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Intelligent and Robust Sensors using Fiber-optic Network Distributed Engine Control

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ABSTRACT

IFOS has developed a distributed fiber-optic backbone network architecture suitable for critical aero-engine performance monitoring. Based on resilient high-reliability and self-healing telecom-class network models, IFOS's distributed fiber-optic Wavelength-Division Multiplexing (WDM) backbone architecture adopts a Coarse Optical Ring Network (CORIN)[1] with standardized optical network interfaces. Experimental results are given for an example CORIN supporting both fiber optic and electrical sensors.

1 INTRODUCTION

The Full-Authority Digital Engine Control (FADEC) centralized architecture has been the norm in aeroengine control systems. In centralized systems, changes are costly and complex. Additionally, requirements for increased performance, wider operability, and reduced life-cycle costs necessitate innovative solutions to replace traditional systems. To address this need, IFOS has developed a distributed fiber-optic backbone network architecture suitable for critical aero-engine performance monitoring. Based on resilient high-reliability and self-healing telecom-class network models, IFOS's distributed fiber-optic Wavelength-Division Multiplexing (WDM) backbone architecture adopts a Coarse Optical Ring Network (CORIN) [1-2] with standardized optical network interfaces. Recent advances in WDM have yielded major capacity increases and reliability improvements overcoming electronic bottlenecks with optical networks.

Distributed control architectures involve engine-mounted "smart" sensors that communicate with the propulsion system controller through high-speed data buses. These "smart" sensors will provide self-reliance for calibration and testing and will only transmit necessary processed data. Use of these smart sensors would eliminate the need for point-to-point wiring of sensors over extended distances from the engine controller thus greatly reducing engine harness weight [3]. The use of smart sensors for jet-engine control is currently limited by the availability of mature high-temperature electronic components that can withstand the engine operating environment. As technology advances, smart sensors will appear in many different engine applications. One of the most challenging areas of turbine-engine sensing is the measurement of the gas temperature exiting the combustor and entering the turbine. The durability and performance limit of engine temperature sensors is an issue for an increased engine temperature.

Therefore, thermocouples are commonly used for engine temperature sensing, but their lifetime is significantly decreased in a high-temperature environment. Consequently, many of these sensors have been moved downstream to a cooler area. Turbine inlet temperature is then estimated using an empirically derived relationship with resulting inaccuracies. Our research aims to address the deficiencies in current sensor technology. The objective of our work is to make available robust intelligent sensor technology, which can operate in an environment with temperatures >1200°F and vibrations >500 g rms. We plan to extend the operating temperature of the sensors to >2000°F.

The IFOS distributed architecture integrates electrical sensors, probes and actuators with future optical sensing systems in a fault-tolerant architecture. This design provides significant size and weight reduction, major reliability gains, operational, maintenance and economic benefits, resulting in enhanced performance and reduced life cycle costs for next-generation avionics. A 4-node (2 optical, 2 electronic) CORIN system combining multiplexed fiber-optic sensors with electronic sensors is shown in with thermocouple-based temperature sensors.

