Design and Development of a Multi Stage Contra Rotating Mini Axial Compressor

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Introduction

The aim of this project is to develop a working model of a contra-rotating 4-stage mini axial compressor to demonstrate the multifarious benefits of a contra-rotating axial compressor over a conventional axial compressor. A contra-rotating compressor means that alternate rotors are rotating in the opposite sense, such that all stators are eliminated thereby decreasing the compressor length & weight significantly. Another benefit of counter-rotation is that it offers a much larger change in angular momentum, facilitating higher pressure ratios with reduced number of blade rows. Contra-rotating compressor rotors are known to process higher mass flows than a regular axial compressor for same flow area. The preliminary aerodynamic & mechanical design of the compressor and a CFD analysis has been completed. The fabrication process is underway.

Design Parameters

Parameters	Value
Hub Diameter	7.5 cm
Tip Diameter	14 cm
Annulus Area	0.01097 sq. m
Number of Stages	4
Gap Between 2 Stages	1 cm
Blade Chord	3 cm
Blade Span	3 cm
Tip Clearance	2.5% of the Span
Shaft Speed (Inner & Outer)	3600 RPM
Mass Flow Rate	0.665 Kg/s

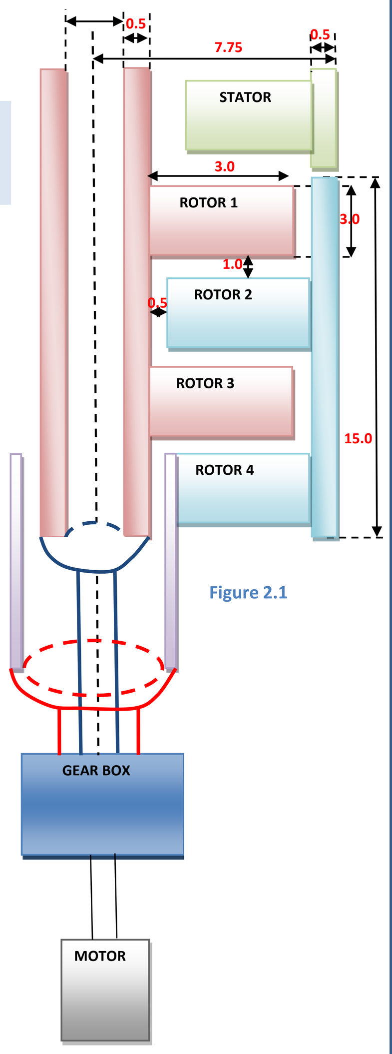


Figure 2.1

Blade Design

The Blades have been designed for Low Subsonic Laminar Flow with Mach Number equal to 0.15. C4 Profiles with Circular Cambers have been used. IGVs have also been used to turn the incoming flow by 1.5 degrees.

The Blade Chord and the Span values have been set at 3 cm and the maximum thickness is 10 % of the chord at half chord. The Diffusion Factor has been kept below 0.6 near the hub and below 0.45 near the tip.

Stage	Radius (cm)		Hub		Tip		No. of Blades
	Hub	Tip	Camber Angle	Stagger Angle	Camber Angle	Stagger Angle	
1	3.75	6.92	40.56^0	-7.19^0	26.78^0	13.67^0	8
2	7.00	3.83	22.45^0	30.73^0	31.95^0	25.47^0	9
3	3.75	6.92	40.46^0	-7.7^0	26.61^0	14.61^0	8
4	7.00	3.83	20.22^0	31.22^0	33.02^0	25.25^0	9

Intake Design Parameters

A Bell mouth intake based on ASME Bell-Mouth design principles, having the following parameters has been designed for the compressor.

