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THERMODYNAMIC DESIGN OF CENTRIFUGAL COMPRESSOR FOR TURBOCHARGER

Sonawane Shubham*, Sondkar Pratik, Qasim Siddiqui, Phirke Indraneel, Prof. R. P. Kakde
* Department of Mechanical Engineering, All India Shri Shivaji Memorial Society's College of Engineering, Pune, India.

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ABSTRACT

The purpose of a turbocharger is to increase the power output of an engine by supplying compressed air to the engine intake manifold so that fuel can be burnt efficiently. In this work, thermodynamic design of a high pressure ratio centrifugal compressor, for 75 kW class engines, was carried out. A pressure ratio of 2.8 was considered with a compressor rotational speed of 60,000 RPM. The compressor was designed for vane less diffuser. The impeller designs were obtained using circular method, with six divisions. The CAD models were built using CATIA. The geometry was then tested using Computational Fluid Dynamics (CFD) simulations to verify the thermodynamic based design.

KEYWORDS: Centrifugal Compressor, Circular-Arc method, Turbocharger design.

INTRODUCTION

Centrifugal compressors are mostly used in refrigeration cycles, refining systems, aircraft auxiliary systems, turbo shaft engines, and other systems where lightweight compact compression is required. The off-design performance characteristics of centrifugal compressors are of interest because of the large effects that compressor component performance has on overall cycle performance and because the compressor is required to operate at off-design conditions much of the time.

In addition to good performance at off-design flow rates it is important that the compressor operate stably over the range of flows and speeds required by the engine operating envelope. The usable range of the compressor pressure ratio-mass flow characteristic is bounded by the surge and chokes mass flow rates. Operation at flows less than the surge point flow should be avoided because of potentially dangerous vibrations induced by the intermittent flow reversals and power loss. Operation with the compressor choked is generally avoided because of the poor compressor efficiency and pressure ratio at the choke point.

The problem undertaken in this analysis is to determine the centrifugal compressor performance characteristics over a range of rotation speeds and flow rates and predict the usable range of flow rates at which the compressor can operate.

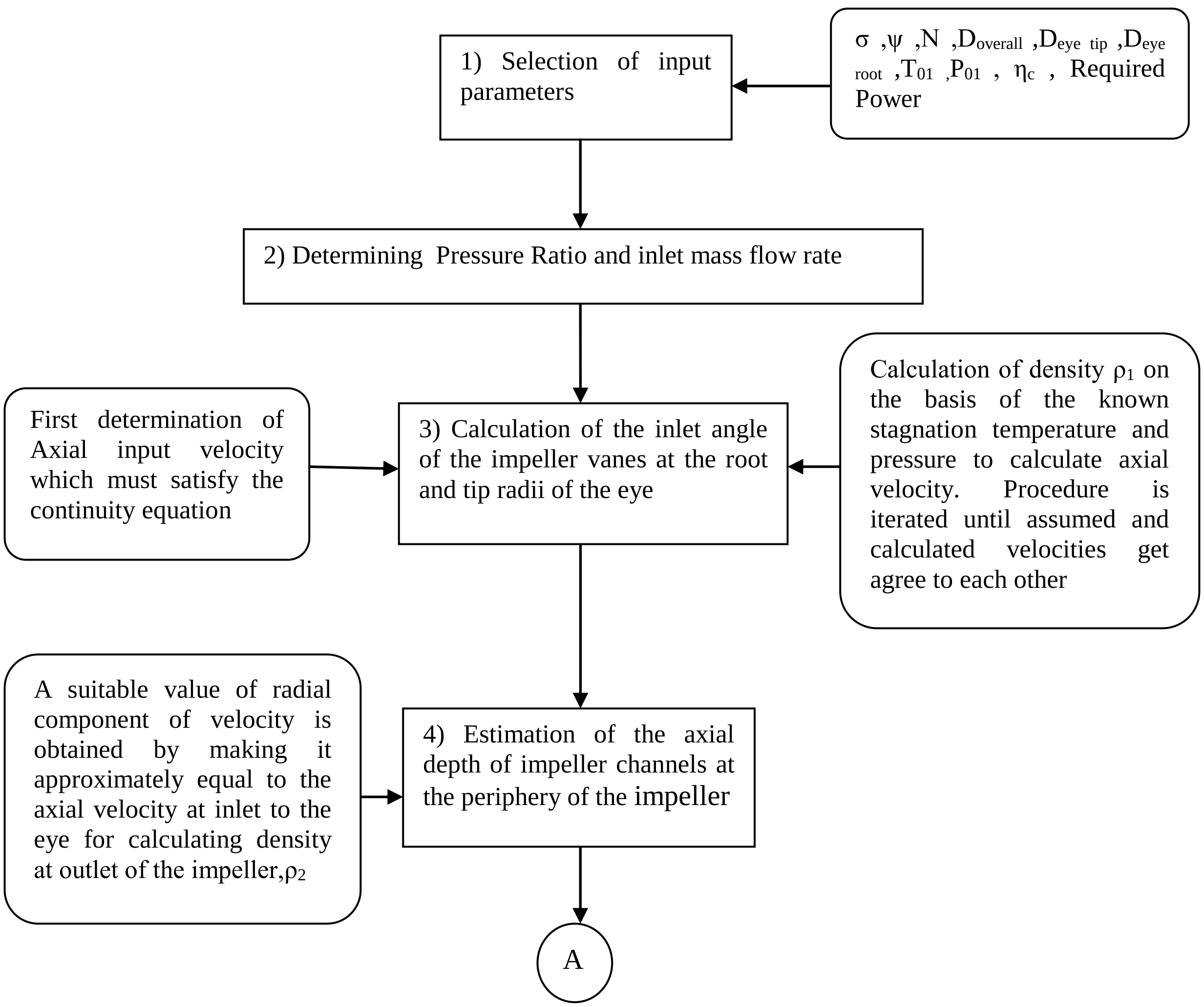
The work will involve the design of centrifugal compressor that is part of the turbocharger. The work will target to have the best design practices, methods, procedures for the components by studying the latest trends in the turbo machinery industry. The CFD simulations for the project will follow the guidelines that are followed in the modern day industries.

