International Journal of Advanced Research in Engineering and Applied Sciences

ISSN: 2278-6252
Impact Factor: 4.817

FINITE ELEMENT ANALYSIS OF COMPONENTS USING VON MISES CRITERION FOR OPTIMIZED INLET GUIDE VALVE IN CENTRIFUGAL AIR COMPRESSOR

Alok P. Tibrewala*

Tushar J. Padave*

Abstract: *Safety Analysis based on Finite Element Analysis of Inlet Guide Valve is carried out using von Mises Criterion which is to be used in Centrifugal Air Compressor. 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 and further to impeller. Since this whirl motion is in the rotational direction of the impeller, it induces stresses in its components. This paper contains the basic concept behind Inlet Guide Valve, theory of von Mises Stress Criterion & the Results obtained.*

Keywords: *von Mises Stress; Inlet Guide Valve; Centrifugal Air Compressor; Finite Element Analysis; Whirl Motion*

*B.E. – Mechanical Engineering, University of Pune, India

I - INTRODUCTION

Inlet Guide Valve is an umbrella term which comprises both inlet Guide Vanes and the mechanism to actuate them. The main components of centrifugal compressor are the inlet guide vanes, the impeller, the diffuser and the volute. And each of these components can improve performances of the centrifugal compressor [4]. Centrifugal compressors sometimes are also termed as radial compressors & are a sub-class of dynamic axis symmetric work-absorbing turbo machinery. They achieve pressure rise by adding kinetic energy / velocity to a continuous flow of fluid through the rotor or impeller. The kinetic energy so produced 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 equal 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. 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. There always exist notch for engineering articles, the existence of notch would cause stress concentration, and change the state of stress concentration at notch root, thus affecting the component strength [5]. Centrifugal compressors are most effective when running at full capacity. Centrifugal air compressors are best suited to applications where demand is relatively constant or in plants where they can be used for base load operation, allowing other types of compressors to be used as trim machines to meet peak demands. Centrifugal air compressors are dynamic machines. Air is compressed by the mechanical action of high-speed, rotating impellers imparting velocity and pressure to the air. Approximately half of the pressure energy is developed in the impeller, with the other half achieved by converting velocity energy to pressure energy as the air speed is reduced in a diffuser and volute. Generally it can be said that the characteristics of centrifugal compressors with impellers having backswept blades have wider operational region then the ones with the straight blades impellers [7].

Whirl Motion induced in the components of Inlet Guide valve can cause Fracture & ultimately Failure of the System. Thus, the system needs to be designed such that it works safely within extreme conditions. Stress Analysis using von Mises Criterion is one such efficient method that will help in detecting safe zone for working of the Compressor.

II – LITERATURE REVIEW

Lower weight and dimensions are favorable for the overall cost of the machine and the supporting structure and also for the natural frequencies of the machine, provided they do not compromise fuel consumption [6]. Hence, it is beneficial to design compressors of lower weight which will save cost. Hence, their material can be optimized considering the FEA method.

2.1 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. Energy savings can be realized 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. The velocity triangle of Inlet Guide Valve is shown in Figure 1.

The main functions of Inlet Guide Vanes are as follows,

1. Imparting a whirl motion to the incoming air into the air compressor.
2. Reducing the energy consumption of air compressor.
3. Increasing the efficiency of air compressor.

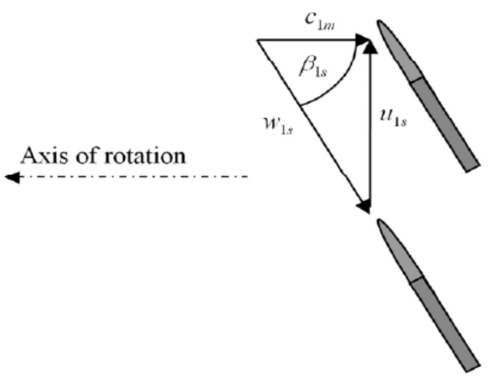


Figure 1 – Velocity Triangle of Inlet Guide Valve [2]

2.2 Control Valve

Control valves are valves used to control conditions such as flow, pressure, temperature, and liquid level by fully or partially opening or closing in response to signals received from controllers that compare a "set point" to a "process variable" whose value is provided by sensors that monitor changes in such conditions. The opening or closing of control valves is usually done automatically by electrical, hydraulic or pneumatic actuators. Positioner's are used to control the opening or closing of the actuator based on electric or pneumatic signals.

III – DESIGNED MECHANISM

3.1 Input Parameters

The following are the input parameters, for which the Inlet Guide Valve was designed,

1. Minimum opening diameter in fully closed position – 25 mm
2. Bore diameter – 200 mm
3. Inlet pressure – 1.033 bar
4. Pressure after air passes through the vanes – 1.033 bar
5. Bearing type to be used – PTFE
6. Bush type to be used – PTFE
7. Number of Vanes - 11
8. Oil free working of the design

3.2 Linear Motion Mechanism

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 used to provide in between the housing and ring to provide 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 provide 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. Different positions of Linear Motion Mechanism are shown in Figures 2 & 3. The assembly of linear motion mechanism is shown in figure 4.

