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Research Paper

3D MODELLING AND ANALYSIS OF MICRO GAS TURBINE COMPRESSOR BLADE

Ajin Elias Alex[1]* and Nadeera M[1]

*Corresponding Author: Ajin Elias Alex, ajinelias@gmail.com

Microturbines can be utilized in refrigerator, generator, air drier, etc., Micro turbine being small in size as compared to large turbine, such that less weight which reflects on pressure ratio, low cost and easy maintenance. Design and analyze of the micro turbine compressor blade is carried out in this thesis. With different material and rotational speed, compressor blade of the micro turbine is analyzed. A 3D Structural design of microturbine generating 120 KW of output power is modeled in Solidworks. Based on the given microturbine output power, the dimensions and physical properties of the compressor blade were calculated. Titanium, Aluminium and Stainless steel alloys, this materials effect on compressor blade are found out by carrying stress and modal analysis. Microturbine systems claimed many advantages over reciprocating engine generators, such as higher power to weight ratio, low pollution and having few moving part. Microturbines have many advantages, such that it may be designed with foil bearings and air-cooling operating without lubricating oil, coolants or other hazardous materials. Microturbines are quicker to respond to output power requirement and also more efficient. Microturbines also have more efficiency at low power levels than reciprocating engines. The variation of rotational speed is a representation of various operating conditions, depending on the required output. By analysis software ANSYS 12, stress and modal analysis are done.

Keywords: Compressor blade, Microturbine, Vibrational analysis

INTRODUCTION

Axial flow compressors are used in medium to large thrust gas turbine and jet engines. The compressor rotates at very high speeds adding energy to the air flow while at the same time compressing it into a smaller space. The design of axial flow compressors is a great challenge, both aerodynamically and mechanically. The aerodynamic compressor design process basically consist of mean line prediction is the first step during compressor blade design.

Nowadays, the need of energy production to be used for either industrial or several

[1] Department of Computer Integrated Manufacturing, T.K.M College of Engineering, Kollam, India.

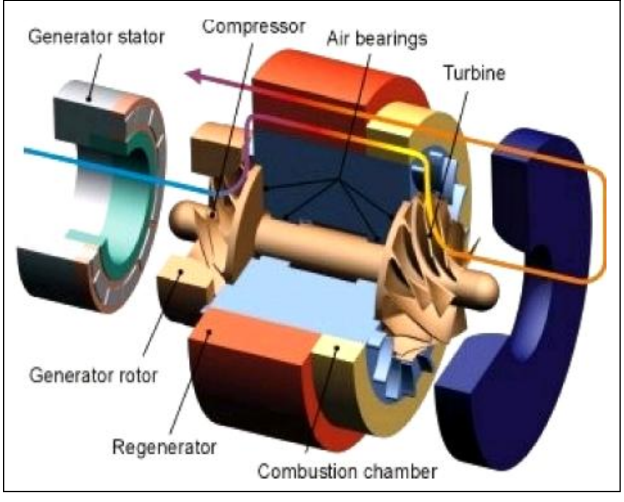
transportations is in great demand. The type of power generation has become the major concern because of its widespread need. For the concern of recent time needs, the suitable power generation type is one which achieves a relatively better efficiency, low in cost, and satisfied the demanding criteria.

Because of its critical role, it is understandable that innovation to a step further is needed. In a field where the major role needed and development costs both are the major concerns, it was thought to build the smallest possible gas turbine, and to explore whether the device could be made into smaller size. The micro turbine is actually the scale-down of the large ordinary gas turbine system.

This is what gave birth to this project since the advantages of gas turbines are already known compared to other. This project deals with designing of micro turbine compressor and the corresponding overall integrity analysis of the designated compressor.

Microturbine is definitely different from the usual large industrial gas turbine, although it has the same principal work and scale-down from the large industrial gas turbine. Microturbines are quicker to respond to output power requirement and also more efficient. The microturbine took in place because of the emerging need of innovation to the existing large gas turbine power plant, especially for the application of remote and limited area to be placed. Microturbines are operated at lower pressure ratios than larger gas turbines.

Figure 1: Microturbine



Objective of Study

The objective of this study is to model a micro turbine compressor blade and conduct stress analysis as well as vibration analysis based on its rotation per minutes.

Materials

- Aluminum alloy.
- Stainless steel alloy.
- Titanium alloy.

Rotational Speed

- 40000 rpm
- 50000 rpm
- 60000 rpm

Scope of Study

The design and the analysis of the structures integrity using finite element method is conducted. It is expected that the project will provide the recommendation that can help to improve the performance of compressor design base on the previous analysis.

The scope of study consists of two major parts. The first is to design the dimension of the compressor based on the given output power. The design is expected to be the most optimal dimension to that proposed output.