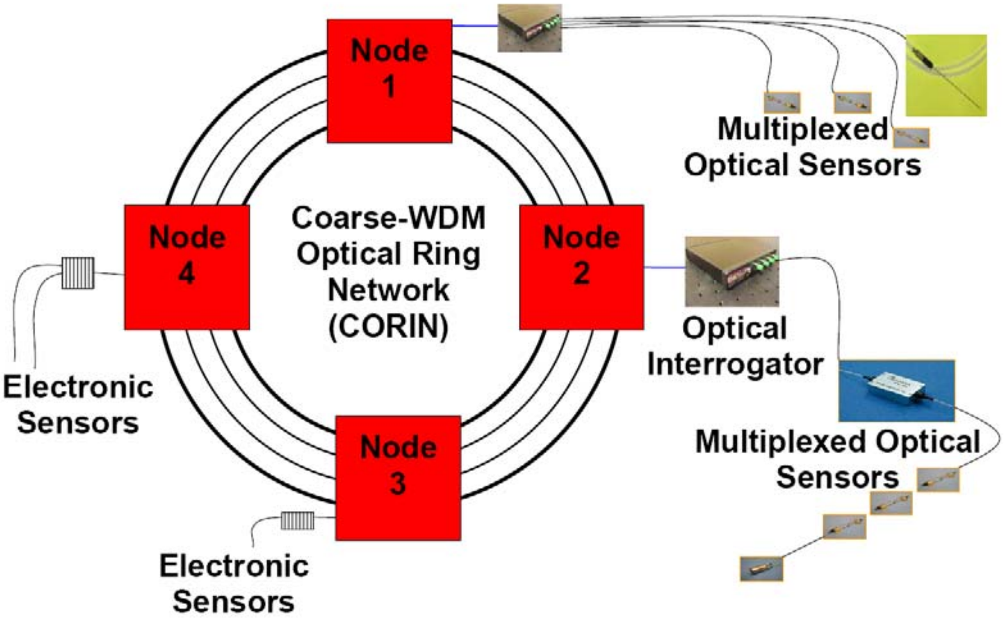


Figure 1: Four-node CORIN

A version of this CORIN system for the case of fiber-optic temperature and strain sensors combined with electrical (thermocouple) sensors was tested at Virginia Tech on a Pratt & Whitney PT6 engine. The test results demonstrated excellent performance of the communications protocols managing information from disparate sensor nodes on the optical ring, thus forming the basis for a Distributed Control System (DCS) architecture. IFOS and Pratt & Whitney plan to transition the technology to government platforms.

2 EXPERIMENTAL RESULTS

The group of engine casing sensors is shown in Figure 3. Data analysis results for the temperature sensors and are shown in Figures 4 and 5, and those for the strain sensors are shown in Figures 5 through 9. Observations are documented within the following paragraphs in this section.

Temperature sensors

The first evaluation is a comparison between FBG and TC temperature sensors. A nonlinear calibration curve, generated with a coarse set of actual FBG readings vs. temperature, was thus applied and updated results are shown in Figure 5. It seems the engine casing temperature was approximately 75°C at idle and 220°C at maximum throttle. The FBG temperature readings are now comparable to the TC readings. Much finer calibration data for both types of sensors would improve correlation and measurement accuracies.

Strain sensors

With the FBG temperature sensor response available, temperature compensated strain sensor data can be evaluated for both longitudinal and circumferential mounting cases.

Figure 4(a) shows the longitudinal strain. Figure 4 shows the magnified first cycle data section in Figure 6. The longitudinal FBG strain sensor readings correlate with engine throttle levels. The strain pattern repeats during the cycle test.

