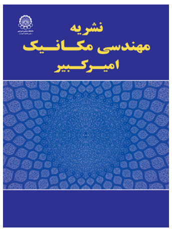

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Effects of air injection at rotor blade row tip region of an axial compressor on its performance under inlet distortion conditions

M. H. Ababaf Behbahani[1] , A. Khoshnejad[2], R. Taghavi Zenouz[1,*] , M. Goodarzi[1]

[1] Department of Mechanical Engineering, Iran University of Science and Technology, Tehran, Iran
[2] Department of Aerospace Engineering, K. N. Toosi University of Technology, Tehran, Iran

ABSTRACT: Improvement of an axial compressor performance through suppression of flow disturbances due to inlet flow blockage, utilizing air injection at the blade tip region, is the subject of the present study. The method of investigation is based on experimental measurements conducted in a low-speed isolated axial compressor rotor blade row. Four different blockage screens of different blockage ratios ranged between 5 and 20 percent of the inlet area are located at the compressor entrance. Instantaneous and time-averaged static pressures are recorded at different locations of the compressor casing. Frequency analyses of pressure signals show that the flow disturbances are being created in the presence of the blockage screens. These disturbances cause the appearance of rotating stall in the flow field when the compressor operates under distorted inflow with low blockage ratios (5 and 10%). To reduce the destructive effects of the inlet distortion, air is injected at the tip region of the rotor through 12 injectors which are located evenly spaced around the compressor circumference. Air injection in small quantities, 1.5% of the main flow, has considerable effects on the compressor performance under inlet distortion. The rotor performance and compressor delivery pressure are improved up to 35% than to the no injection case. By implementation of short-time Fourier transform technique effects of air injection on elimination or reduction of flow disturbances are also demonstrated.

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1- Introduction

Gas turbine engine may suffer from any possible flow disturbances occurred at its entry region. Under some conditions, inlet distortions may cause hazardous effects which can significantly deteriorate the performance of the compressor and the whole engine. Generally speaking, several parameters like severe flight maneuvers, inlet duct geometry, cross-wind, atmosphere gust, and any upstream irregularity can cause distortion in the inlet flow [1]. Inlet distortions are known as one of the main factors responsible for the commencement of instabilities. They may cause a reduction in the main stream axial velocity and increase in the flow incidence of the rotor blade rows, which in turn, could lead to the formation of stall cells. These cells rotate with the rotor blades but at a speed of 20-80% of the rotor rotational speed [2]. Continuous growth of the stall cells may lead to the occurrence of surge. Up to now, many experimental and numerical works are conducted to study the Compressor's performance deterioration when they are exposed to the inlet distortions. For example, distortions resulting from the ingestion of fuselage boundary layer by JT15D-1 turbofan engine are investigated by Lucas [3]. He presented that a decrease of 15.5% in corrected thrust force and an increase of 14% in specific fuel consumption. Air injection at the rotor blade row tip region is an efficient active control method for suppression of the flow instabilities. This technique could successfully be implemented on both the low and high-speed axial compressors with a different arrangement of the injectors [4]. The first attempt in controlling flow instabilities, due to the inlet distortions, by means of the air injection at the blade tip region is carried out experimentally by Spakovszky et al. [5]. They showed that a steady axisymmetric air injection of 4% of the compressor mass flow rate can result in reduction of stalling mass flow rate by 9.7% relative to the no-injection case.

The present experimental research work is devoted to studies on the effects of the blade row tip air injection on the performance of a low-speed axial compressor while being exposed to different inlet distortions. Entry flow distortions have been imposed by mounting screens of different geometries upstream of the rotor blade row. Frequency analyses of the pressure signals through the compressor provided to realize the effectiveness of this technique in the suppression of the flow instabilities.

2- Methodology

An axial compressor rotor blade row consisting of 12 blades of NACA-65 airfoil series is used for the current