Figure 2 – Fully Closed Position of Linear Motion Mechanism [2]

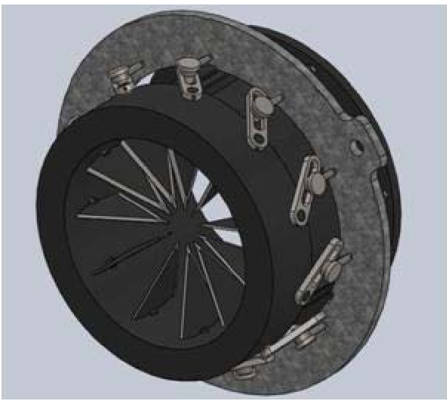
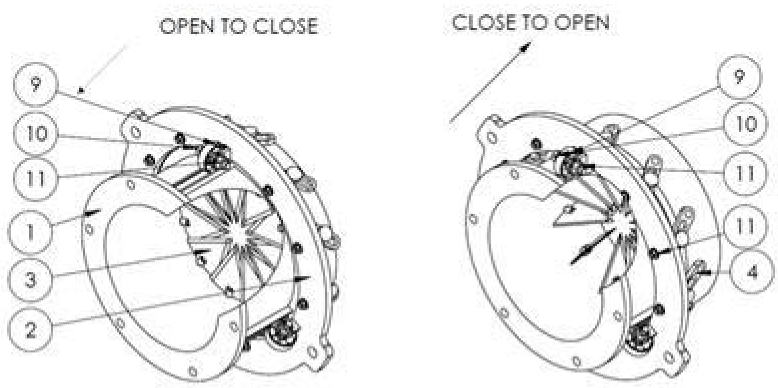


Figure 3 – Fully Open Position of Linear Motion Mechanism [2]



ITEM NO.	PART NAME
11	HEX. FLANGE NUT
10	HEX. FLANGE BOLT
9	BALL BEARING (SELAED ON BOTH SIDES)
8	GRUB SCREW
7	BUSH
6	PIN
5	PIN HOLDER
4	SLOTTED LINK
3	GUIDE VANE
2	RING
1	HOUSING

Figure 4 – Assembly of Linear Motion Mechanism

IV – FINITE ELEMENT ANALYSIS

Finite element analysis or FEA as is called usually has become common in recent method of detecting fractures in recent years. Numerical solutions to even very complicated stress problems can now be obtained using FEA. Finite Element Analysis can also be defined as a numerical technique for finding approximate solutions to boundary value problems for differential equations. It uses variational methods (the calculus of variations) to minimize an error function and produce a stable solution.

FEA consists of 3 important steps,[1]

1. **Preprocessing**: A model of the part to be analyzed is constructed in which the geometry is divided into a number of discrete sub regions, connected at discrete points called nodes.
2. **Analysis**: The dataset prepared by the previous method is used as input to the finite element code, which constructs and solves a system of linear or nonlinear algebraic equations,

$$K_{ij}u_j = f_i$$

Where, u and f are the displacements and externally applied forces at the nodal points.

3. **Postprocessing**: Analyzing the result obtained and making necessary changes.

4.1 von Mises Stress Criterion

In an elastic body that is subjected to a system of loads in 3 dimensions, a complex 3 dimensional system of stresses is developed. That is, at any point within the body there are stresses acting in different directions usually along the three axes, and the direction and magnitude of stresses changes from point to point.

The Von Mises criterion is a formula for calculating whether the stress combination at a given point will cause failure. There are three "Principal Stresses" that can be calculated at any point, acting in the x, y, and z directions.

Von Mises found that, even though none of the principal stresses exceeds the yield stress of the material, it is possible for yielding to result from the combination of stresses. The Von Mises criteria are a formula for combining these 3 stresses into an equivalent stress, which is then compared to the yield stress of the material.

The equivalent stress is often called the "Von Mises Stress" as a shorthand description. It is not really a stress, but a number that is used as an index.

If the "Von Mises Stress" induced in the material exceeds the Yield stress of the material, then the material is considered to be at the failure condition.[3]

The formula can be written as,[3]

$$(S_1-S_2)^2 + (S_2-S_3)^2 + (S_3-S_1)^2 = 2S_e^2$$

Where,

S_1, S_2 and S_3 - Principal stresses

S_e - Equivalent stress, or "von Mises Stress".

For Safety,

von Mises Stress < Yield Stress

Where, Von Mises Stress is the Induced Stress & Yield Stress is Maximum Permissible Stress.

Flow Simulation tool in Solidworks 2012 was used to conduct Von Mises Stress Analysis. Von Mises Stress Analysis is equivalent to Finite Element Analysis (FEA).

V – VON MISES ANALYSIS OF DIFFERENT COMPONENTS

5.1 Pin Holder

Pin holder is fitted in the ring which reciprocates and which is connected to the slotted link so that it will operate the vane when the assembly is in working condition. It is the part of assembly which transfers the motion of ring to the slotted link. It is connected with the help of pin to the slotted link. Pin holder is having pin which is fitted at the centre with adhesive material and also alternatively by threads. Pin holder is having threads at the end which are causing fitting to the ring. Figure 5 below shows the pin holder.

Figure 5 – Pin Holder

Table 1 – Material Properties – Pin Holder

Model Reference	Properties	Components
	Name: Stainless Steel (ferrite) Model type: Linear Elastic Isotropic Default failure criterion: Max von Misses Stress Yield strength: 1.72339e+008 N/m^2 Tensile strength: 5.13613e+008 N/m^2	Solid Body 1(Cut-Sweep5)(pin holder)

Material used is Stainless Steel whose properties are shown in Table 1.