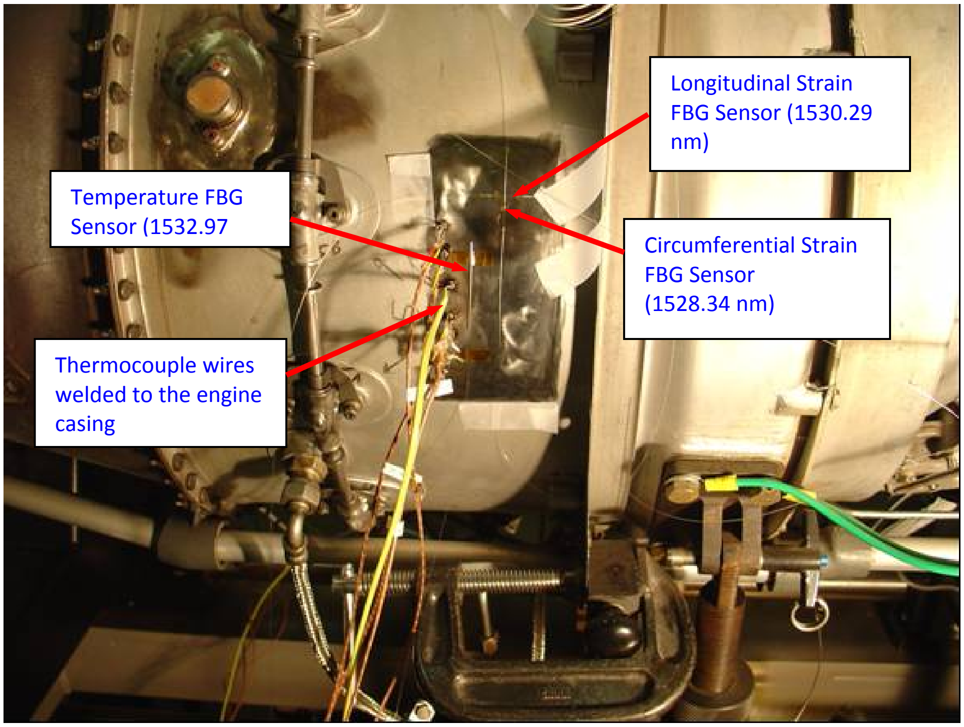


Figure 2: Electrical and fiber optic sensors on the PT6 engine casing.

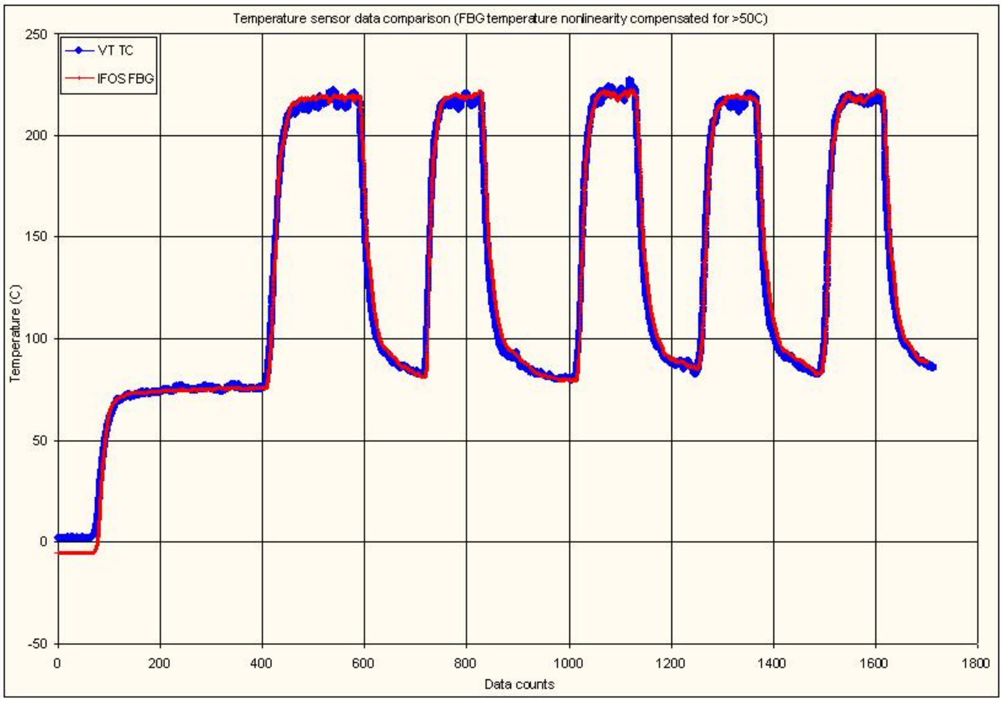
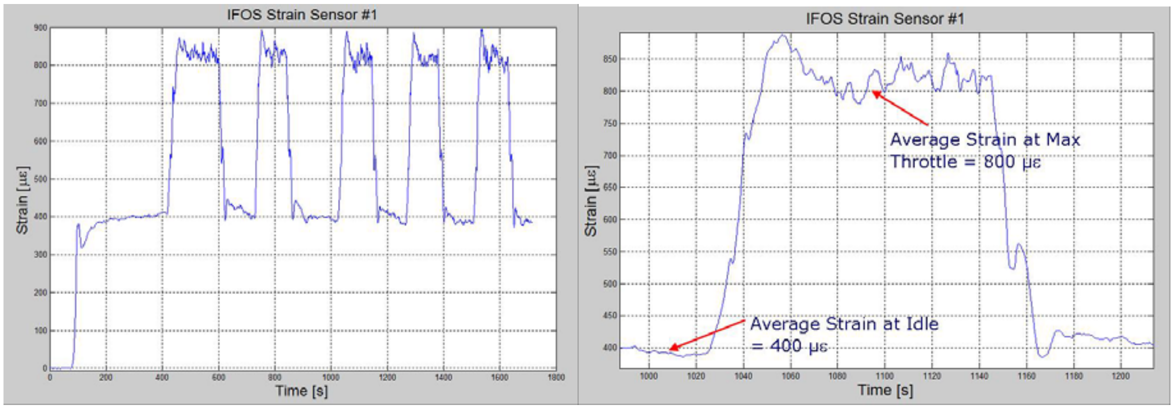


