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# Active feedback control of stall in an axial flow fan under dynamic inflow distortion

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ABSTRACT

This work proposes an active feedback control strategy using cross-correlation technique in a single stage axial flow fan operating under dynamic inflow distortion. Experiments were carried out under dynamic inflow distortion at the design speed with only three sensors and actuators, each. The stall inception mechanism studies under dynamic inflow distortion were carried out using 1-D continuous Morlet wavelet transform. It was observed that stall inception under co- (in the same direction of rotor rotation) and counter-rotating (in the opposite direction of rotor rotation) inflow distortion occurred through long and short length-scale disturbances, respectively. The knowledge of the nature of instabilities under dynamic inflow distortion was used to set the threshold of the correlation coefficient. It was observed that the active feedback control strategy resulted in a stall onset delay of 125 ($\simeq$3.125 s) and 65 ($\simeq$1.625 s) rotor revolutions under co- and counter-rotating inflow distortions, respectively. The highest delay under co-rotating inflow distortion was attributed to the substantially higher stall warning time as compared to counter-rotating inflow distortion.



## 1. Introduction

Instabilities that are present in the axial compressors fall broadly into two categories, namely, rotating stall and surge. Rotating stall is a localized instability, whereas surge is a global phenomenon. Both, rotating stall and surge cause detrimental effects on the compressor performance. Surge is a more matured stage of flow instability that results in severe deterioration of the compressor performance as compared to rotating stall. Non-uniform inlet flow can add further deterioration as a few of the sectors get over-loaded, whereas the rest of the annulus is under-loaded. Several methodologies have been developed over the years to control rotating stall under clean and distorted inflows. Various experimental studies on the use of inlet guide vane control, bleed valve control and jet injection upstream of the first rotor were used as a means to control rotating stall. Badmus et al. [1] used six pressure sensors at the compressor inlet to compute the Discrete Fourier Transform. This information was used to control a throttle valve to delay stall inception. Haynes et al. [2] used control vanes to stabilize the first and second harmonics of a circumferential travelling wave in a three stage low speed axial compressor. The inflow velocity as measured by a circumferential array of hot wire sensors was used as a feedback parameter to extend the compressor operating point. With this feedback control strategy, a stall margin improvement of about 8% was observed over the baseline case.

D'Andrea et al. [3] carried out experimental studies to delay rotating stall using pulsed air injection in a low speed, axial flow compressor. Six equally spaced pressure sensors were incorporated to determine the Fourier modes of the harmonics. Injection was initiated as soon as the magnitude of the first mode exceeded a predefined threshold value. Dhingra et al. [4] developed a stochastic model for compressor stability measure based on auto-correlation technique. Time between two successive valleys in the auto-correlation function was chosen as an event and the arrival pattern as the variable. The stochastic model predicted that events are exponentially distributed in time. Cameron and Morris [5] developed a scalar metric that was sensitive to the disturbances, while, preserving both spatial and temporal resolution. The resulting function based on a two point correlation between adjacent sensors was found to provide sufficient information about the pre-stall and stall inception behavior. Tahara et al. [6] proposed a unique stall warning index based on auto-correlation technique in a single stage research compressor. The time histories of the current and the previous one rotor revolution were compared and a unique stall warning index was developed. It was observed that correlation degraded with the onset of pressure fluctuations and subsequently reduced to zero as the fluctuations amplified. Subsequently, Nakakita et al. [7] used the above stall warning index in a transonic multistage compressor and verified the stall inception mechanism as proposed by Tahara et al. [6]. Recently, Christenstein et al. [8] implemented auto-correlation for the stability of gas turbine engines. A sampling rate of 200 kHz and a window of 72 samples were used in the experiments. Based on a preset threshold

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