Effects of Air injection at Rotor Blade Row Tip Region of an Axial Compressor on its Performance under Inlet Distortion Conditions

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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. 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 pressure are recorded at different locations of 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 to 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 main flow, has considerable effects on the compressor performance under inlet distortion. The rotor performance and compressor delivery pressure is 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 demonstrated, too.

KEYWORDS

Axial compressor, Tip injection, Inlet distortion, Short-time Fourier transform, Aerodynamic instability

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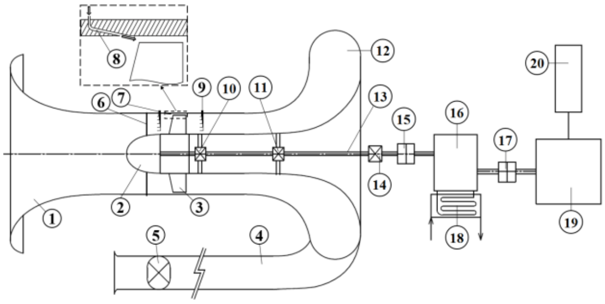
1. Introduction

Any gas turbine engine may suffer from any possible flow disturbances occured 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 commencement of instabilities. They may cause reduction in the main stream axial velocity and increase in the flow incidence of the rotor blade rows, which in turn, could lead to formation of stall cells. These cells rotate with the rotor blades but at a speed 20-80% of the rotor rotational speed [2]. Continuous growth of the stall cells may lead to occurrence of surge. Up to now, many experimental and numerical works are conducted to study the compressors performance deterioration when they are exposed to the inlet distortions. For example, distortions resulting from 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 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. [15]. 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 experimental studies on effects of the blade row tip air injection on 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 effectiveness of this technique in 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 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. Blockage ratio of these distortion screens are 5%, 10%, 15%, 20% of the clean compressor annulus passage cross sectional area. Air injection system consists of 12 injectors, with internal diameter of 2 mm for each one, mounted within the compressor casing wall. They are distributed evenly spaced along the compressor circumference upstream the test model at a distance of 12 mm from the leading edge. Schematic of the test rig and injection system is shown in the Figure 1. Experiments included unsteady measurements of fluctuating flow utilizing high response pressure sensors.



1- Bell Mouth Air Intake	8- Injector	15- Coupling #1
2- Spinner	9- Rear Pressure Rakes	16- Increasing Gearbox
3- Rotor Blades	10- Bearing #1	17- Coupling #2
4- Outlet Duct	11- Bearing #2	18- Oil Cooler
5- Throttle Valve	12- Spiral Collector	19- Electro-motor
6- Distortion Screen	13- Rotor Shaft	20- Inverter
7- Front Pressure Rakes	14- Bearing #3	

Figure 1. Schematic layout of IUST axial compressor test rig

3. Discussion and Results

Results of Fast Fourier Transform (FFT) of the pressure signals for the clear and distorted flow are shown in Figure 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 is mainly due to the geometry of the distortion screens. High magnitude inflow distortions are induced strong fluctuations on the compressor main flow due to the large wakes which are generated by the screens.

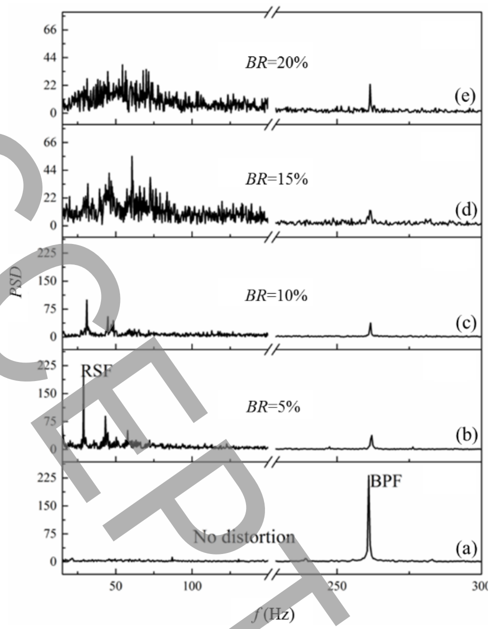


Figure 2. Frequency spectrums for different distortion cases

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 the Figure 3 for no-injection, injection of 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 increasing in the local velocity. Summary of compressor delivery pressure improvement is presented in the Figure 4. For all cases air injection has positive effect on the 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 investigation of flow unsteadiness. As shown in the Figure 5, many disturbances are appeared in different frequencies below the 260 Hz. This disturbances are evidence that the compressor operates in an unstable condition (Figure 5-a). Air injection is caused to reduction in flow unsteadiness; and disturbances are suppressed ultimately when only dominant frequency equals to the BPF (Figure 5-c).

4. Conclusions

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

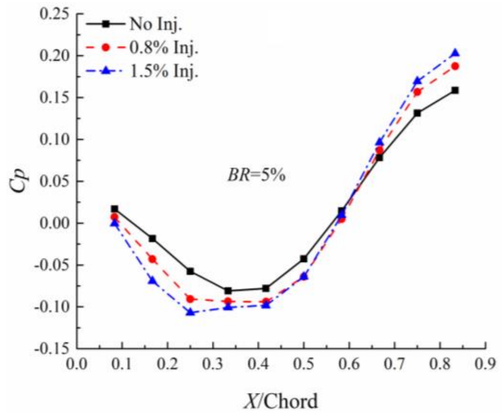


Figure 3. Static pressure along the blade chord

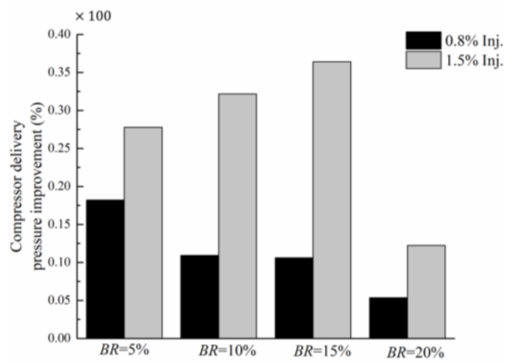


Figure 4. Improvement of compressor delivery pressure

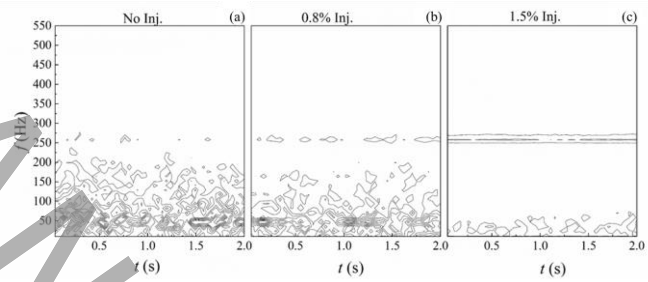


Figure 5. STFT analysis of static pressure signals, BR=15%

5. References

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