DEVELOPMENT OF HIGH TEMPERATURE COOLED AND UNCOOLED FAST RESPONSE PROBES FOR GAS TURBINE APPLICATIONS

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Accurate hot gas path measurements (including combustion diagnostics) are recognized as a major need for the assessment of engine component health and performance. Regarding unsteady pressure measurements above temperatures of 1300K (~1000°C), little, if any, accurate and reliable technique exists to measure the time-resolved gas path total pressure.

Among various approaches to create a solution to this problem, cooling of a standard off-the-shelf sensor is found to be the most feasible solution. The design of a pressure probe and its cooling system constructs the basis of this study. Emphasize is given on heat transfer and aerodynamics around the probe. Following the manufacturing of the cooled probe designed, it has been tested in Rolls-Royce Viper Mk201 turbojet engine (aft of the turbine disc), and at Rolls-Royce Intermediate Pressure Combustion Rig at high temperatures. A second prototype has been built with several improvements and tested in a Volvo Aero RM-12 low bypass military turbofan engine (aft of the LP Turbine rotor).

The probe is water cooled by a high pressure cooling system and uses a conventional piezo-resistive pressure sensor which yields therefore both time-averaged and time-resolved pressures. The initial design target was to gain the capability of performing measurements at the temperature conditions typically found at high pressure turbine exit (1100-1400K) with a bandwidth of at least 40kHz and in the long term at combustor exit (2000K or higher).

The probe was first traversed at the turbine exit of a Rolls-Royce Viper turbojet engine, at exhaust temperatures around 750 °C and absolute pressure of 2.1bars. The probe was able to resolve the high blade passing frequency (~23kHz) and several harmonics up to 100kHz. Besides the average total pressure distributions from the radial traverses, phase-locked averages and random unsteadiness are presented. The probe was also used in a virtual three-hole mode yielding unsteady yaw angle, static pressure and Mach number. The same probe was used for measurements in a Rolls-Royce intermediate pressure burner rig. Traverses were performed inside the flame tube of a kerosene burner at temperatures above 1600 °C. The probe successfully measured the total pressure distribution in the flame tube and typical frequencies of combustion instabilities were identified during rumble conditions.

A second prototype having several improvements, the greatest of which is the inclusion of a leadless sensor with added robustness, is manufactured and tested in into the engine through the bypass duct between turbine exit and flame-holders of the afterburner of a Volvo RM12 engine, at exhaust temperatures above 900 °C. The probe was able to resolve the blade passing frequency (~17 kHz) and several harmonics up to 100 kHz.

The cooling performance of the probe is compared to estimations at the design stage and found to be in good agreement. The frequency response of the probe is compared to cold shock tube results and a significant increase in the natural frequency of the line-cavity system formed by the conduction cooled screen in front of the miniature pressure sensor were observed.

Figure 1: VKI Cooled Probe installed on RR Viper before and Engine, and the cooling system (right) installation (center)

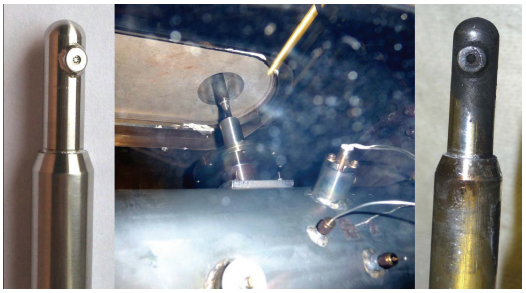

Figure 2: Photos of the cooled probe after IP Rig Tests and probe