Single Stage Compressor-AE345

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1 Introduction

A single-stage compressor (SSC) functions by drawing in atmospheric air and compressing it to a higher pressure in a single continuous step. It is widely utilized across different applications, including industrial machinery and jet engines. We will get to know about these important performance parameters including pressure ratio, efficiency, and power consumption of the SSC.

2 Theory

An axial single-stage compressor operates on the principle of converting the kinetic energy of incoming air into increased pressure. In an axial compressor, the airflow is parallel to the axis of rotation, unlike in a centrifugal compressor where the airflow is radial.

2.1 Components

1. Rotors: These are rotating blades attached to a central shaft.
2. Stators: These are stationary blades fixed to the compressor casing.

2.2 Working Principle

1. Air Intake: Air enters the compressor through an inlet.
2. Rotors: The air first encounters the rotor blades, which are rotating. As the rotor blades move, they impart kinetic energy to the air, increasing its velocity.
3. Stators: After passing through the rotors, the air enters the stator blades. The stator blades are designed to convert the increased kinetic energy (high velocity) of the air into pressure energy by decelerating the airflow. This process increases the air pressure.
4. Outlet: The high-pressure air exits the compressor and can be directed to the next stage (if it's part of a multi-stage compressor) or to the combustion chamber (in the case of a gas turbine engine).

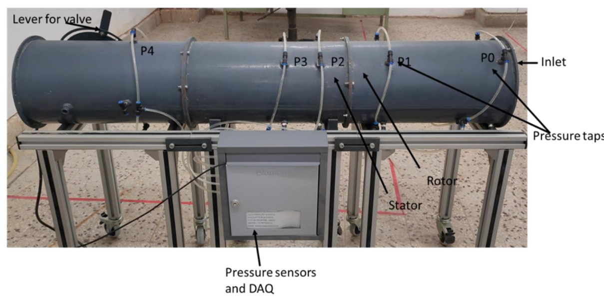

Figure 1: Experimental Setup

3 Apparatus

- Single stage compressor setup (stagger industries)
- Variable frequency drive (VFD – FRECON)
- Data acquisition system (DAQ)
- Data recording device and software (LabView)
- Pressure sensors

4 Experimental Setup

The experimental setup for the single-stage compressor involves a compressor unit connected to a Variable Frequency Drive (VFD) to control rotor speed. Pressure sensors are placed at various points to measure pressure changes, and a Data Acquisition System (DAQ) with LabView software records these measurements. An adjustable outlet valve controls the mass flow rate, allowing for the study of compressor performance under different operating conditions.
This is the experimental setup 1

5 Observation Table

Here is the Observation Table 1

S.No.	RPS	P_0	P_1	P_2	P_3	P_4	Mass Flow Rate
1	14	-11.618	-6.697	1.963	2.135	2.062	0.196
2	14	-9.294	-5.401	6.759	6.929	5.457	0.175
3	14	-5.527	-3.463	8.975	10.041	8.418	0.135
4	24	-33.602	-20.041	3.003	3.468	3.949	0.333
5	24	-28.39	-15.898	13.017	15.996	14.149	0.306
6	24	-17.042	-10.032	24.419	26.62	25.406	0.237
7	34.8	-67.654	-39.154	1.505	6.105	9.032	0.472
8	34.8	-52.747	-31.298	26.337	32.912	30.74	0.417
9	34.8	-28.384	-16.548	47.606	50.04	50.602	0.306

