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Study of Inlet Guide Vanes for Centrifugal Compressor in Miniature Gas-Turbines

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ABSTRACT
we believe miniaturization is the step forward. This paper gives a brief overview of a gas-turbine, how miniaturization of it has a plenty of applications and specifically focuses on the miniaturization of the centrifugal compressor used in it. This paper suggests that the centrifugal compressor of an automobile turbocharger can be used as the compressor for the miniature gas turbine due to its geometrical similarities and also provides an insight into the challenges that might be faced when this is incorporated. It also suggests a few modifications, when applied to the turbo-compressor; it may overcome the challenges and the modification being introduction of a pre-whirl effect. The pre-whirl effect proves to be efficient as it helps reduce surging, turbulence, chocking and shocks that might be induced into the turbo-compressor when it is used in a miniature gas turbine due to high speed. Therefore this paper is a step towards miniaturization of the gas turbine at a low cost, at the same time uses a high precision manufactured product (turbo-compressor).
Keywords: Centrifugal Compressor, Gas Turbine, Turbo Charger, Pre-whirl, Miniaturisation, Guide Vanes.

I. INTRODUCTION

Gas turbine which is also known as Jet engine is an internal combustion reaction type engine, which produces a fast moving jet, which in-turn provides the thrust. This is known as jet propulsion. A typical gas turbine is a highly technical, geometrically large and a very expensive machine which is engineered, manufactured and produced with the highest possible precision techniques. [1] The leading manufacturers of the gas turbines like GE, ROLLS ROYCE, PRATT AND WHITNEY etc. concentrate in manufacturing engines for large scale applications. Hence research towards small scale applications of gas turbine is often neglected. A miniaturized gas turbine finds its applications mainly in militaristic devices such as drones. As there is no proper research done in this field, the manufacturing of these mini gas turbines turns out to be an extremely expensive affair. The small gas turbines which are made with the required reliability end up being extremely expensive partly because they are made in such small numbers and also because their configurations change for each application. There are many acceptable configurations of the miniature gas turbines, the most commonly accepted design is the use of single stage compressor and turbine, with the compressor being centrifugal in nature.

Fig. 1 : Miniature Gas Turbine

This paper focuses primarily towards the compressors used in gas turbine.
There are only two types of compressors used in gas turbines [2]

a) Axial flow compressors: Used in large scale applications.
b) Radial flow compressors: Used in small scale applications

Fig. 1 : Centrifugal Compressor

These radial flow compressors are also known as centrifugal compressors. This paper is oriented towards research on the centrifugal compressor. There are a wide variety of centrifugal compressors that are currently used in the market. One such application in which centrifugal compressors are pre-eminently used is the turbocharger of automobiles. As this research is focused on miniaturization of gas turbine, it can be taken into account that the turbo-compressor is geometrically small and it can also be observed that the characteristics of the turbo-compressors were very similar to that of the required compressor at its working range, relative to the inlet and outlet requirements. Hence it was theoretically possible by the equation that governs all centrifugal compressors that the pressure ratio created by the turbo-compressor is in accordance with the required conditions at the working range of the gas turbine.[3]
The working range of the turbocharger is at a speed range of 60000-120000 rpm at a pressure ratio of approximately 3, when this working range is taken in comparison with the working range of a gas turbine, the speed range of miniature gas turbine is around 150000-200000 rpm at a pressure ratio of 9.

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II. CHALLENGES

If this turbo-compressor is to be incorporated into a gas turbine, it is going to run at a speed of 150000-200000 rpm, therefore the pressure ratio of the turbo-compressor increases automatically. The following are the challenges that might be posed due to the increase in the speed and the pressure ratio:

- ✓ The relative velocity between the blades and inlet air is very high, therefore shock maybe induced.
- ✓ Due to the high speeds, turbulence is created, which in-turn creates vibrations, which might lead to failures.
- ✓ Since turbo-compressors work at an optimum rpm the output air flow might be less due to pressure build up, hence surging might occur.
- ✓ Also if the air flow is too high then chocking might occur.

