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Flow Analysis of Upstream Fluid Flow using Simulation for Different Positions of Optimized Inlet Guide Vane in Centrifugal Air Compressor

Alok P. Tibrewala[1], Tushar J. Padave[2], Trushart P. Wagh[3], Prof. C. M. Gajare[4]
[1](Mechanical Engineering Department, KJCOEMR/ University of Pune, India)
[2](Mechanical Engineering Department, KJCOEMR/ University of Pune, India)
[3](Mechanical Engineering Department, KJCOEMR/ University of Pune, India)
[4](Mechanical Engineering Department, KJCOEMR/ University of Pune, India)

Abstract: - The performance of Inlet Guide Valve is optimized with designing new efficient mechanism for their actuation. Inlet Guide Valve is an umbrella term which comprises both inlet Guide Vanes and the mechanism to actuate them. Guide vanes not only provide the inlet pressure drop but also impart a whirl motion to the gas as it enters the compressor impeller. Since this whirl motion is in the rotational direction of the impeller, it reduces the amount of work the impeller is required to do on the gas. This paper contains the basic concept behind Inlet Guide Vane, their working & importance. Also included is the new designed mechanism. The results of various positions of Inlet Guide Vane on Upstream Fluid Flow are analyzed & include in this paper.

Keywords: - *Centrifugal Air Compressor, Inlet Guide Vane, Upstream Fluid Flow¸ Variable Inlet Guide Valve, Whirl Motion.*

I. INTRODUCTION

Inlet Guide Valve is an umbrella term which comprises both inlet Guide Vanes and the mechanism to actuate them. A centrifugal compressor can be divided in four major parts viz., the inlet guide vanes, the impeller, the diffuser and the volute. And each of these components can improve performances of the centrifugal compressor.[6] Centrifugal compressors, sometimes termed radial compressors, are a sub-class of dynamic axis symmetric work-absorbing turbo machinery. It achieves a pressure rise by adding kinetic energy / velocity to a continuous flow of fluid through the rotor or impeller. This kinetic energy is then converted to an increase in potential energy / static pressure by slowing the flow through a diffuser. The pressure rise in impeller is in most cases almost equals to the rise in the diffuser section. One of the main components of the compressor is Inlet Guide Vane which is fitted at the suction end of the air compressor. Inlet guide vanes provide an efficient method of turndown for centrifugal compressors. Higher Energy savings can be realized using Inlet Guide Vanes compared to inlet throttling by butterfly valves. An inlet butterfly valve achieves turndown through an inlet pressure drop. Guide vanes not only provide the inlet pressure drop but also impart a whirl motion to the gas as it enters the compressor impeller. Since this whirl motion is in the rotational direction of the impeller, it reduces the amount of work the impeller is required to do on the gas. It is this whirl motion that results in energy savings at the design conditions.

II. LITERATURE REVIEW

2.1 Centrifugal Air Compressor

Centrifugal compressors; also known as turbo-compressors belong to the roto-dynamic type of compressors. In these compressors the required pressure rise takes place due to the continuous conversion of angular momentum imparted to the refrigerant vapor by a high-speed impeller into static pressure. Unlike reciprocating compressors, centrifugal compressors are steady-flow devices hence they are subjected to less vibration and noise. This greatly improves life & reliability of the system. The operating costs are also greatly reduced thus making it economically viable.

1.2 Inlet Guide Valve

Inlet guide valve is an umbrella term which includes both Inlet guide vanes and the mechanism to actuate it. Inlet guide vanes provide an efficient method of turndown for centrifugal compressors. Higher Energy savings can be realized using Inlet Guide Vanes compared to inlet throttling by butterfly valves. An inlet butterfly valve achieves turndown through an inlet pressure drop. Guide vanes not only provide the inlet pressure drop but also impart a whirl motion to the gas as it enters the compressor impeller. Since this whirl motion is in the rotational direction of the impeller, it reduces the amount of work the impeller is required to do on the gas. It is this whirl motion that results in energy savings at the design conditions. Fig. 1 shows the velocity triangle at impeller of Inlet casing. Fig.2 shows the structure of compressor with inlet guide vanes.