Table 1: Observation Table

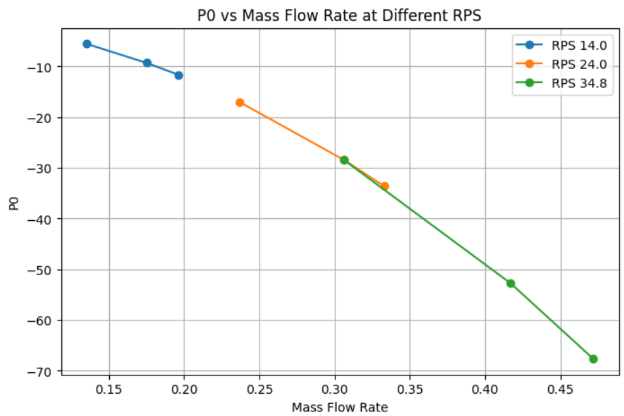

Figure 2: P_0 vs Mass flow rate

6 Results and Discussions

6.1 Pressure vs Mass flow rate at different RPS

Here are the plots: Figure no. 2, 3, 4, 5 and 6

6.2 Pressure Ratio and plot with Mass flow rate at each RPS

Pressure Ratio $= \frac{OutletPressure}{InletPressure} = \frac{P_4}{P_0}$

- For 14 RPS: Pressure Ratio $= \frac{2.062}{-11.618} =$ -0.1774
- For 24 RPS: Pressure Ratio $= \frac{3.949}{-33.602} =$ -0.1175
- For 34.8 RPS: Pressure Ratio $= \frac{9.032}{-67.654} =$ -0.1335