A. SURGE: To understand surge one needs to know the working principle of the compressor, which is imparting kinetic energy to the fluid at the impeller and then sacrificing this kinetic energy at the diffuser to increase the static pressure of the fluid and decreasing the kinetic energy of the fluid.[4] If maximum head capacity is reached, then pressure in diffuser will be greater than pressure at impeller outlet. This will prevent fluid from moving further at impeller outlet and causes the fluid in diffuser to flow back, i.e. flow reversal takes place. This can be deteriorating as it has potential to damage the bearings and other rotating parts, and also cause high vibrations.

B. SHOCK: When the relative velocity between the working fluid and blades reach the speed of sound, there are characteristic waves produced causing damage to the blades.

C. CHOKE: It is operating point at minimum flow capacity condition where high velocity air flow causes severe damage on the compressor creating instability.[5]

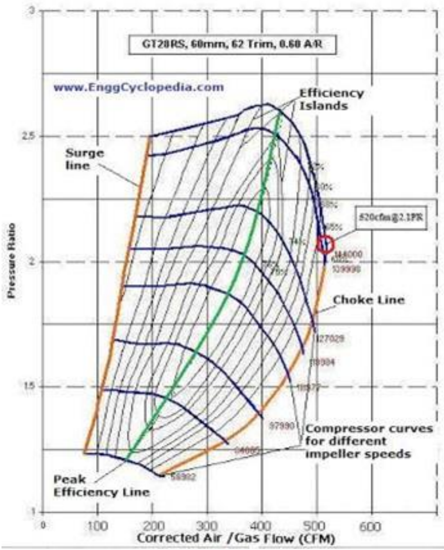

Fig. 2 : Surge and Choke Margin

III. OBJECTIVES

Even though the pressure ratio increases due to the rapid increase in the speed, this pressure ratio cannot be sustained due to the above mentioned phenomenon. So this paper suggests the adoption of the below mentioned methods in order to sustain the pressure ratio created.

- Inclusion of inlet guide vanes[6]
- Diffuser vanes
- Use of vortex generator

This paper exclusively deals with the changes that might occur on the account of inclusion of guide vanes at inlet of the turbo-compressor. These guide vanes induces pre-whirl. Pre-whirl is the phenomenon of adding a circular component to the inlet air. The circular component maybe towards or away from the inlet blade angle of the compressor. Pre-whirl reduces the angle of attack and increases the mass flow rate and hence the surging is prevented. [7]

By accommodating the guide vanes with a positive angle of attack, a positive pre-whirl can be generated, which in-turn increases the speed of the compressor blades. By accommodating the guide vanes with a negative angle of attack, a negative pre-whirl is generated, which in-turn decreases the speed of the compressor blades. If surge is detected, a positive angle is given to the inlet guide vanes in-turn increasing the flow rate of air. If choke is detected a negative angle of attack is established which in-turn produces a negative pre-whirl this reduces chocking.

IV. METHODOLOGY

In this paper we are considering the use of the automotive turbocharger compressor from GARRETT model GT-28. This turbocharger was used in the Nissan skyline GT-R, which was famed for its reliability and its excellent performance far beyond its official capacity. It was intended to design a virtual model of a compressor according to the geometry and dimensions of the compressor used in the above mentioned automobile turbocharger, so that the guide vanes can be designed for the same.