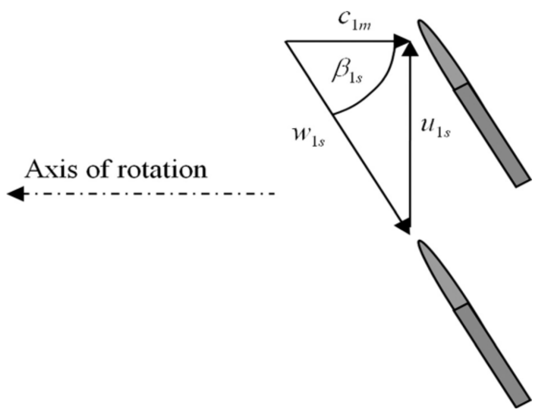

Figure 1 - Velocity triangle at Impeller of Inlet Casing

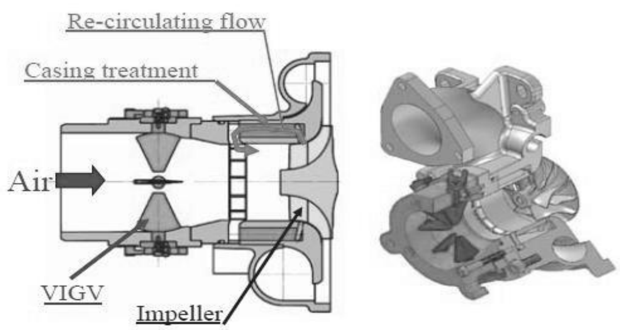

Figure 2 - Structure of Compressor with Variable Inlet Guide Vanes

III. DESIGNED MECHANISM

To actuate the Inlet Guide Vane a new efficient mechanism was designed - Linear Motion Mechanism. The mechanism as shown in below figures, fig. 3 & fig. 4, will slide in reciprocating fashion on the guides provided on the housing. This will in turn ensure that the angles of Inlet guide Vanes are changed according to the position of the mechanism. Fig.3 shows the mechanism in Fully Open Condition, while fig. 4 shows the mechanism in Fully Closed Condition.

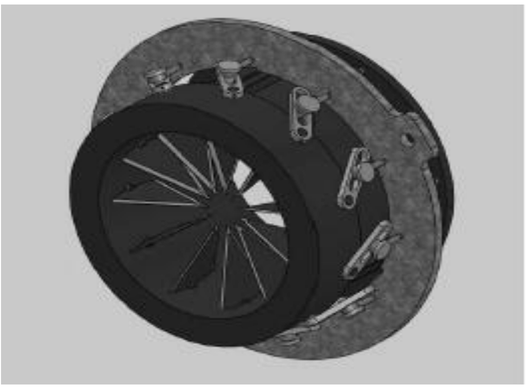

Figure 3 – Mechanism in Fully Open Condition

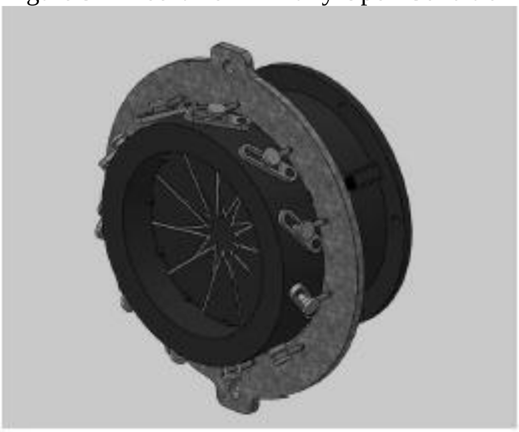

Figure 4 – Mechanism in Fully Closed Condition

The linear motion mechanism will consists of linear actuator for actuation. The linear actuator will be connected to the ring that will move on the housing. PTFE bearings will be provided in between the housing and ring for smooth movement of ring. Pin holder will be bolted to the ring and will mesh with the slotted link through a pin. The slotted link will be fitted on the guide vane using a grub screw. When the linear actuator provides linear actuation, the linear motion will be converted to rotary motion of the guide vane through the movement of slotted link and thus the vane angle can be changed.

