INVESTIGATION OF A POLYVINYLIDENE FLUORIDE FOIL AS AN ALERTNATIVE FOR INSTATIONARY PRESSURE SENSORS IN STALL DETECTION

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ABSTRACT

Stall and surge detection methodologies based on unsteady pressure measurements typically rely on a specific sensor layout, a defined number of sensors, or at least one pressure sensor to provide the data required for conventional detection algorithms as well as machine and deep learning approaches. However, the available space and weight budget for advanced measurement instrumentation continue to decrease, creating the need for alternative sensing solutions. In this paper, a novel polyvinylidene fluoride (PVDF) foil is investigated to assess its feasibility as a surrogate for conventional unsteady pressure sensors in the detection of stall and its inception mechanisms, including spike-type stall inception and prestall phenomena such as rotating instabilities.

INTRODUCTION

Modern turbomachinery design trends require innovative and cost-efficient measurement techniques to facilitate the development of efficient and low-emission aero engines. For instance, the increasing bypass ratios of next-generation aero engines result in smaller core engine diameters. As the available space for instrumentation decreases while relative tip clearances increase, the question arises how stall events and their precursors can be detected reliably.

The proposed paper investigates the application of a novel polyvinylidene fluoride (PVDF) foil for stall detection to prevent unstable operation of a single-stage research compressor. The crystalline structure acquired by the polymer after artificial polarization results in piezoelectric properties, causing a change in surface charge under mechanical loading.

The investigations are intended to determine the ability of the PVDF foil to resolve blade passing frequencies in both the time and frequency domains. Furthermore, the applicability of established stall analysis methodologies, such as those proposed by Camp et al. [1], Tahara et al. [2], and Eck et al. [3], is evaluated. To assess the capabilities of the PVDF foil beyond stall detection, the investigations also include the identification of prestall instabilities such as rotating instability.

RESULTS AND DISCUSSION

The results shown in Figure 1 represent the time series of three rotor revolutions. The investigations were conducted on the single-stage low-speed axial research compressor at the Chair of Aero Engines. Figure 1 compares the signals of all eight PVDF sensor elements with a reference Kulite XCS-190 pressure sensor installed circumferentially on the compressor shroud in the rotor leading edge plane. The PVDF signals are band-pass filtered to account for current design limitations of the foil. Low-frequency components between 1 and 60 Hz are removed to minimize the temperature-dependent offset introduced by the polyvinylidene fluoride material. In addition, frequencies above the blade passing frequency (BPF) are excluded due to the high sensitivity of the foil. The results demonstrate good agreement regarding the number of rotor blades resolved during each revolution. Minor differences can be attributed to oxidation of the electrical traces, resulting in varying electrical resistances that influence the measured signal. This limitation is addressed in the next iteration of the PVDF foil.

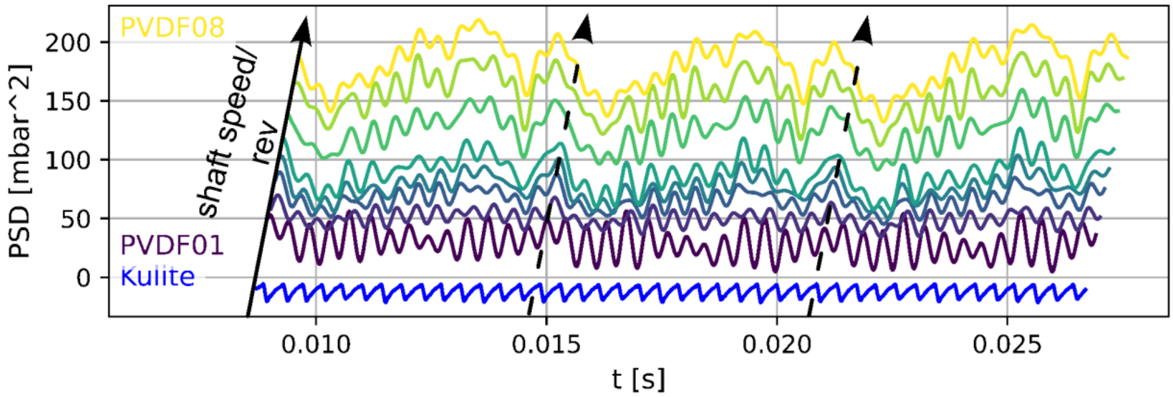

Figure 1. Comparison of time series data from a Kulite sensor with the all eight PVDF sensing elements

Figure 2 presents the power spectral density (PSD) of two PVDF sensor elements compared with the same reference Kulite sensor. The evaluation includes three operating points (OP) along the compressor throttling line, where OP9 and OP15 contain the onset of rotating stall and stall inception, respectively. The PVDF foil produces good agreement with the Kulite measurements in the frequency domain. The characteristic frequency hump associated with rotating instabilities (RI) is captured at the expected frequencies. Further throttling towards the stall limit also reproduces the shift of the rotating instability frequencies previously reported by Eck et al [4].

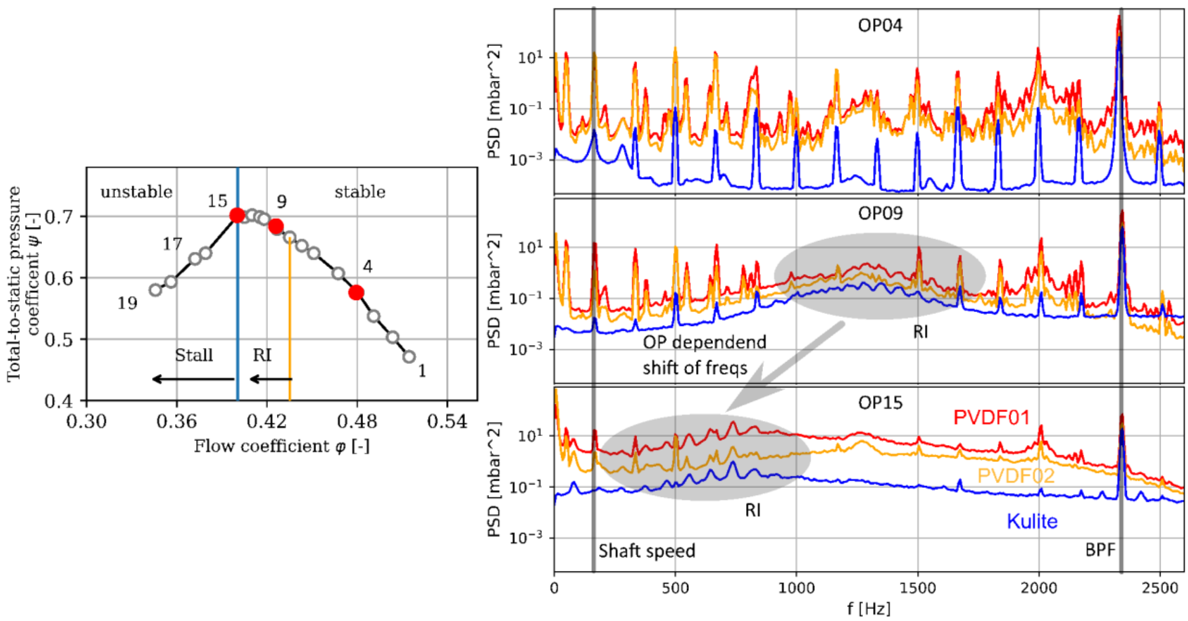

Figure 2. PSD results of two PVDF sensing elements compared to Kulite results for three operating points with emergence of rotating instability

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