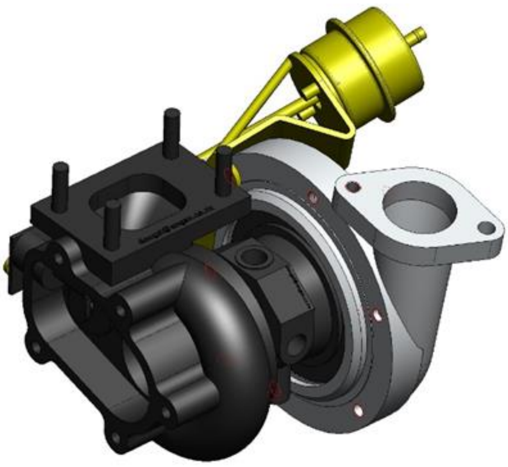

Fig 4: GARRETT Turbocharger

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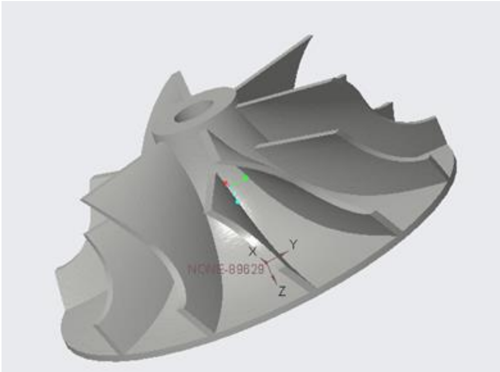

Fig 5: CAD Model of GARRETT GT-28 compressor

Design suggestions for pre-whirl:

- Inlet guide vanes can either be fixed or variable. Since this particular application deals with the working of compressor above the speed at which it was designed to work at, the characteristics may abruptly change with little or no variation in the working parameters. This has to be controlled at all speeds, hence variability is required.
- The general blade design of guide vane is of parabolic shape, this brings unwanted components into this particular application. Therefore for this application the guide vanes are initially linear and have no angle relative to the inlet air direction and later have a parabolic curve for the induction of pre-whirl.[7][8]

V. DESIGN OF INLET GUIDE VANES

As mentioned earlier, the angle of attack of the guide vanes determines the nature of the Pre-Whirl effect that is imparted to the inlet air. Keeping this in mind the following steps were taken to design the Inlet Guide Vanes.

- ✓ The diameter of the Casing for the Inlet Guide vanes was considered to be the same as that of the compressor casing.
- ✓ To begin with, Straight blades were designed. Straight Blades are blades without any curvature with respect to the flow. This designed had to be abandoned because it induced unwanted characteristics to the Inlet Air
- ✓ Then curved parabolic blades were also designed and were found to be inducing sufficient Pre-whirl into the inlet air.
- ✓ Blades which were initially straight in orientation and gradually transformed into parabolic shape with respect to the inlet air were found to be the most efficient, because these blades produced better results at high velocities compared to just the straight and parabolic ones.
- ✓ The blades were designed according to the nature of the whirl required at a particular distance from the blade. Since the radial velocity increases linearly along the radius of the blade, the same thing was

incorporated into designing the pre-whirl also the angle of the blade has been increased from root to the tip linearly.

- ✓ To give perspective into this design, A 30 degree blade will have a root angle of 15 degree at the impeller and an angle of 45 degree at the tip (casing). This design was adopted to give more whirl at the points on the blades which have higher velocity.

The following steps are to be done.

- Simulate the working of turbo-compressor at working speed of gas turbine with and without pre-whirl using Ansys Fluent.
- Give the working parameters, speed of blade, flow conditions, boundary conditions to the virtual assembly.
- Simulate the virtual assembly at all speeds and angles of attack and plot for each.
- Suggest the best guide vane angle at a given speed.

VI. CONCLUSIONS

The project team has designed a turbo-compressor similar to the geometry of the turbocharger mentioned in the paper (GARRETT GT-28). After testing the different blade profiles for this particular high velocity application. Following were the results obtained

- Straight blades: At low velocity there was low pressure area situated behind the active part of the blade. And at high velocities the blade produced whirls which had negative effect.
- Parabolic blades: At low velocity they worked as intended. But at high velocity whirls were created right behind blades at terminal end of the blade.
- Mixed Profile blades: They work efficiently at all flow velocities.

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