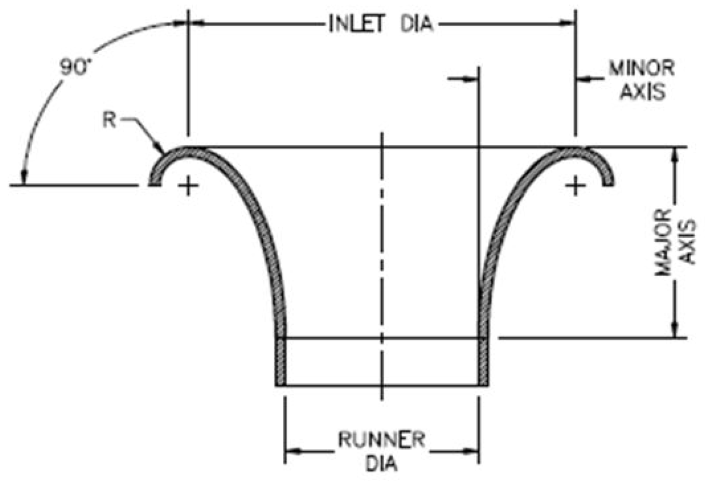
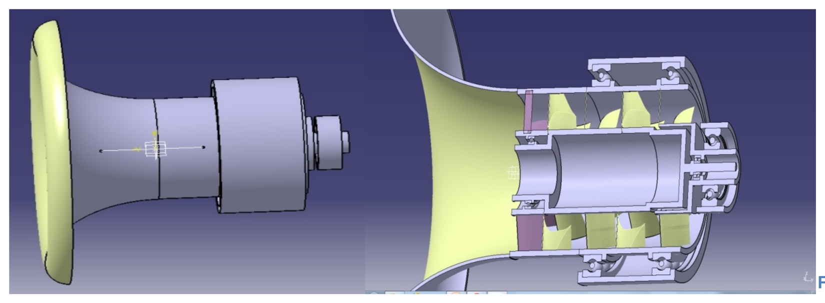


Figure 3.1

Parameter	Value
Major Axis	14.5 cm
Minor Axis	7.25 cm
Radius, R	2.9 cm
Inlet Diameter	29.0 cm
Area Ratio	4.0 : 1.0
Minimum Center	35.1 cm

Mechanical Configuration

The 4 rows of rotors are to be mounted on 2 contra-rotating shafts. It has been decided to arrange the 2nd and 4th rotor blades in inward cantilever manner integrated to a rotating casing which is housed inside a stationary backbone shell. The 1st and 3rd stage rotors are to be integrated to an inner hollow shaft which is in counter-rotation with the outer casing. The thickness of the inner shaft and the outer casing has been set at 0.5 cm based on the stress and vibrational analysis that has been carried out for the compressor.



Overall Compressor with the Intake and Backbone Shell

Figure 5.5

Both the inner shaft and the outer casing are to be rotated by a single motor using a contra-rotating gearbox as shown in Figure 2.1

To enable smooth functioning of the compressor, deep groove ball roller bearings are to be used at 5 different locations as per the following configuration:

