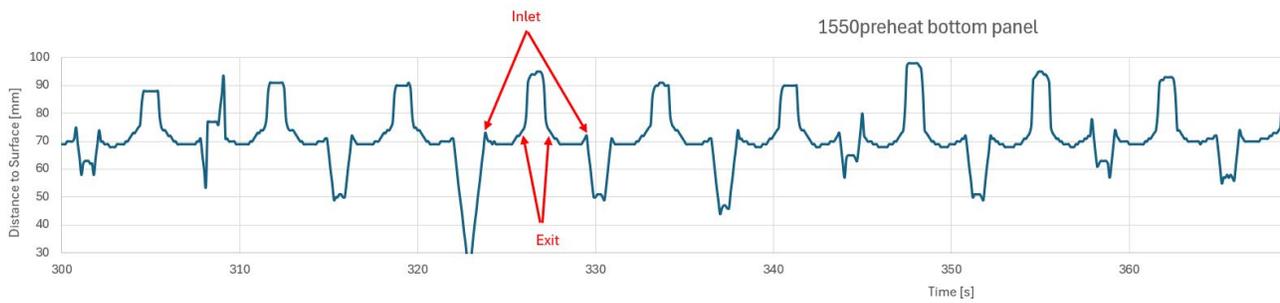


Figure 9: ACE 1.4 60 Hz preheat bottom panel



Figure 10: ACE 1.3 50Hz Upper Panel

VII. Future Applications

For future development of the dual sensor system, the primary goal will be to enhance its precision and ensure more stable data output. One planned update involves using two sensors positioned along the horizontal axis to measure distance more accurately when approaching the corners of the transition.

This adjustment will improve measurement accuracy, especially when the sensors are at an angle to the surface, rather than perpendicular.

Additionally, the material used for the fixtures that hold the sensors onto the robotic arm will be improved. Options such as CNC machining or injection molding are being considered to provide more durable and precise components.

Another focus of optimization is selecting sensors with lower uncertainty and a larger measurement range, which will further improve data acquisition and overall system performance. These updates aim to refine the system's functionality and increase its reliability in industrial applications.

VIII. Conclusion

The dual sensor system project has successfully addressed the challenges of measuring the thickness of thermal barrier coatings in gas turbine transitions. By utilizing two sensors—one for precise measurements and the other for broader region assessments—the system achieves a balance between accuracy and coverage. Key advantages of the system include its quick setup and removal process, which minimizes disruption to production workflows, and its ability to export data in an easily analyzable format, enhancing the efficiency of thickness evaluation. Features such as real-time calibration between sensors and noise reduction through the application of a floating average filter significantly improve the reliability of the measurements. Future enhancements include the introduction of horizontally aligned sensors to improve corner measurements and the use of higher-quality fixture materials for greater durability. The system's modular design and adaptability make it a valuable tool for improving the precision and speed of thermal barrier coating assessments in industrial settings.