The linear motion can be provided through suitable gearing arrangement if rotary motor is used. Linear actuators can also be used which have advantage over rotary motors, since no extra gearing setup needs to be done for actuation.

To prevent the friction / wear & tear of the sliding ring on the housing suitable self lubricating material can be provided on the housing. This will ensure that the mechanism remains external lubrication free to provide oil free air to the compressor.

Two linear actuators can be provided on the ring to facilitate better accuracy & faster response time, however this will also add to the overall cost of the mechanism.

IV. ANALYSIS

The primary aim of using Inlet Guide Vane is to provide Whirl Motion to the incoming air in air compressor. This is done so as to reduce the energy consumption & improve working efficiency. The designed mechanisms along with Inlet Guide Vane were analyzed using Flow Simulation Tool available in Solidworks 2012, the results of which are shared below.

The simulation tool was used to study two-dimensional laminar & turbulent flow arising due to different vane positions. A minimal opening of 0.025m diameter was kept at the centre, as a safety precaution.

The main aim of the analysis was to find the maximum velocity of air after it passes Inlet Guide Vane for safety considerations of compressor. The highest value to which the velocity of air can rise is 75m/s. Necessary modifications in vane design were done to bring the air velocity within the permissible limits.

The factors upon which the vane was designed & modified to reduce the air velocity are,

1. Aerodynamic Factors
2. Strength Factors
3. Economical Factors
4. Aesthetic & Ergonomics Factors

4.1 Analysis Parameters

The design was analyzed subjected to the following parameters,

1. Fluid Used – Air
2. Suction Pressure – Atmospheric Pressure i.e. 102642.23 Pa
3. Suction Temperature – Ambient Temperature – 293.20K
4. Vane rotation Possible – from 0^0 to $90^{0\backslash}$
5. Positions Analyzed – 3 Positions Analyzed,
   a. Initial Position - 0^0
   b. Intermediate Position - 45^0
   c. Final Position - 90^0
6. Minimum opening – 25mm
7. Maximum opening – 200mm

The air temperature & pressure after it passed through Inlet Guide Vanes relies on the amount of air being sucked by the compressor to meet the demand. For the compressor to work in safe condition air velocity after passing through the IGV should not exceed a certain safe value. This will ensure that internal mechanisms of compressor are not subjected to excessive stress due to high air velocity & operate safely.