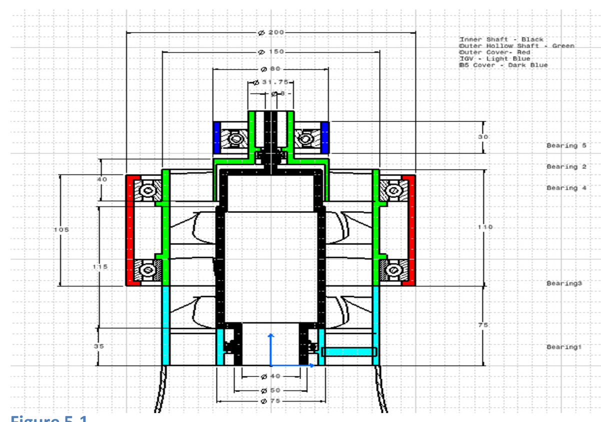


Figure 5.1

Bearing Configuration

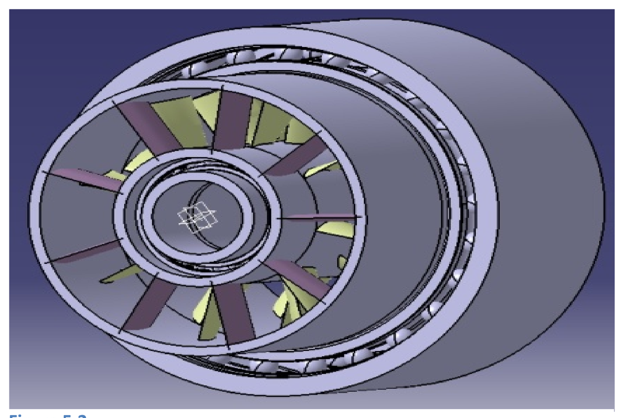


Figure 5.2

Compressor with IGVs

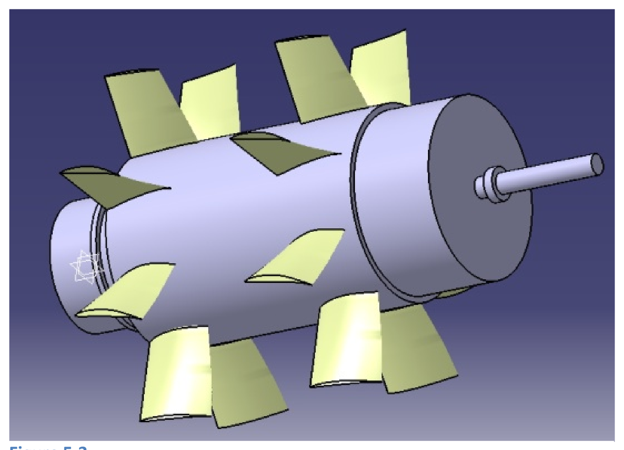


Figure 5.3

Inner Shaft with Stage 1 & 3 Blades

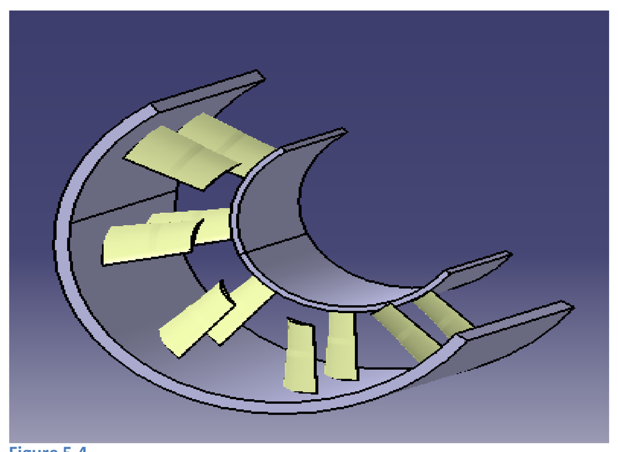


Figure 5.4

CFD – Results

Ansys Turbogrid and CFX solver software were used for carrying out the simulations. The entire compressor was divided into 6 domains (4 Rotating and 2 Stationary). The RPM for the rotating domains was set at 3600.

Model: Shear Stress Transport along with 5 % Turbulence model was used for the simulations.

Mesh: A very fine mesh (2 million nodes) was generated for each domain using H/J/C/O grids.

Boundary Conditions: Total Pressure of 1 atm at inlet and Mass flow rate of 0.665 kg/s at the outlet.