Table 2 – Loads & Fixtures – Pin Holder

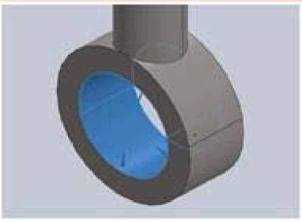
Fixture name	Fixture Image	Fixture Details
Fixed-3		Entities: 2 face(s) Type: Fixed Geometry
Load name	**Load Image**	**Load Details**
Force-3		Entities: 1 face(s) Type: Apply normal force Value: 18 N

Table 2 shows the different loads & fixtures the Pin Holder will be subjected to.

Table 3 – Mesh Information – Pin Holder

Mesh type	Solid Mesh
Mesher Used:	Standard mesh
Automatic Transition:	Off
Include Mesh Auto Loops:	Off
Jacobian points	4 Points
Element Size	1.19714 mm
Tolerance	0.0598568 mm
Mesh Quality	High
Total Nodes	26567
Total Elements	16490
Maximum Aspect Ratio	17.498
% of elements with Aspect Ratio < 3	87
% of elements with Aspect Ratio > 10	0.0485
% of distorted elements(Jacobian)	0
Time to complete mesh(hh;mm;ss):	00:02:25
Computer name:	ADMIN-8A606A5A7

Table 3 shows the Mesh Information for Pin Holder.

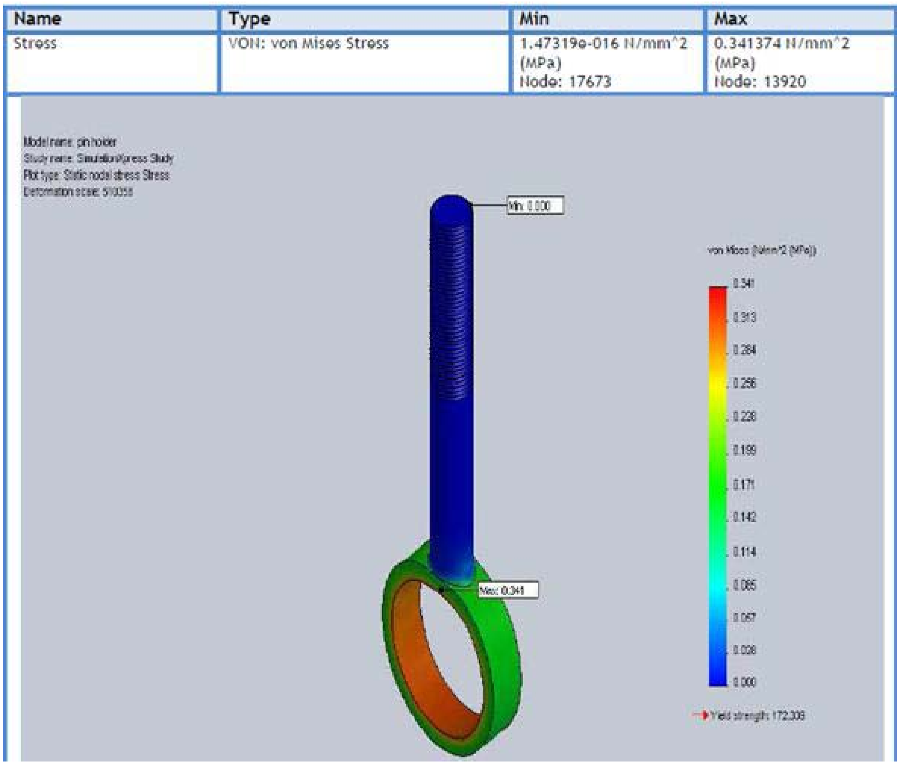


Figure 6 – von Mises Stress in Pin Holder

Figure 6 shows von Mises stresses in Pin Holder.

Table 4 – Stresses in Pin Holder

Maximum von Mises Stress	Yield Stress
0.341 MPa	**172.309 MPa**

Thus, it can be seen from table 4 that maximum von Mises Stress induced in Pin Holder is much less than its yield stress. Hence, the Pin Holder designed is safe.

5.2 Pin

Pin is the part which is fitted in the pin holder which causing the motion due to the pin holder as their sliding motion will happen across the slotted part. Pin holder is an intermediate component over the Ring where motion of vane causes controlling of fluid entering inside. Pin is the component which is fitting in to the pin holder and which will reciprocate in the guides of the slotted link. It is the component which is the connecting ember between reciprocating motion and linear motion. Figure 7 shows the 3 Dimensional vies of Pin.

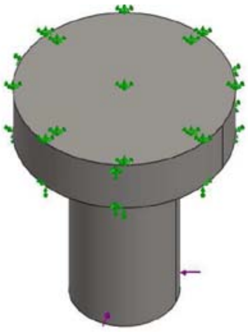
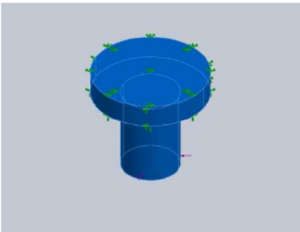


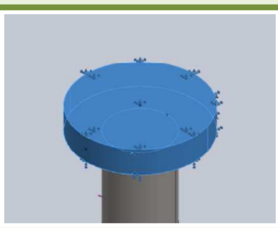
Figure 7 – Pin

Table 5 – Material Properties - Pin

Model Reference	Properties	Components
	**Name:** Stainless Steel (ferritic) **Model type:** Linear Elastic Isotropic **Default failure criterion:** Max von Mises Stress **Yield strength:** 1.72339e+008 N/m^2 **Tensile strength:** 5.13613e+008 N/m^2	SolidBody 1(Boss-Extrude2)(pin)

Material used is Stainless Steel whose properties are shown in Table 5.