4.2 At 0^0

The results of fluid flow simulation at 0^0 are shared below,

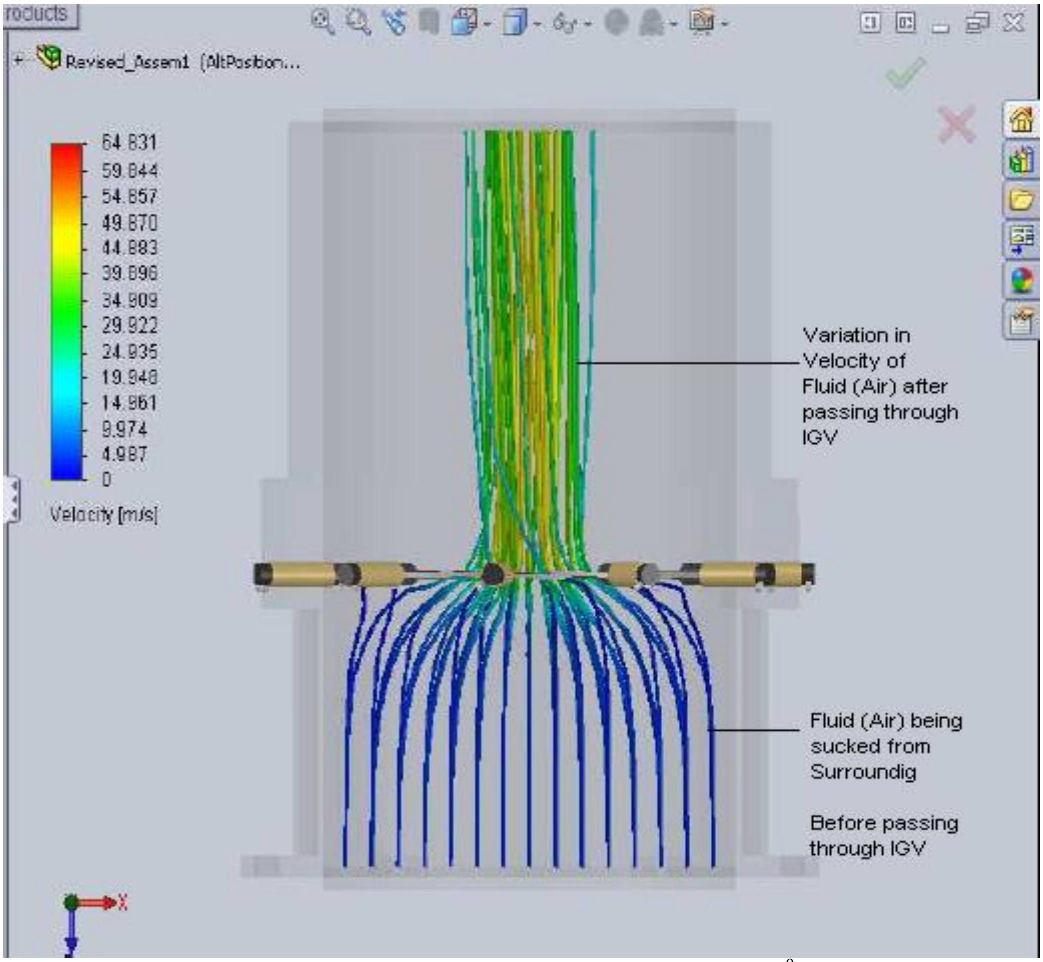

Figure 5 – Variation in Velocity of Fluid (Air) at 0^0

At 0^0, the air passes only through the small opening (of 25mm) provided. This simulates the initial condition when the IGV would be closed. This also ensures that the compressor is safe i.e. if the compressor is started when all the IGV are closed (above condition), then a minimal amount of air (through opening of 25mm) will pass in the compressor.

The velocity variation obtained at this position can be seen in the different colour lines with 0 m/s being the lowest and 59.498 m/s being the highest.
It is also worth noting that after passing through the IGV at 0^0, the air does not spread inside the housing. Thus, at this position the impact of the incoming air will be maximum as can be seen from the figure 5. Thus, maximum stress could be developed at this position both in the vanes and internal mechanisms of compressor.

4.2.1 Environment Condition 1 – Ambient Condition

TABLE 1 – Ambient Environmental Condition

Type	Environment Condition 1 – Ambient Condition
Value	Pressure - 102642.23 Pa Temperature - 293.20 K

4.2.2 Environment Condition 2 – After passing through IGV

TABLE 2 – Environmental Condition after passing through IGV

Type	Environment Condition 1 – Environmental Condition after passing through IGV
Value	Pressure - 104668.73 Pa Temperature - 333.00 K

The environmental conditions used are as in table 1 & table 2.

4.2.3 Result / Maximum Air Velocity

The maximum air velocity due to angle of vane at 0^0 is shown in table 3.

TABLE 3 – Maximum Air Velocity at 0^0

Parameter	Unit	Value
Maximum air Velocity	m/s	59.498

Thus, the maximum velocity achieved by air during 0^0 is 59.498 m/s.

4.3 At 45^0

At 45^0, the air has more space to enter the compressor and not only limited to small opening (of 25mm) provided. Here intermediate condition when the IGV would be partially open is simulated & analyzed.
The velocity variation obtained at this position can be seen in the different colour lines with 0 m/s being the lowest and 72.316 m/s being the highest.
It can also be noted that after passing through the IGV at 45^0, the air spreads inside the housing. Thus, at this position the impact of the incoming air will be somewhat less as compared to fully closed position and can be seen from the figure 6. Thus, relatively lesser stress would be developed at this position both in the vanes and internal mechanisms of compressor.

At positions between 0^0 and 45^0, maximum air velocity and stresses developed would lie in between the values for both 0^0 and 45^0.

It is also worth noting that due to more space available to air to enter the compressor, the temperature after passing through IGV has reduced due to lesser friction between the air molecules.