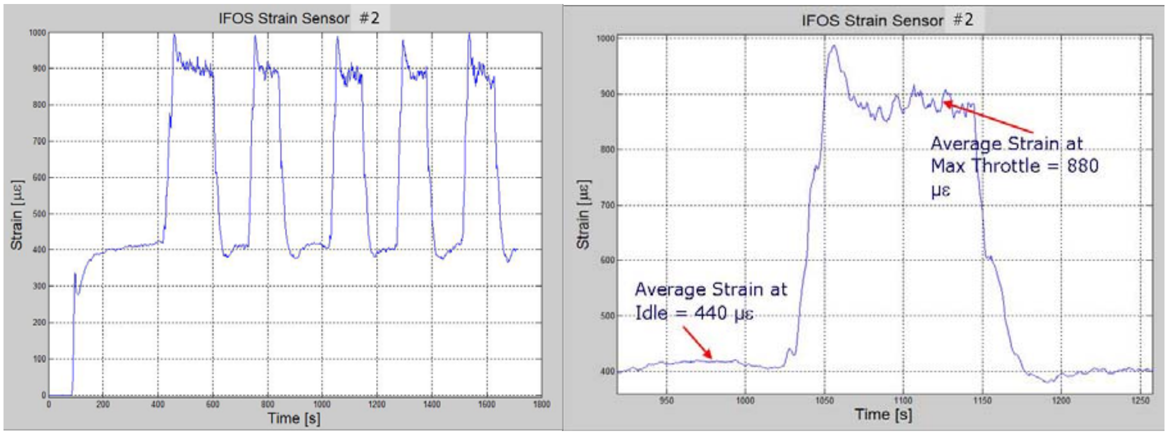
Figure 3: Cycle test – FBG (*nonlinear* calibration curve) vs. TC temperature readings.

Figure 5(a) shows the circumferential strain. Figure 5(b) shows the magnified first cycle data section of Figure 5(a). The circumferential FBG strain sensor readings also correlate with engine throttle levels, and the strain pattern also repeats during the cycle test. The circumferential strain levels were observed to be approximately 10% higher than longitudinal strains.



(a) (b)

Figure 4: (a) Longitudinal casing strain (temperature compensated) with (b) zoom of first cycle.



(a) (b)

Figure 5: (a) Circumferential casing strain (temperature compensated) with (b) zoom of first cycle.

3 CONCLUSIONS

Data analysis confirmed successful demonstration of an optical ring architecture on a PT6 jet engine. Calibration curves and data processing algorithms were developed to process raw data into temperature readings.

4 REFERENCES

[1] M Xia, B Moslehi, B Mukherjee, AR Behbahani, R Miller, *AVFOP* 2008

[2] R Wang, RJ Black, B Moslehi, AR Behbahani, B Mukherjee, "Lightweight Optical Aero-Engine Control Network," *OFC-NFOEC 2011 (*The Optical Fiber Communication Conference and Exposition (OFC) and the National Fiber Optic Engineers Conference), 3 pages, Session: Short Reach Enabling Technologies, Presentation Number: OThZ4 (March, 2011).

[3] KD Tillman and TJ Ikeler, "Integrated Flight/Propulsion Control for Flight Critical Applications: A Propulsion System Perspective," *J. Eng. Gas Turbines & Power*, 114(4), 755, 1992.