ME-PhD Thesis Colloquium

Emergence and Propagation of Aerodynamic Instabilities in Centrifugal Compressors with Vaned Diffusers: Effect of Diffuser Solidity and Stagger

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ABSTRACT

Centrifugal compressors are widely utilized in turbochargers and small gas turbines as they offer higher compression per stage and are compact. However, during off-design operation or throttle transients, rotating instabilities can occur, limiting the operating range and potentially causing mechanical damage. This study aims to understand the effect of diffuser geometries, specifically the solidity(number of vanes) and stagger(vane angle), on these aerodynamic instabilities towards gaining insights for early detection, avoidance, and control of such instabilities.

The methodology involved designing and developing a centrifugal compressor with a replaceable vane ring diffuser to facilitate the study of different configurations, as well as setting up a high-speed rotating compressor test facility. The baseline diffuser had a 65° stagger and fifteen vanes, with additional diffusers featuring lower solidity, varying vane angles, and a vaneless configuration. The test facility was equipped with pressure and temperature measurements to establish the steady-state performance of the compressor, and fast-response pressure measurements were utilized to study the stalling behaviour. Steady-state CFD analysis was also carried out to understand the flow field in the compressor for the various diffuser configurations.

The study explored the influence of diffuser solidity and stagger on the route to surge. At a part-speed condition, the compressor underwent stall inception through spike-type instabilities with length scales spanning a fraction of one passage width between the blades of the rotor and time scales of the order of the rotor's rotational speed. This was followed by persistent rotating stalls, which had a length spanning several rotor passages and rotating at a fraction of the rotor's speed. In most cases, surge occurred after stall. The features of the spikes, such as amplitude, time scales and repetition rate, and the characteristics of the surge were found to be influenced by the diffuser's solidity and stagger.

As solidity decreased, the compressor characteristics exhibited a positive slope, associated with an improved flow range from stall inception to surge. The reduction in solidity also escalated the frequency and variability of stall spikes, accompanied by a reduction in their average period. The average spike amplitude was lowest for the baseline configuration. For rotating stalls, the number of stall cells and their propagation velocity remained relatively constant with a change in solidity. Additionally, a milder form of surge preceded deep surge with a reduction in solidity, indicating the influence of solidity changes on the characteristics of instabilities. The effect of stagger was also studied, and its influence on the nature of the instabilities has also been reported in the study.

The findings of this study report the fundamental influence of solidity and stagger on the dynamics of compressor stalling and overall stability, which can be helpful for the design and operation of centrifugal compressors in turbomachinery applications.

ABOUT THE SPEAKER

Kishore Kumar C is a scientist working at Gas Turbine Research Establishment at DRDO. He is currently pursuing his PhD through an external registration program at the Mechanical Engineering Department at the Indian Institute of Science, with his research focused on experimental studies of aerodynamic instabilities in high-speed centrifugal compressors. He holds a bachelor's degree in Aeronautical Engineering from Madras Institute of Technology, Chennai. His professional experience at DRDO includes the development of turbochargers for large diesel engines, the design and testing of compressors for aero-gas turbine engines, as well as the development of related test facilities.