At this position maximum Whirl Motion as seen in fig. 6, is obtained in the air after it passes through the IGV. Thus, it would be theoretically most economical in terms of energy consumption to run the compressor at this position always during the operation of compressor.

However due to practical limitations it is not always feasible. Thus Inlet Guide Vanes need to provide Whirl Motion at most of the positions they are operated at.

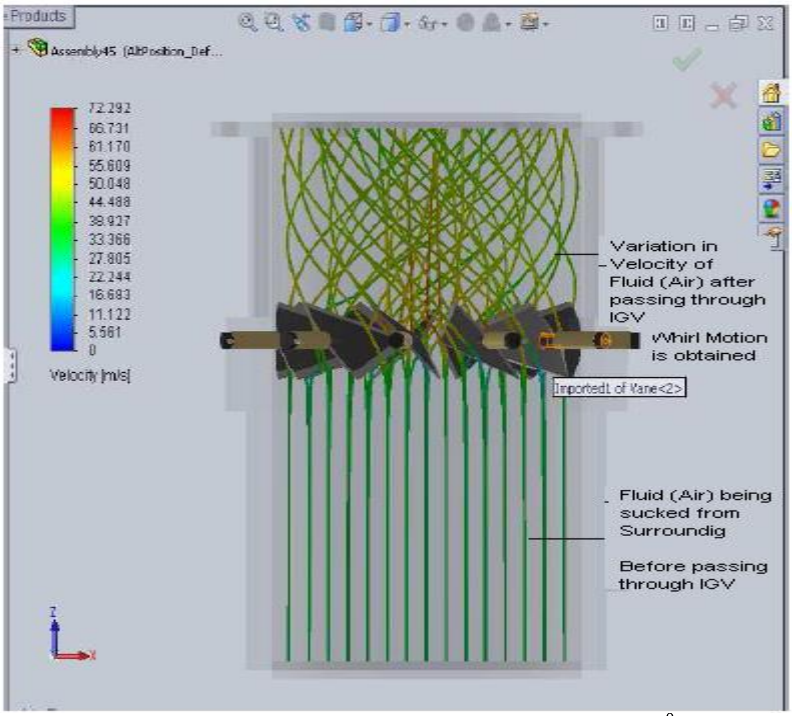

Figure 6 - Variation in Velocity of Fluid (Air) at 45^0

4.3.1 Environment Condition 1 – Ambient Condition

TABLE 4 – Ambient Environmental Condition

Type	Environment Condition 1 – Ambient Condition
Value	Pressure - 102642.23 Pa Temperature - 293.20 K

4.3.2 Environment Condition 2 – After passing through IGV

TABLE 5 – Environmental Condition after passing through IGV

Type	Environment Condition 1 – Environmental Condition after passing through IGV
Value	Pressure - 104668.73 Pa Temperature - 300.00 K

The environmental conditions used are as in table 4 & table 5.

4.3.3 Result / Maximum Air Velocity

The maximum air velocity due to angle of vane at 45^0 is shown in table 6.

TABLE 6 – Maximum Air Velocity at 45^0

Parameter	Unit	Value
Maximum air Velocity	m/s	72.316

Thus, the maximum velocity achieved by air during 45^0 is 72.316 m/s.

4.4 At 90^0

At 90^0, the air has most space available to enter the compressor and not limited to small opening (of 25mm) provided. Here final condition i.e. when the IGV would be fully open is simulated & analyzed.

The velocity variation obtained at this position can be seen in the different colour lines with 0 m/s being the lowest and 70.024 m/s being the highest.

It can also be noted that after passing through the IGV at 90^0, the air spreads inside the housing. Thus, at this position the impact of the incoming air will be somewhat less as compared to fully closed position and can be seen from the figure 7. Thus, relatively lesser stress would be developed at this position both in the vanes and internal mechanisms of compressor.
At positions between 45^0 and 90^0, maximum air velocity and stresses developed would lie in between the values for both 45^0 and 90^0.
It is also worth noting that due to more space available to air to enter the compressor, the temperature after passing through IGV has reduced due to lesser friction between the air molecules, compared to fully closed position.
This condition wherein Inlet Guide Vane is fully open would be sparingly used only when the compressor needs to work at full capacity.
Also minimal Whirl Motion is obtained in this position. Thus theoretically this position is the most inefficient position in terms of energy consumption and must be most sparingly used. However due to practical limitations this position need to be used every time there is maximum load demand from the compressor.