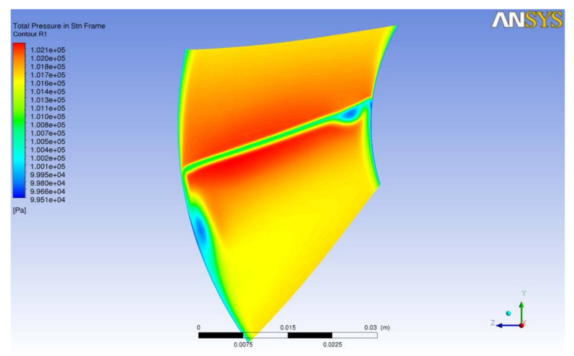


Figure 6.1

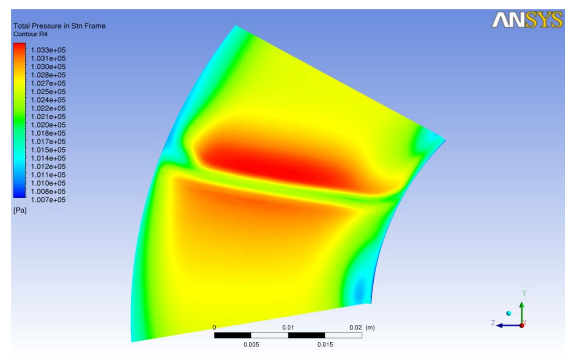


Figure 6.2

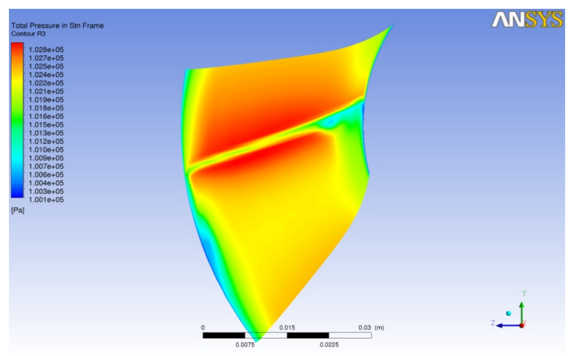


Figure 6.3

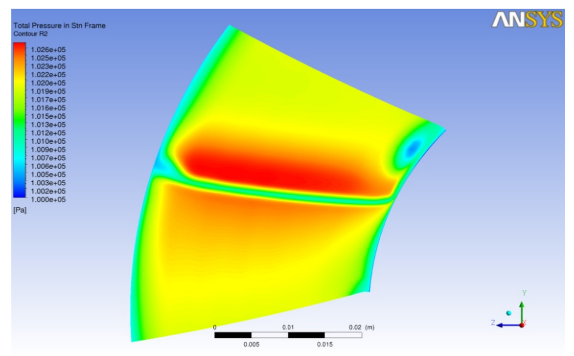


Figure 6.4

Wake Profiles behind blades of Rotor 1, Rotor 2, Rotor 4 & Rotor 3 (Beginning from top left corner and moving clockwise)

Stage	Total Pressure Rise	Isentropic Efficiency
Rotor 1	434 Pa	86.5 %
Rotor 2	331 Pa	79 %
Rotor 3	358 Pa	85.5 %
Rotor 4	315 Pa	78.5 %
Overall	1290 Pa	74 %

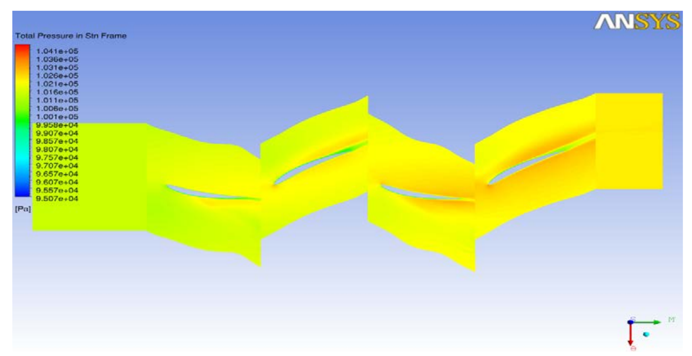


Figure 6.5

Total Pressure Contours at 90% Span

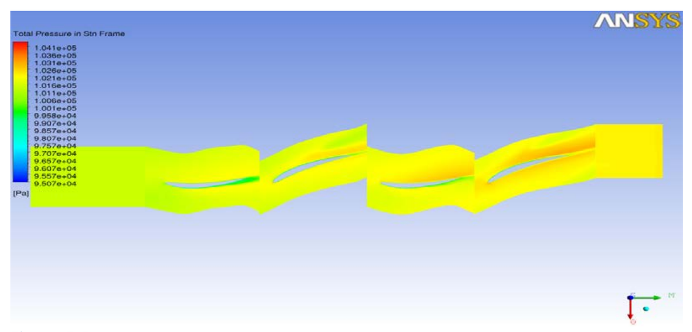


Figure 6.6

Total Pressure Contours at 10% Span

Fabrication

The demonstrator compressor is being fabricated in five parts out of nylon plastics using rapid proto-typing and vacuum casting process. The outer rotating casing of the compressor is to be housed inside a non-rotating outer backbone shell using deep grove ball roller bearings. The bell mouth intake is to be integrated with this backbone.

Acknowledgement

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