*Corresponding author's email: taghavi@iust.ac.ir

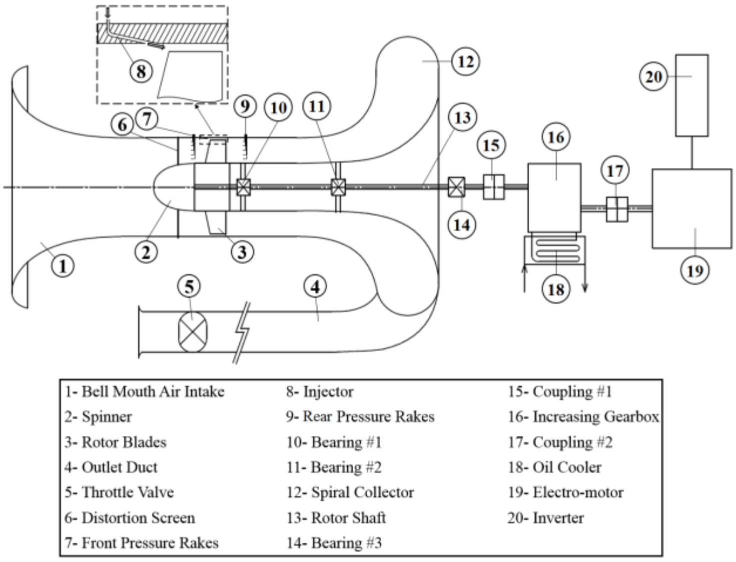

Fig. 1. Schematic layout of IUST axial compressor test rig

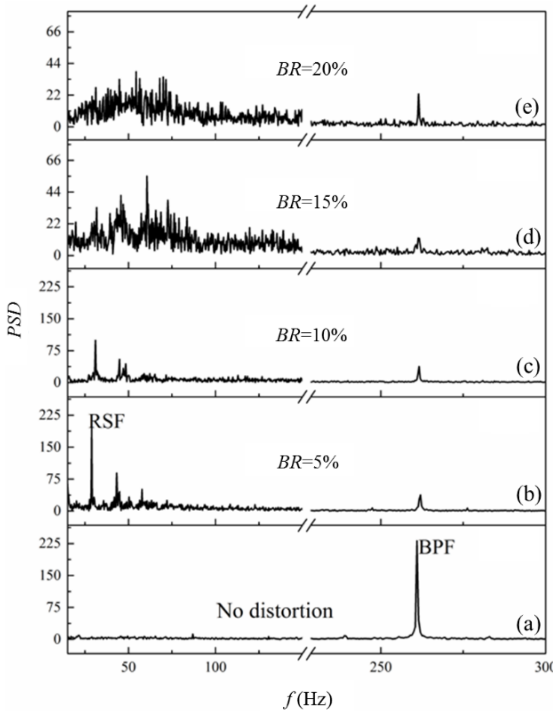

Fig. 2. Frequency spectrums for different distortion cases

20% of the clean compressor annulus passage cross-sectional area. Air injection system consists of 12 injectors, with an internal diameter of 2 mm for each one, mounted within the compressor casing wall. They are distributed evenly spaced along the compressor circumference upstream of the test model at a distance of 12 mm from the leading edge. The schematic of the test rig and injection system is shown in Fig. 1. Experiments included unsteady measurements of fluctuating flow utilizing high response pressure sensors.

3- Results and Discussion

Results of Fast Fourier Transform (FFT) of the pressure signals for the clear and distorted flow are shown in Fig. 2. At no-distortion case, the only dominant peak has appeared at a frequency of 260 Hz. This frequency corresponds to the Blade Passing Frequency (BPF). It means that the only dominant oscillations are those caused by the rotor revolution. With increasing distortion screens area, there can be seen many disturbances in the frequency spectrum which