Table 6 – Loads & Fixtures - Pin

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** 3 face(s) **Type:** Fixed Geometry

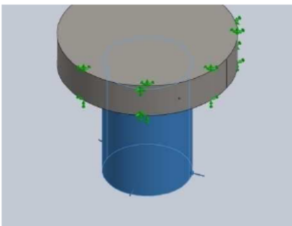
Load name	Load Image	Load Details
Force-1		**Entities:** 1 face(s) **Type:** Apply normal force **Value:** 18 N

Table 6 shows the different loads & fixtures the Pin will be subjected to.

Table 7 – Mesh Information - Pin

Mesh type	Solid Mesh
Mesher Used:	Standard mesh
Automatic Transition:	Off
Include Mesh Auto Loops:	Off
Jacobian points	4 Points
Element Size	1.3386 mm
Tolerance	0.06693 mm
Mesh Quality	High
Total Nodes	10820
Total Elements	6934
Maximum Aspect Ratio	4.0134
% of elements with Aspect Ratio < 3	99.8
% of elements with Aspect Ratio > 10	0
% of distorted elements(Jacobian)	0
Time to complete mesh(hh;mm;ss):	00:00:02
Computer name:	ADMIN-8A606A5A7

Table 7 shows the Mesh Information for Pin.

Name	Type	Min	Max
Stress	VON: von Mises Stress	0.166888 N/m^2 Node: 7791	45945.8 N/m^2 Node: 9813

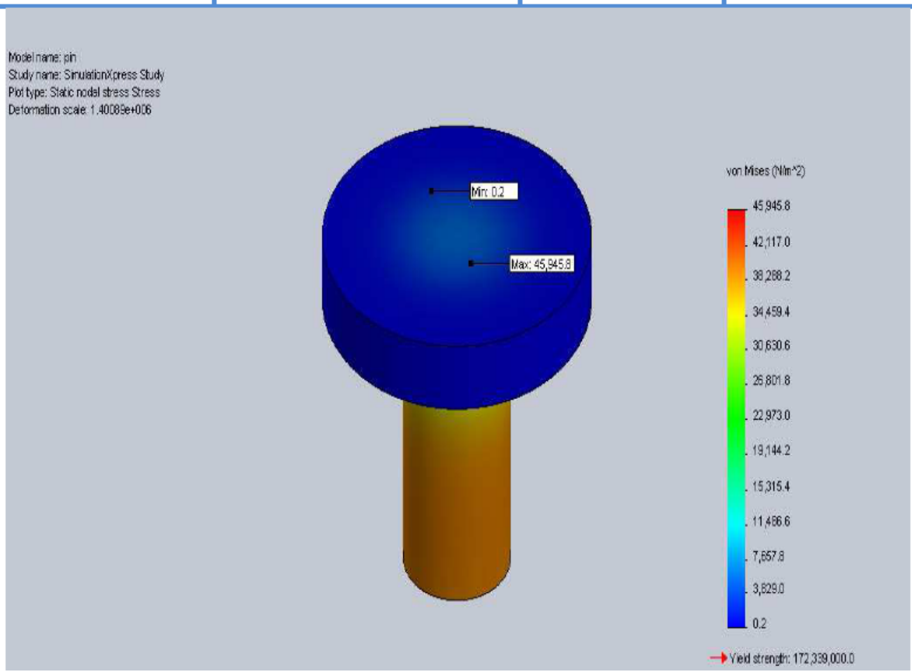


Figure 8 - von Mises Stress in Pin

Table 8 – Stresses in Pin

Maximum von Mises Stress	Yield Stress
0.05 MPa	172.309 MPa

Thus, it can be seen from table 8 that maximum von Mises Stress induced in Pin is much less than its yield stress. Hence, the Pin designed is safe. The von mises in pin is shown in figure 8.

5.3 Slotted Link

The slotted link will have one slot at its centre and pin will move along the slot which in turn will guide the Vane motion. It will be fitted with grub screw in shank of the vane. The slotted link will give motion to the vane as its one end is pivoted and corresponding rotary motion is conserved from linear motion. Figure 9 below shows slotted link.

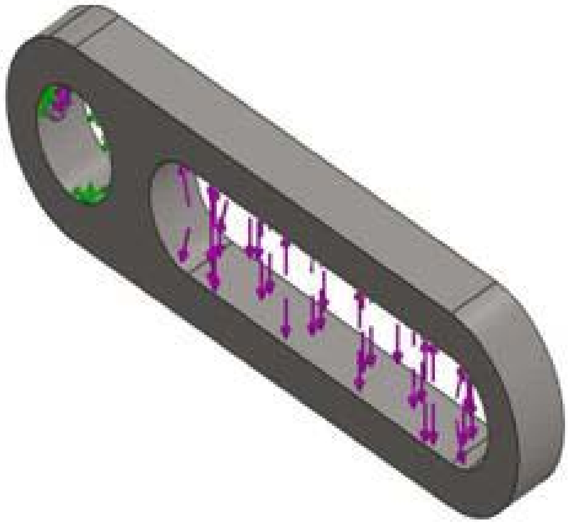
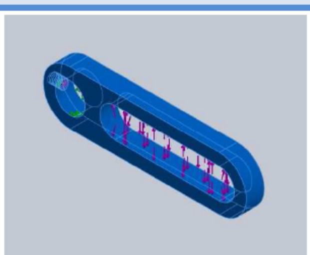


Figure 9 – Slotted Link

Table 9 – Material Properties – Slotted Link

Model Reference	Properties	Components
	**Name:** Stainless Steel (ferritic) **Model type:** Linear Elastic Isotropic **Default failure criterion:** Max von Mises Stress **Yield strength:** 1.72339e+008 N/m^2 **Tensile strength:** 5.13613e+008 N/m^2	SolidBody 1(Cut-Sweep1)(slotted link)

Material used is Stainless Steel whose properties are shown in Table 9.