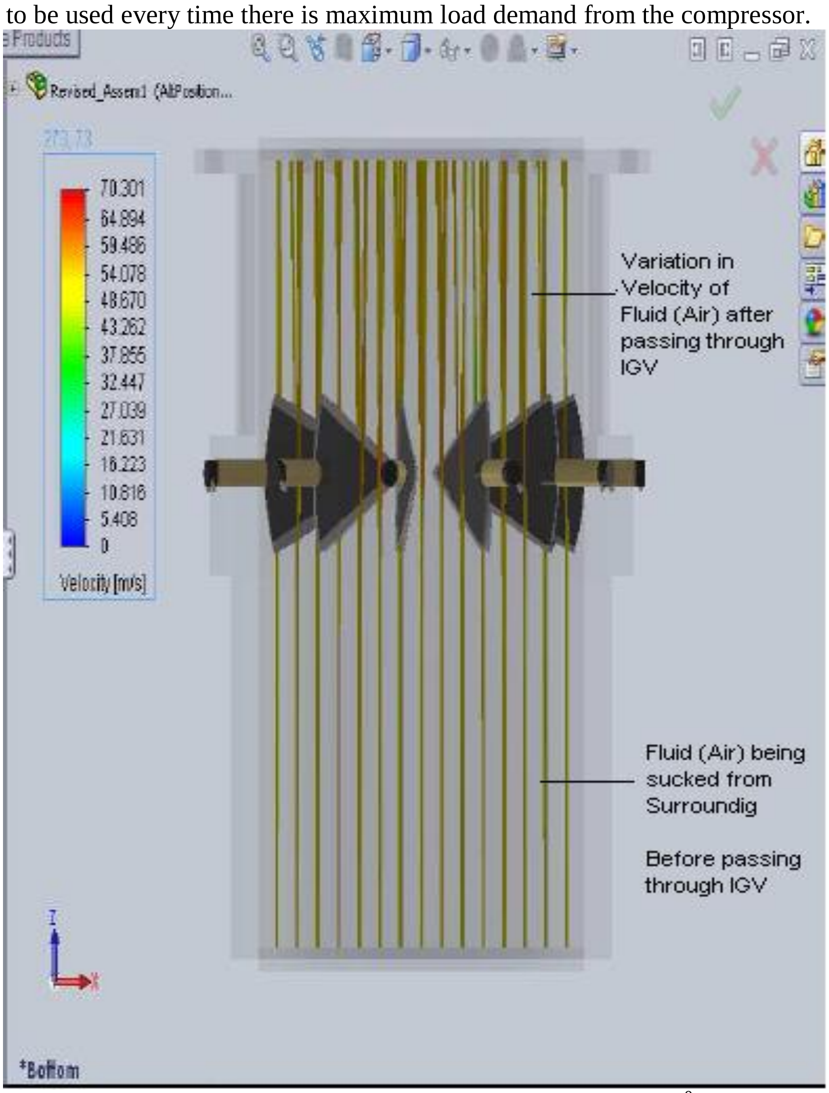

Figure 7 - Variation in Velocity of Fluid (Air) at 90^0

4.4.1 Environment Condition 1 – Ambient Condition

TABLE 7 – Ambient Environmental Condition

Type	Environment Condition 1 – Ambient Condition
Value	Pressure - 102642.23 Pa Temperature - 293.20 K

4.4.2 Environment Condition 2 – After passing through IGV

TABLE 8 – Environmental Condition after passing through IGV

Type	Environment Condition 1 – Environmental Condition after passing through IGV
Value	Pressure - 104668.73 Pa Temperature - 300.00 K

The environmental conditions used are as in table 4 & table 5.

4.4.3 Result / Maximum Air Velocity

The maximum air velocity due to angle of vane at 90^0 is shown in table 6.

TABLE 9 – Maximum Air Velocity at 90^0

Parameter	Unit	Value
Maximum air Velocity	m/s	70.024

Thus, the maximum velocity achieved by air during 90^0 is 70.024 m/s.