The second part is the analysis of the designed dimension of the compressor. This part is investigating the stress acting on the compressor and conducting vibrational analysis of the model using the finite element analysis program. ANSYS is the software used for analysis. 3D model obtained from Solid Works is imported to ANSYS in IGES format.

METHODOLOGY

Geometrical Modelling

Solidworks is used for the modelling purpose. This are the geometric parameter used for modelling.

Figure 2: Methodology

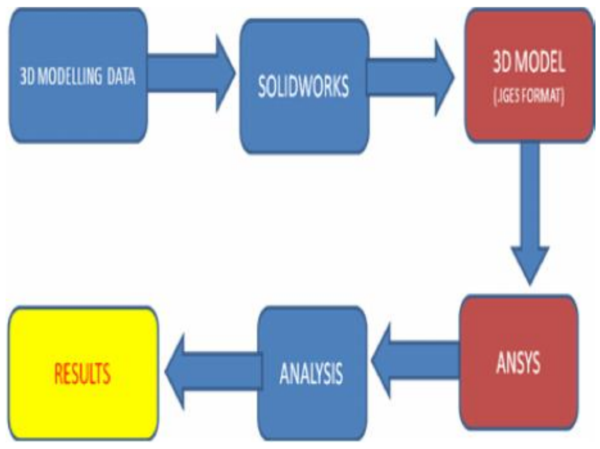


Table 1: Compressor Geometry Parameter

Items	Parameter	Value
Shaft Diameter	D(mm)	20
Impeller Inner Diameter	D_1(mm)	55
Impeller Outer Diameter	D_2(mm)	136
Impeller Thickness to Shaft	h(mm)	42
Impeller Outflow Thickness	b(mm)	4.825
Blade Degree	(degree)	23.20
Blade Number	-	11

Source: Vyas and Basia (2013)

Analysis

ANSYS Workbench 12 is the software used for analysis. 3D model obtained from Solid Works is imported to ANSYS in IGES format.

Compressor Materials

The material properties are assigned as part of the analyses. The material for the compressor blade is chosen into three different materials.

Table 2: Different Material and its Details

Materials	Items	Parameter	Value
Titanium Alloy Ti-b-120UCA	Elastic modulus	E(MPa)	$0.102E^6$
	Poisson ratio	N	0.3
	Density	°(kgm^3)	4850
	Ultimate Tensile Strength	UTS(MPa)	1675
Aluminum Alloy AL-a7079	Elastic modulus	E(MPa)	$0.717E^5$
	Poisson ratio	N	0.33
	Density	°(kgm^3)	2740
	Ultimate Tensile Strength	UTS(MPa)	558
Stainless Steel Alloy 304	Elastic modulus	E(MPa)	$0.193E^6$
	Poisson ratio	N	0.29
	Density	°(kgm^3)	8030
	Ultimate Tensile Strength	UTS(MPa)	1147

Source: Vyas and Basia (2013)

Various conditions for analysis are:

Rotational Speed

- 40000 rpm
- 50000 rpm
- 60000 rpm

Materials

- Aluminum alloy
- Stainless steel alloy
- Titanium alloy
  - Stress Analysis
  - Vibrational Analysis

RESULTS

Analysis Result of 60000 rpm

The Titanium alloy material at 60000 rpm creates maximum stress of 6.178×10^8 Pa and minimum stress of 2.22×10^6 Pa.

Figure 3: Stress Analysis of Titanium Alloy at 60000 rpm

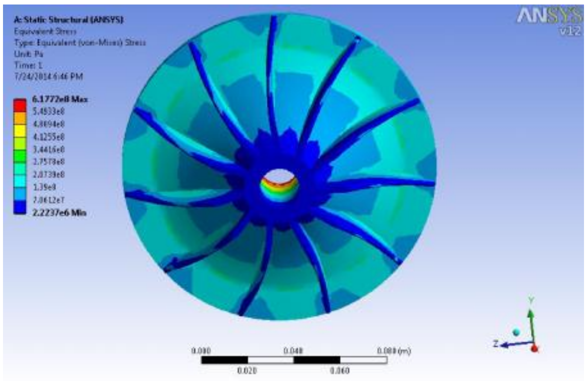
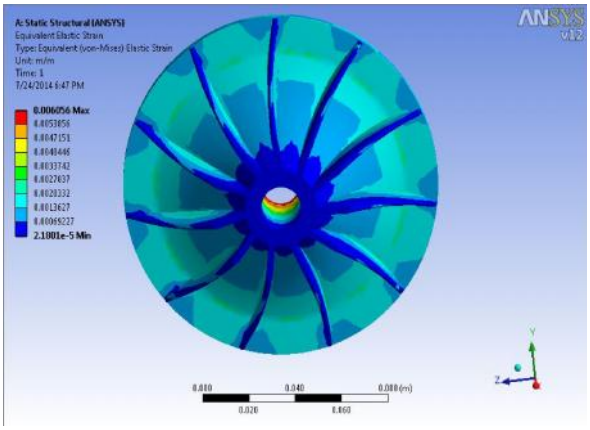


Figure 4: Strain Analysis of Titanium Alloy at 60000 rpm



The Titanium alloy material at 60000 rpm creates maximum strain of 0.0061 m/m and minimum strain of 2.18×10^{-5} m/m.