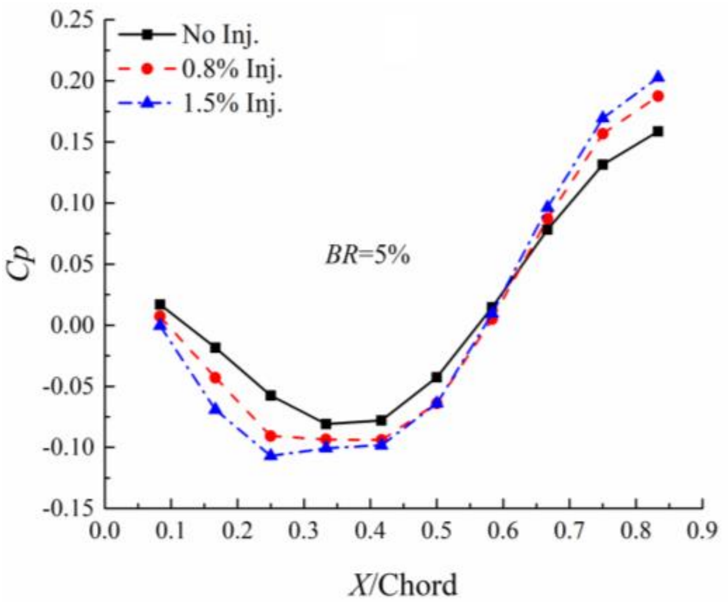

Fig. 3. Static pressure along the blade chord

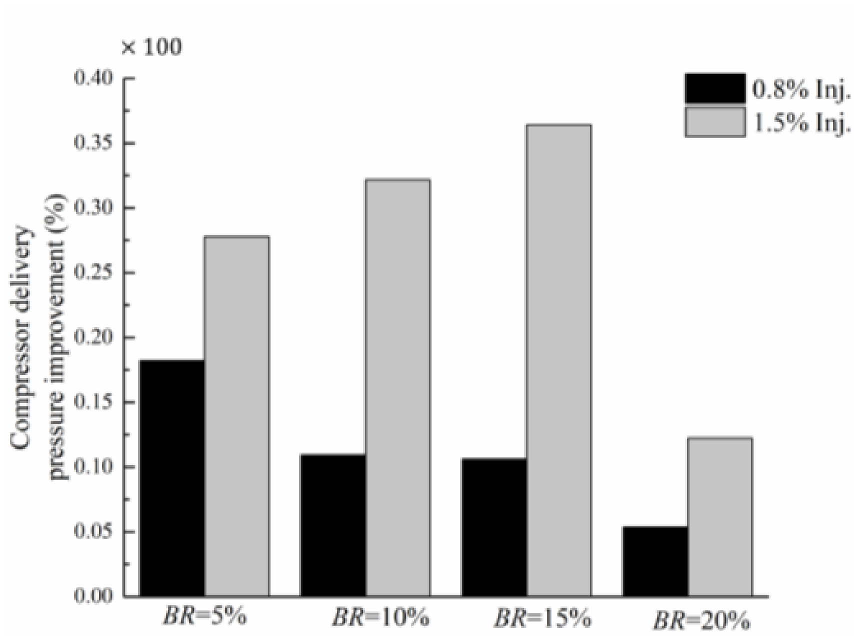

Fig. 4. Improvement of compressor delivery pressure

research work. The external diameter of this rotor blade row with blades row aspect ratio of 0.76 is 45 cm. All the tests are performed at a rotor speed of 1300 rpm. Entry flow distortions have been imposed by mounting screens of different geometries upstream of the rotor blade row. Each screen has been mounted 1.5 times the blade tip chord length upstream of the rotor blade row measured from its leading edge. The blockage ratios of these distortion screens are 5%, 10%, 15%, is mainly due to the geometry of the distortion screens. High magnitude inflow distortions are induced strong fluctuations in the compressor main flow due to the large wakes which are generated by the screens.

For investigation of air injection effects on the compressor performance under inlet distortion, first, the static pressure along the blade chord at the tip region is measured. The results are shown in Fig. 3 for no-injection, injection of

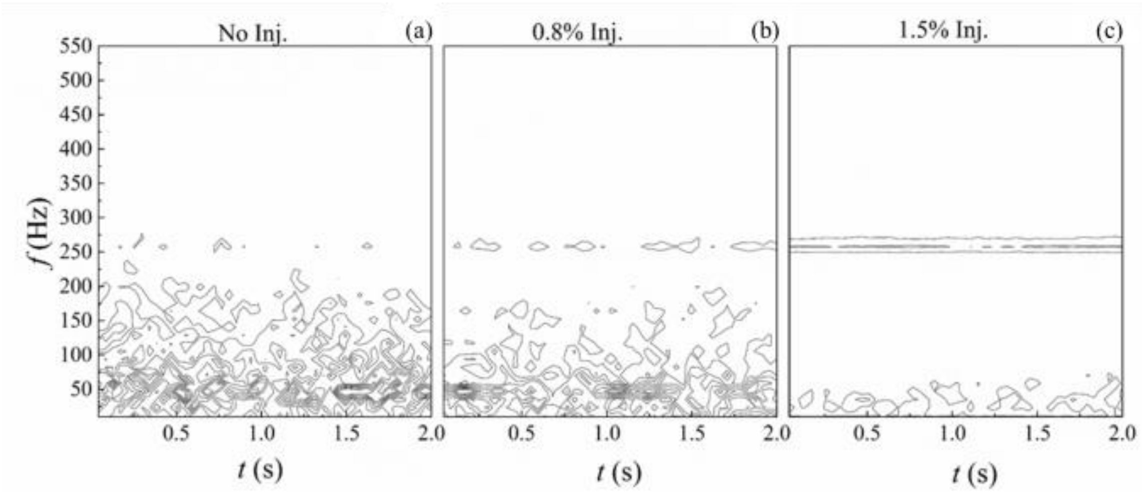

Fig. 5. STFT analysis of static pressure signals, BR=15%

0.8% and 1.5% of the main flow. In this case, air injection is improved the compressor delivery pressure significantly. Also, the static pressure at the rotor entry region is decreased which is related with increase in the local velocity. Summary of compressor delivery pressure improvement is presented in Fig. 4. For all cases, air injection has a positive effect on compressor performance. More amount of injected flow has better influence, especially in large distortion screens. Short-Time Fourier Transform (STFT) analysis is used as a powerful technique for the investigation of flow unsteadiness. As shown in the Fig. 5, many disturbances have appeared in different frequencies below the 260 Hz. These disturbances are evidence that the compressor operates in an unstable condition (Fig. 5(a)). Air injection has caused a reduction in flow unsteadiness, and disturbances are suppressed ultimately when only dominant frequency equals the BPF (Fig. 5(c)).

4- Conclusions

The effect of air injection on the improvement of the compressor under inlet distortion is the subject of this study. Inflow distortion is caused to formation of rotating stall in some cases. In a higher level of blockage, the compressor's main flow is influenced considerably. Air injection as an active control method could decrease or eliminate these undesirable effects and leads to an increase in compressor delivery pressure.

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