Here is the plot: Figure no. 7

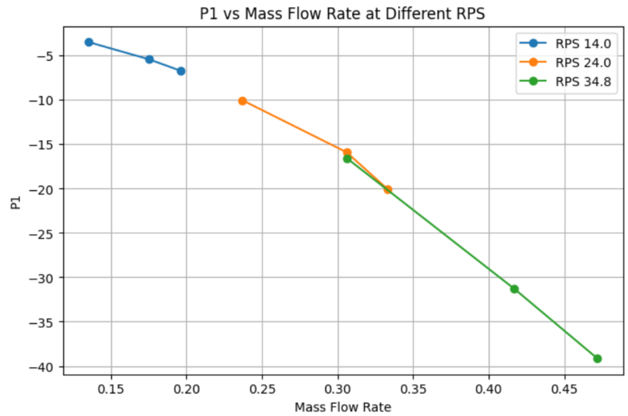

Figure 3: P_1 vs Mass flow rate

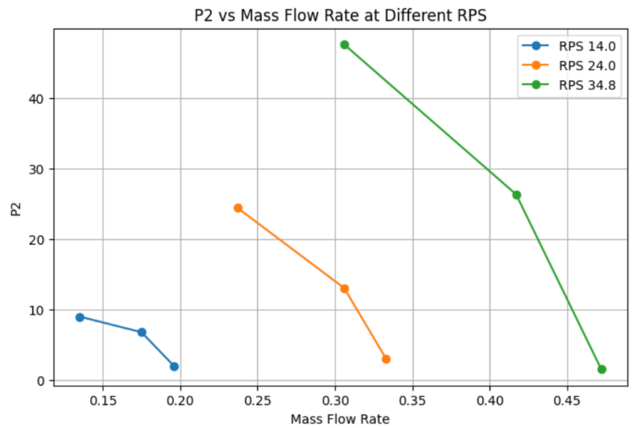

Figure 4: P_2 vs Mass flow rate

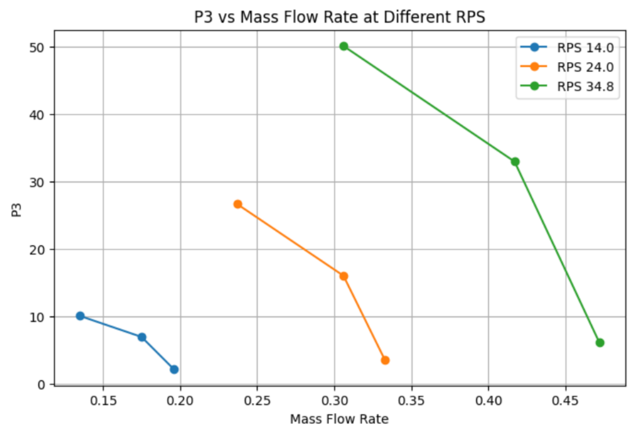

Figure 5: P_3 vs Mass flow rate

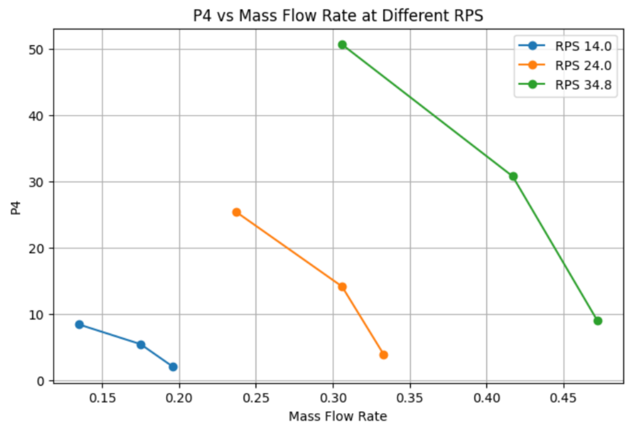

Figure 6: P_4 vs Mass flow rate

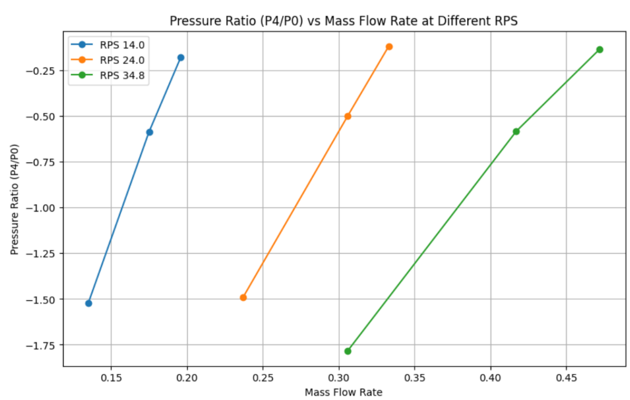

Figure 7: P_4 vs Mass flow rate

6.3 Observations and Results

- Increasing the motor RPS leads to a higher rate of air intake, which aligns with the expected behavior since more rapid rotor movement creates a very low pressure at the inlet (negative gauge pressure) thereby draws in more air into the compressor.

- The pressure readings at different stages of the compressor typically follow the order $P_0 < P_1 < P_2 < P_3$. This trend shows the expected pressure increase as air passes through the rotors and stators. Ideally, it should be $P_0 < P_1 < P_2 < P_3 \approx P_4$ because post-stator blades there is nothing that can increase or decrease the pressure. In the observation table we can see that sometimes $P_3 > P_4$ or $P_3 < P_4$ or $P_3 \approx P_4$. Any deviations from ideal pattern might result from measurement errors or system anomalies.

- A higher mass flow rate results in a decrease in the pressure ratio ideally. This decrease can be explained by the shorter residence time of the air in the compression zone, reducing the effectiveness of the pressure buildup. But from my data, it decreases first and then increases. This is due to the system anomalies.

6.4 Different pressures

These all are *gauge* pressures.

1. P_0 (Inlet Pressure): It is located before the rotor or at inlet of compressor. This is initial pressure which is at atmospheric pressure.

2. P_1 (Pre-Rotor Pressure): It is located just before the rotor blades. This shows the pressure when air approaches the rotor blades.

3. P_2 (Post-Rotor or Pre-Stator Pressure): It is located just after the rotor blades. This measures the pressure of the air after the interaction with rotor blades. This pressure should be greater than P_1 as rotor increases its kinetic energy and pressure.

4. P_3 (Post-Stator Pressure): It is located just after the stator blades. Here air slows down and its kinetic energy changes into pressure energy. So $P_3 > P_2$.

5. P_4 (Outlet Pressure): It is located at the exit. This represents the final pressure after passing through the compressor.

6.5 Conclusion

As the mass flow rate through a compressor increases, the fluid velocity rises, causing a decrease in static pressure (according to Bernoulli's theorem), thereby lowers the pressure ratio since the outlet pressure drops while the inlet pressure remains constant.

7 QR Codes

- QR Code for Python code

- QR Code for Latex code