The Aluminium alloy material at 60000 rpm creates maximum stress of 3.51×10^8 Pa and minimum stress of 1.10×10^6 Pa.

Figure 5: Stress Analysis of Aluminium Alloy at 60000 rpm

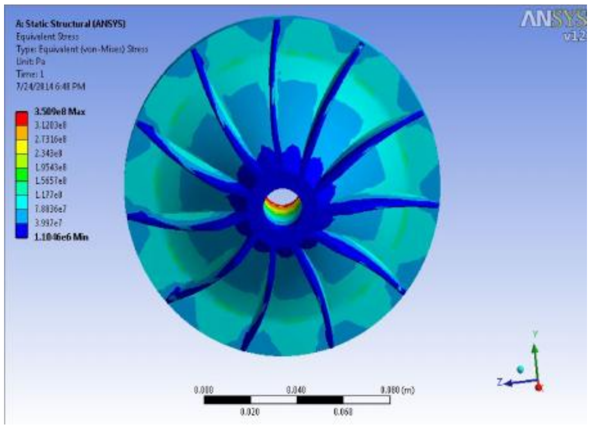
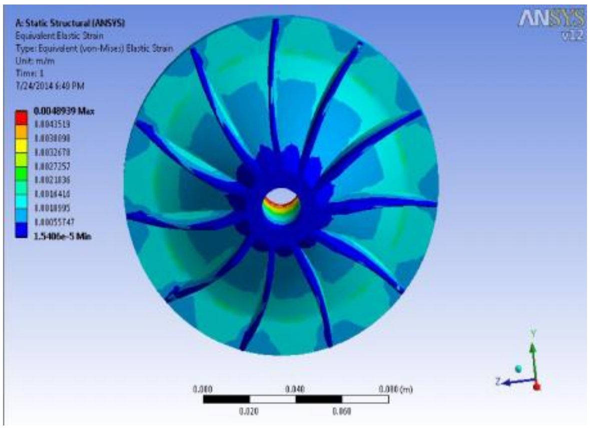


Figure 6: Strain Analysis of Aluminium Alloy at 60000 rpm



The Aluminium alloy material at 60000 rpm creates maximum strain of 0.00489 m/m and minimum strains of 1.54×10^{-5} m/m.

The Stainless steel material at 60000 rpm creates maximum stress of 1.02×10^8 Pa and minimum stress of 3.89×10^6 Pa.

Figure 7: Stress Analysis of Stainless Steel 60000 rpm

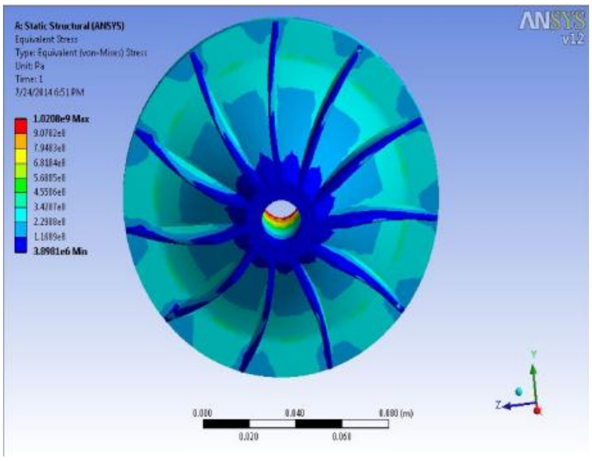
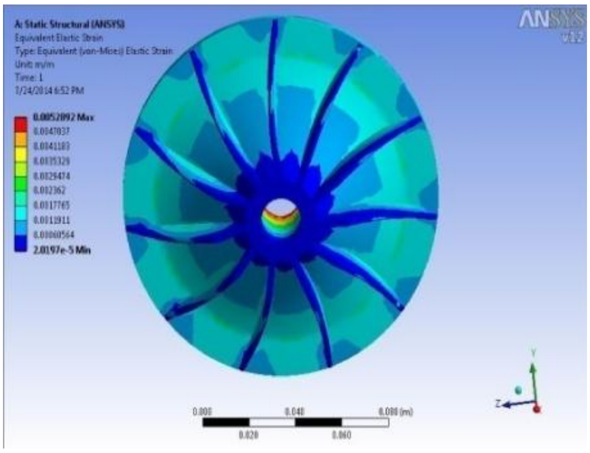


Figure 8: Strain Analysis of Stainless Steel 60000 rpm



The Stainless steel material at 60000 rpm creates maximum stress of 0.0052 m/m and minimum stress of 2.019×10^{-5} m/m.