Table 10 – Loads & Fixtures – Slotted Link

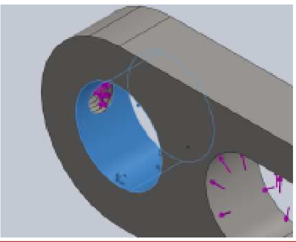
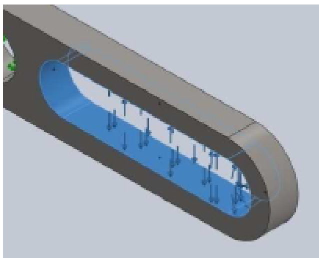
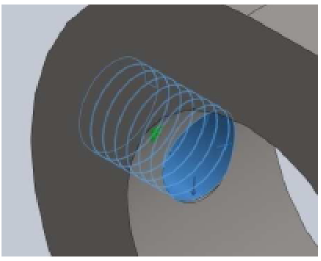
Fixture name	Fixture Image	Fixture Details
Fixed-1		Entities: 1 face(s) Type: Fixed Geometry
Load name	**Load Image**	**Load Details**
Force-1		Entities: 4 face(s) Type: Apply normal force Value: 18 N
Force-2		Entities: 1 face(s) Type: Apply normal force Value: 1 N

Table 10 shows the different loads & fixtures the Slotted Link will be subjected to.

Table 11 – Meshing Information – Slotted Link

Mesh type	Solid Mesh
Mesher Used:	Standard mesh
Automatic Transition:	Off
Include Mesh Auto Loops:	Off
Jacobian points	4 Points
Element Size	1.56875 mm
Tolerance	0.0784373 mm
Mesh Quality	High
Total Nodes	13485
Total Elements	7977
Maximum Aspect Ratio	17.057
% of elements with Aspect Ratio < 3	97.6
% of elements with Aspect Ratio > 10	0.113
% of distorted elements(Jacobian)	0
Time to complete mesh(hh;mm;ss):	00:00:05
Computer name:	ADMIN-8A606A5A7

Table 11 shows the Mesh Information for Slotted Link.

ISSN: 2278-6252
Impact Factor: 4.817

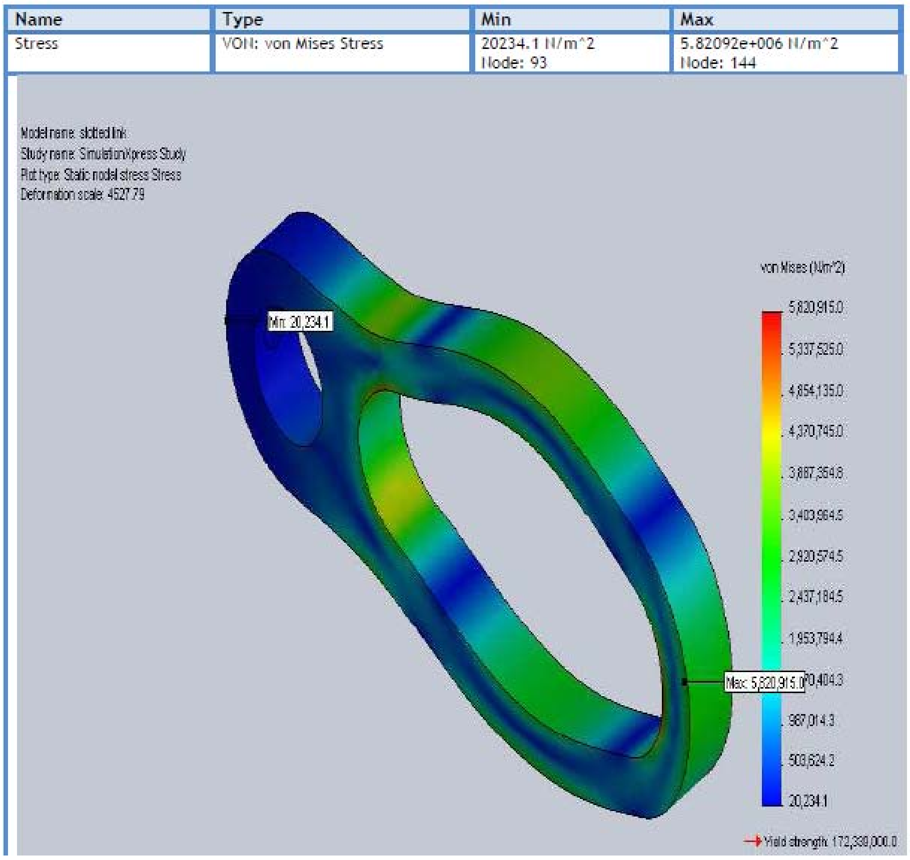


Figure 10 – von Mises stress in Slotted Link

Figure 10 shows von Mises stress in Slotted Link.

