

Spatial and Temporal High-Resolution Optical Tip-Clearance Probe for Harsh Environments

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A measuring system based on low-coherence interferometry has been developed to obtain temporally resolved tip-clearance data from the early stages of gas turbines. The measurement technique relies on the interference between back-reflected light from the blade tips during the blade passage time and a frequency-shifted reference. Due to the measurement principle the absolute spatial accuracy only relies on the coherence length of the light source (typically tens of microns). The probe can hence be mounted in a cooled recess without compromising accuracy. The system allows to monitor transient effects during turbine start-up and shut-down. A single optical fiber of arbitrary length connects the self-contained optical and electronics setup to the turbine, thus separating it from heat, noise, and vibrations.

The presented prototype of such a system is an all-fiber assembly, with self-calibrating capabilities and a spatial resolution of less than 50 μm . The data acquisition system consists of a digital storage oscilloscope and a common PC. The probe has been applied successfully to a laboratory cold-gas turbine and to the first stage behind the combustor of a large-scale power generation gas turbine (GT26-Alstom).

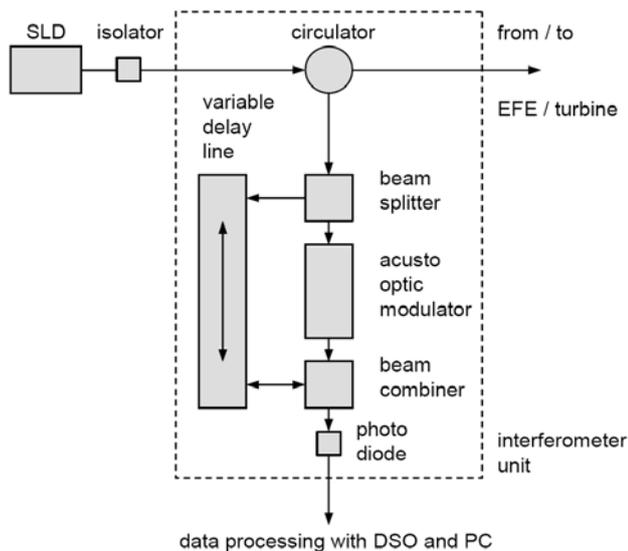


Fig. 1 Schematic setup of optical components in the interferometer unit, which also includes the light source.

Fig. 1 shows the schematic setup of the optical components in the measuring circuit of the system. A superluminescent diode emits low-coherence light into a single-mode fiber. A fiber-optical isolator protects the sensitive light source from back-reflections and guides the light to a polarization insensitive optical circulator. The circulator is used to transfer

the light through a single-mode optical fiber to the endoscopic front end (EFE), where a collimator lens directs the light out of the fiber onto the passing blade tips. A small fraction of the incident light is reflected back onto the collimator lens and into the fiber towards the circulator, where it is deflected into the interferometer part of the measurement system. A small fraction ($\sim 1\%$) of the light is also reflected off the two surfaces of the collimator lens, which provides a spatial reference. Following the nomenclature of Fig. 2, the light reflected from the blade tips is denoted as ray 1 and the light reflected from the lens's front and back surfaces as rays 2 and 3, respectively. The light back-reflected from the turbine blades and the collimator surfaces (rays 1, 2, 3) is fed into two interferometer arms by a beam splitter. In the reference arm, an acousto-optical modulator (AOM) shifts the frequency of the light by 55 MHz, corresponding to several periods within the blade passage time ($\sim 1\ \mu\text{s}$). The delay arm contains a motorized variable delay line (VDL). The light from the two interferometer arms is re-combined by another beam splitter/combiner and a broadband photo-receiver serves as detector.

As shown in Fig. 2, the path length of ray 1 is longer than that of rays 2 and 3. Denote the tip-clearance as D , the optical thickness of the collimator lens as d and the path lengths of both interferometer arms (between the two beam splitters/combiners) as l_{ref} and l_{delay} , respectively. If the VDL is set such that $l_{ref} + 2(D+d) = l_{delay}$, for example, the part of ray 1 going through the reference arm interferes with those parts of ray 2 which go through the delay arm. The frequency of the AOM is now recorded as a beat-signal at the detector, which is detected as a peak in the power spectrum. Similarly, interference between ray 1 and ray 3 is observed, when $l_{ref} + 2D = l_{delay}$. By checking the delay setting where ray 2 and ray 3 interfere, i.e., when $l_{ref} + 2d = l_{delay}$, the system can be calibrated with the known thickness and thermal behavior of the sapphire lens used in the custom made EFE.

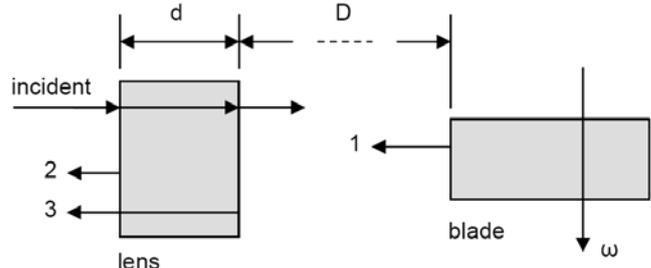


Fig. 2 Incident light and sources of reflections.