DESIGN METHODOLOGY

For thermodynamic design of turbocharger first various input factors like power input factor, slip. Slip is nothing but equalization of whirl velocity of air and impeller speed. How far the whirl velocity at the impeller tip falls short of the tip speed depends largely upon the number of vanes on the impeller. The greater the number of vanes, the smaller the slip. It's important to assume slip factor σ in compressor design. Slip factor σ is defined as ratio of C_{w2}/U. increase in no of vanes increases the solidity of impeller eye which will reduce effective flow area. Σ is assumed as 0.9 in this design. Work done is positively treated. Actual work input is always greater than theoretical work input because of various losses like friction loss between casing and moving air around the impeller and other losses which have breaking effect like disk friction or windage losses. The power input factor should be considered to take account of this. ψ is considered as 1.04 in this work and it is degraded into thermal energy Therefore work done is equal to $\sigma\psi U^2$ .The overall stagnation pressure ratio follows as

$$\frac{P_{02}}{P_{01}} = \left(\frac{T'_{02}}{T_{01}}\right)^{\gamma/(\gamma-1)} = \left[1 + \frac{\eta_c(T_{03} - T_{01})}{T_{01}}\right]^{\gamma/(\gamma-1)} = \left[1 + \frac{\eta_c \psi \sigma U^2}{c_p T_{01}}\right]^{\gamma/(\gamma-1)}$$

How much of the work is actually used to raising the pressure of the air is nothing but the isentropic efficiency of air, η_c and it is assumed as 0.87. The following flowchart will explain the design procedure of centrifugal compressor.



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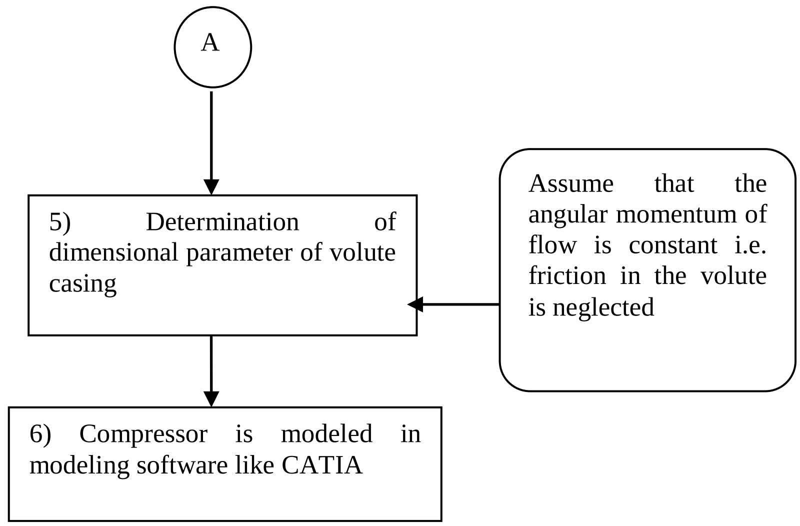

Construction of vane profile

All dimensional parameter like inlet and outlet vane angle ,radii at tip and root ,blade height are obtained from thermodynamic design .circular arc method is used to get vane profile. in circular arc method circle is divided into no of circle having equal interval and starting with innermost circle with given calculated angle in design. Curve is drawn up to extreme circle. Both root and tip curve can be obtained by this method