Table 12 – Stresses in Slotted Link

Maximum von Mises Stress	Yield Stress
5.82 MPa	172.309 MPa

Thus, it can be seen from table 12 that maximum von Mises Stress induced in Slotted Link is much less than its yield stress. Hence, the Slotted Link designed is safe.

5.4 Ring

Ring is the component which is used to actuate the vane, while being connected to the Linear actuator, which is further connected to the signaling circuit or a closed loop system. As the ring moves forward which on account causes the opening of the vanes and while it moves back causes the closing action. Ring is concentric with the housing. The ring is having 11 pin holders on it, which make connection with the slotted link through pin. The ring is shown in Figure 11.

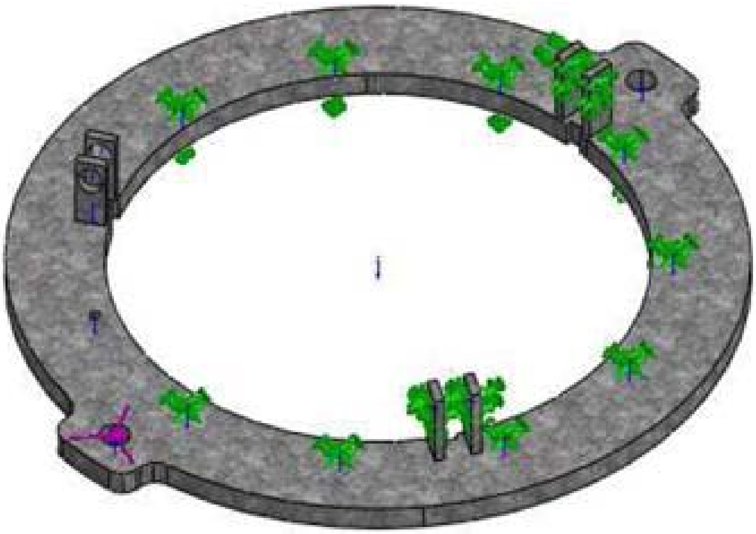
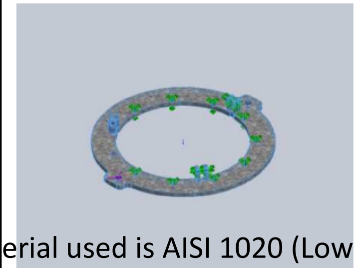


Figure 11 - Ring

Table 13 – Material Properties - Ring

Model Reference	Properties	Components
	**Name:** AISI 1020 **Model type:** Linear Elastic Isotropic **Default failure criterion:** Max von Mises Stress **Yield strength:** 3.51571e+008 N/m^2 **Tensile strength:** 4.20507e+008 N/m^2	SolidBody 1(Cut-Extrude9)(ring)

Material used is AISI 1020 (Low Carbon Steel) whose properties are shown in Table 13.

Table 14 – Loads & Fixtures – Ring

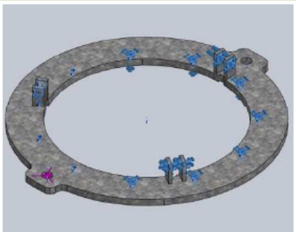
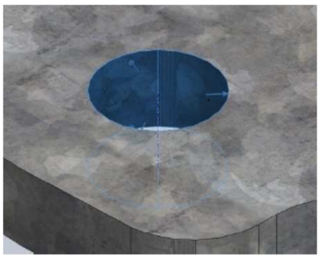
Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** 17 face(s) **Type:** Fixed Geometry
Load name	**Load Image**	**Load Details**
Force-1		**Entities:** 1 face(s) **Type:** Apply normal force **Value:** 18 N

Table 14 shows the different loads & fixtures the Ring will be subjected to.

Table 15 – Meshing Information – Ring

Mesh type	Solid Mesh
Mesher Used:	Standard mesh
Automatic Transition:	Off
Include Mesh Auto Loops:	Off
Jacobian points	4 Points
Element Size	7.90116 mm
Tolerance	0.395058 mm
Mesh Quality	High
Total Nodes	20938
Total Elements	11391
Maximum Aspect Ratio	7.8277
% of elements with Aspect Ratio < 3	96.3
% of elements with Aspect Ratio > 10	0
% of distorted elements(Jacobian)	0
Time to complete mesh(hh;mm;ss):	00:00:06
Computer name:	ADMIN-8A606A5A7

Table 15 shows the Mesh Information for Ring.

Name	Type	Min	Max
Stress	VON: von Mises Stress	9.66627e-006 N/m^2 Node: 20496	76273.8 N/m^2 Node: 20468