V. COMPARISON OF DIFFERENT VANE POSITIONS

The comparison of different parameters for the three vane positions studied is provided in table 10, while figure 8 shows Variation of Air Temperature after passing through IGV and figure 9 shows Variation in Maximum Air Velocity.

TABLE 10 – Comparative Analysis of Different Vane Positions

Sr. No.	Parameters	At 0	At 45	At 90
1	Ambient Pressure (in Pa)	102642.23	102642.23	102642.23
2	Ambient Temperature(in K)	293.2	293.2	293.2
3	Air Pressure after passing through IGV (in Pa)	104668.73	104668.73	104668.73
4	Air Temperature after passing through IGV (in K)	333	300	300
5	Maximum Air Velocity (in m/s)	59.498	72.316	70.024

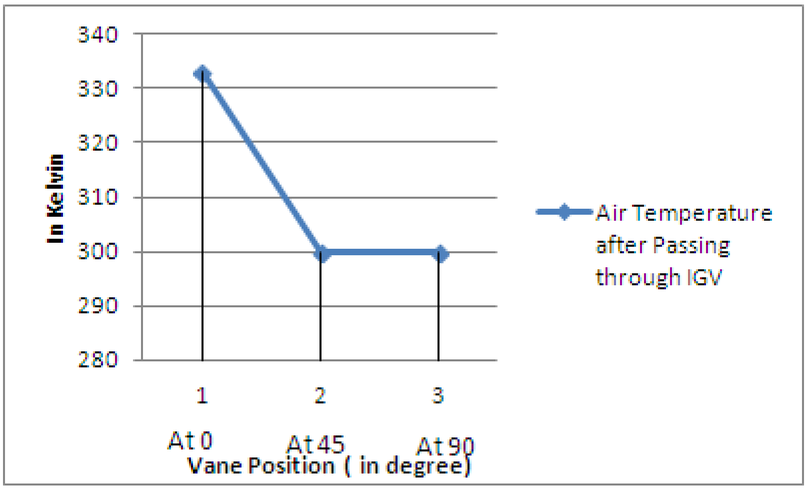

Figure 8 – Variation of Air Temperature after passing through IGV

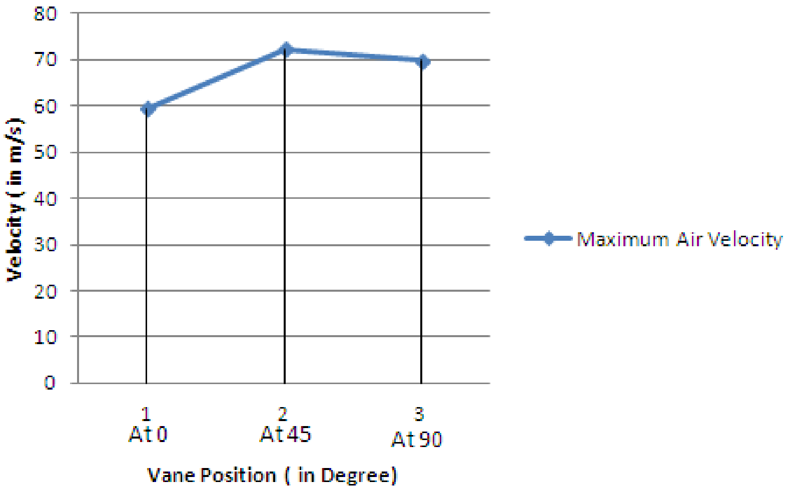

Figure 9 – Variation in Maximum Air velocity

VI. CONCLUSION

In this research work, flow simulation was carried out using Flow Simulation tool of Solidworks 2012 and most optimum vane position was found. The effect of different Vane angle positions on parameters of fluid flow such as Temperature of Fluid after passing through IGV and Maximum Air Velocity were studied, analyzed and compared. The most efficient vane position was identified to be at 45^0, since maximum Whirl Motion is obtained at this position. However, the velocity of air is also maximum at this position, hence maximum stresses would be induced. Future work would be carried out to minimize the stresses induced in optimum position by modifying the vane design.

VII. ACKNOWLEDGEMENTS

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