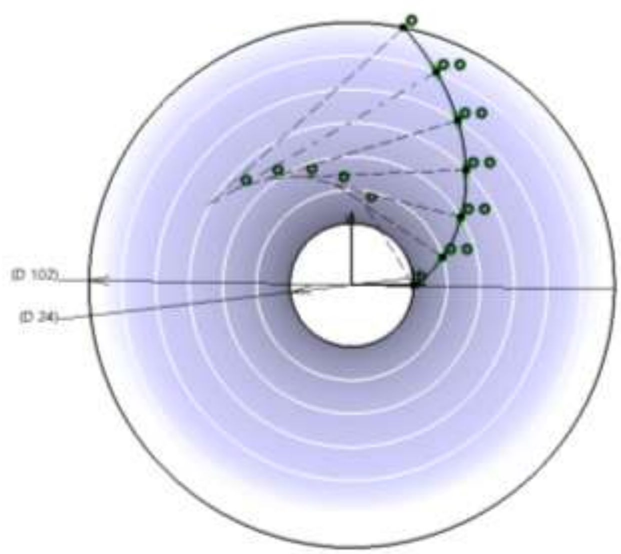

Figure 1: circular arc method construction

3D Model

3D model is created using CATIA software. different view are shown below

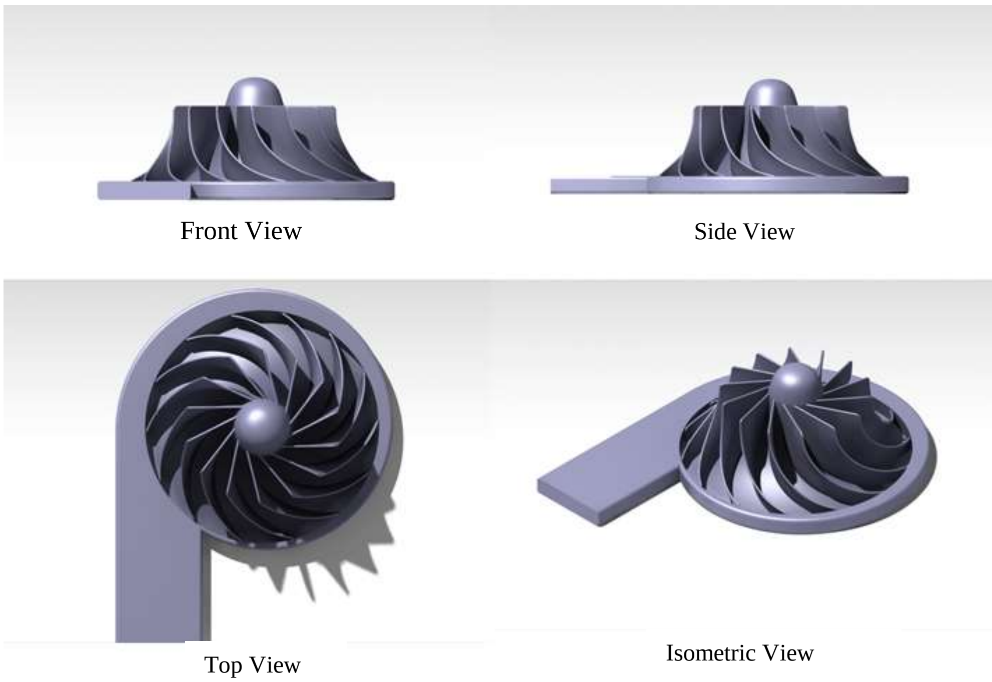

Figure 2 Various views of compressor assembly

RESULTS AND DISCUSSION

Table 1 input and output parameters

No.	Input Parameters	Values	No.	Output parameters	Values
1)	Power input factor, ψ	1.04	1)	Pressure ratio	2.87
2)	Slip factor, ρ	0.9	2)	Mass flow rate	0.78 Kg/s
3)	Rotational Speed, N	60000 rpm	3)	Density at inlet	1.99 Kg/m^3
4)	Overall impeller diameter, $D_{overall}$	0.102 m	4)	Axial velocity at inlet	124.11 m/s
5)	Eye tip diameter, $D_{eye\ tip}$	0.0678 m	5)	α at root	58.7°
6)	Eye root diameter, $D_{eye\ root}$	0.024 m	6)	α at tip	30.229°
7)	Power required	75 KW	7)	Density at outlet	2.898 Kg/m^3
8)	Inlet stagnation temperature, T_{01}	295 K	8)	Depth of impeller channel	0.00675m
9)	Inlet stagnation pressure, P_{01}	1.8 bar			
10)	Isentropic efficiency , η_c	87%			

CONCLUSION

Study of centrifugal compressor is done. The basic analytical design methodology is produced. Circular arc method is used to get vane profile. Various dimensional parameters are used to get compressor geometry to build 3D geometry which can be used further for analyzing the system.

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