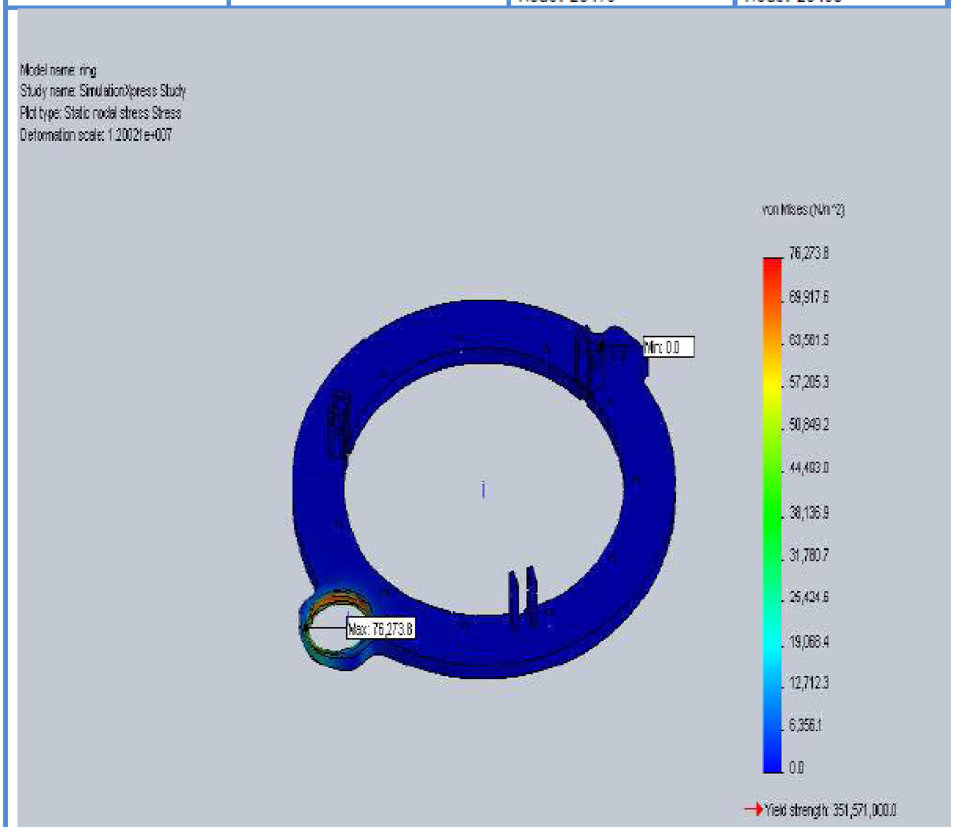


Figure 12 – von Mises Stress in Ring

Figure 12 shows the von Mises stresses in ring.

Table 16 – Stresses in Ring

Maximum von Mises Stress	Yield Stress
0.076 MPa	**230 MPa**

Thus, it can be seen from table 16 that maximum von Mises Stress induced in Ring is much less than its yield stress. Hence, the Ring designed is safe.

5.5 Vane

Vane is the component which is present at inlet of the compressor & is useful to guide the fluid which is flowing through the valve. It is usually Triangular in shape with chamfered ends & it provides whirl motion on specific arrangement on the axis of entrance. Vane is made using alloy metals so that its weight should not increase and force applied on the end of the vane gets spread over the entire body. For better motion and accuracy the vane should be made of material with high strength and lower weight. 11 numbers of vanes is used in the system. Vane should be electroplated, as it is directly exposed to incoming air which may contain moisture to prevent corrosion. Vane is shown in figure 13.

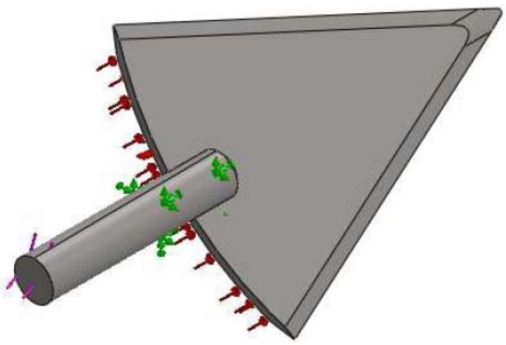
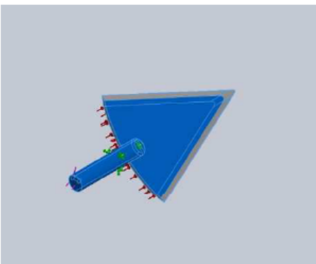


Figure 13 – Vane

Table 17 – Material Properties - Vane

Model Reference	Properties	Components
	Name: Cast Alloy Steel Model type: Linear Elastic Isotropic Default failure Max von Mises Stress Yield strength: 2.41275e+008 N/m^2 Tensile strength: 4.48083e+008 N/m^2	SolidBody 1(Fillet2)(Vane)

Material used for the vane is Cast Steel Alloy whose properties are shown in Figure 17.

Table 18 – Loads & Fixtures - Vane

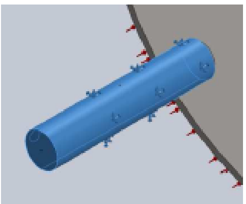
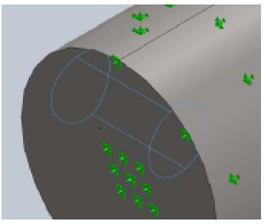
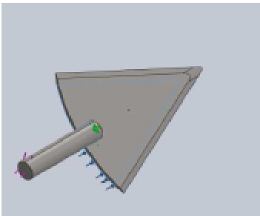
Fixture name	Fixture Image	Fixture Details
Fixed-1		Entities: 2 face(s) Type: Fixed Geometry
Load name	**Load Image**	**Load Details**
Force-1		Entities: 1 face(s) Type: Apply normal force Value: 18 N
Pressure-1		Entities: 1 face(s) Type: Normal to selected face Value: 1.033 bar Units: psi

Table 18 shows the different loads & fixtures the Vane will be subjected to.

Table 19 – Meshing Information - Vane

Mesh type	Solid Mesh
Mesher Used:	Standard mesh
Automatic Transition:	Off
Include Mesh Auto Loops:	Off
Jacobian points	4 Points
Element Size	2.06259 mm
Tolerance	0.10313 mm
Mesh Quality	High
Total Nodes	14390
Total Elements	7758
Maximum Aspect Ratio	75.181
% of elements with Aspect Ratio < 3	95
% of elements with Aspect Ratio > 10	0.477
% of distorted elements(Jacobian)	0
Time to complete mesh(hh;mm;ss):	00:00:03
Computer name:	ADMIN-8A606A5A7

Table 19 shows the Mesh Information for Vane.

Name	Type	Min	Max
Stress	VON: von Mises Stress	4.34864e-007 N/mm^2 (MPa) Node: 5494	0.536121 N/mm^2 (MPa) Node: 30

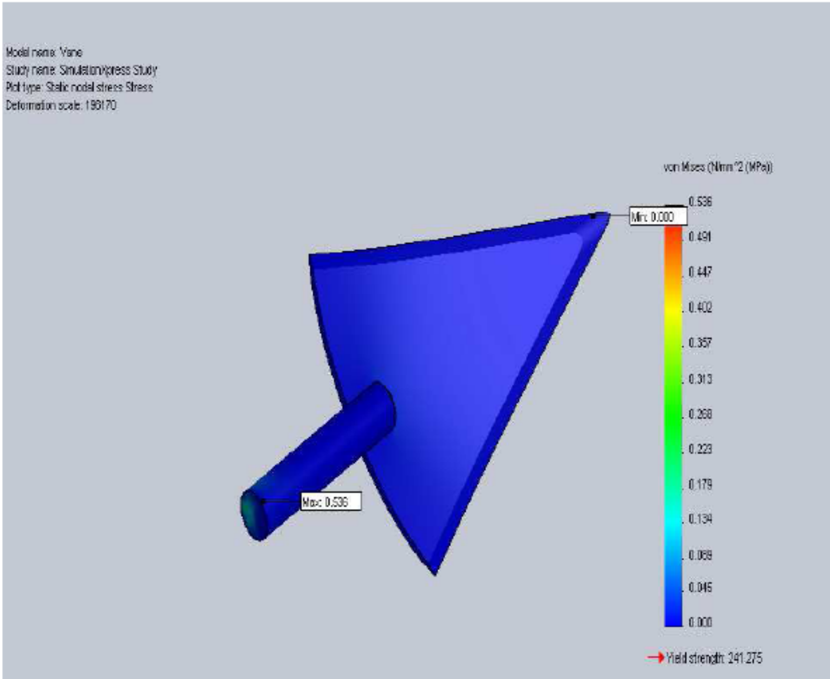


Figure 14 – von Mises stresses in Vane

Figure 14 shows the von Mises stresses in Vane.

Table 20 – Stresses in Vane

Maximum von Mises Stress	Yield Stress
0.536 MPa	**241.75 MPa**

Thus, it can be seen from table 20 that maximum von Mises Stress induced in Vane is much less than its yield stress. Hence, the Vane designed is safe.

VI – CONCLUSION

The von Mises Stress Analysis was carried out for different components of Inlet Guide Valves. These calculated values were then compared with the Yield Stress value which is property of material concerned.

A summary of stress values & their comparison with yield stress for different components is shown below.

Table 21 – Summary of Stress Values – A Comparison

Sr. No.	Component	Material	Von Mises Stress (Induced Stress) MPa	Yield Stress (Maximum Permissible Stress) Mpa	Conclusion
1	Pin Holder	Stainless Steel (Ferrite)	0.341	173.304	**SAFE**
2	Pin	Stainless Steel (Ferrite)	0.05	172.309	**SAFE**
3	Slotted Link	Stainless Steel (Ferrite)	5.82	172.309	**SAFE**
4	Ring	AISI 1020 (Low Carbon Steel)	0.076	230	**SAFE**
5	Vane	Cast Alloy Steel	0.536	241.75	**SAFE**

It can be observed from table 21 that the von Mises Stresses (Induced Stress) in the Components is much Less than the Yield Stress (Maximum Permissible Stress) of the Components. Hence, it can be stated that all the components are found to be safe for the material prescribed & stated operating conditions.

REFERENCES

1. David Roylance, 'Finite Element Analysis', Department of Material Science & Engineering, Massachusetts Institute of Technology, USA, February 28, 2001.
2. Alok P. Tibrewala, Tushar J. Padave et. al., 'Flow Analysis of Upstream Fluid Flow using Simulation for Different Positions of Optimized Inlet Guide Vane in Centrifugal Air Compressor', American Journal of Engineering Research, Volume-03, Issue-02, February 2014.
3. K Vamsi Krishna, S Porchilamban, 'Development and Structural Analysis of Masthead for a Twin Boom Stacker', International Journal of Engineering Development and Research, Volume 2, Issue 1, March 2014.
4. Bogdan Gherman, Cristina Silivestru & Marian Draghici, "Aerodynamic Geometry optimization of a centrifugal Blower," U. P. B. Sci. Bull, Series D., vol. 74, 2012.
5. Taylor D., 'A mechanistic approach to critical-distance methods in notch fatigue', Fatigue & Fracture of Engineering Materials & Structures; 2001

6. Daniel Rusch, Michael Casey, 'The design space boundaries for High Flow Capacity Centrifugal Compressors', ASME Turbo Expo 2012, Copenhagen, Denmark, June 2012.
7. P. Kmoch, A. Jilek, 'Velocity Field Calculation and Measurement at the Inlet of Centrifugal Compressor', Advances in Military Technology, Volume – 4, No. – 2, December 2009.