Table 3: Analysis Result of 60000 rpm

	Titanium Alloy	Aluminium Alloy	Stainless Steel Alloy
Maximum Stress (Pa)	6.177×10^8	3.509×10^8	1.021×10^9
Maximum Strain (m/m)	0.00606	0.00489	0.00529

Safety Factor of this compressor model is:

Titanium Alloy Material (Ti-b-120UCA) = UTS/Fmax

$= 1147 \times 10^6$ Pa/6.177×10^8 Pa

= 1.857

Aluminium Alloy Material (AL-a7079) = UTS/Fmax

$= 558 \times 10^6$ Pa/3.509×10^8 Pa

= 1.590

Stainless Steel Alloy Material (STLAISI-304)

$= 1675 \times 10^6$ Pa/1.021×10^8 Pa

= 1.640

Analysis Result of 50000 rpm

The Titanium alloy material at 50000 rpm creates maximum stress of 4.33×10^8 Pa and minimum stress of 1.56×10^6 Pa.

The Titanium alloy material at 50000 rpm creates maximum stress of 0.0042 m/m and minimum stress 1.53×10^{-5} m/m.

The Aluminium alloy material at 50000 rpm creates maximum stress of 2.46×10^8 Pa and minimum stress of 7.75×10^5 Pa.

Figure 9: Stress Analysis of Titanium Alloy at 50000 rpm

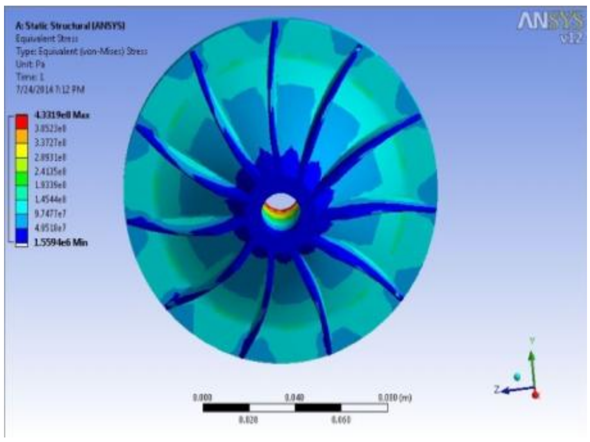


Figure 10: Strain Analysis of Titanium Alloy at 50000 rpm

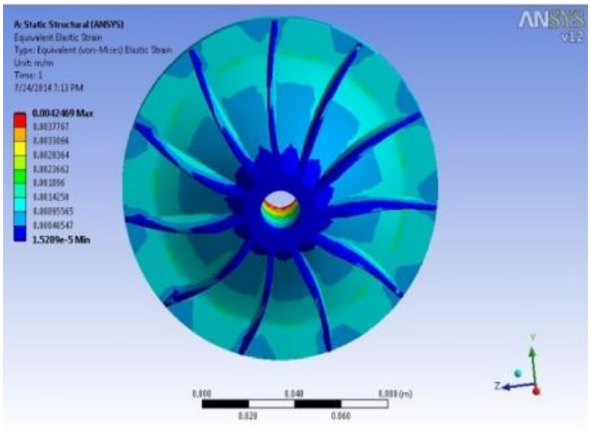


Figure 11: Stress Analysis of Aluminium Alloy at 50000 rpm

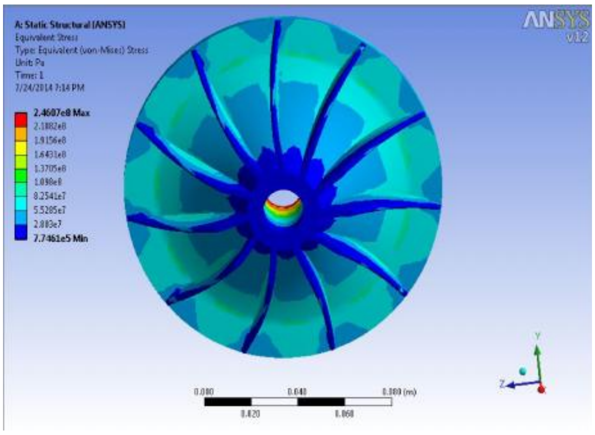


Figure 12: Strain Analysis of Aluminium Alloy at 50000 rpm

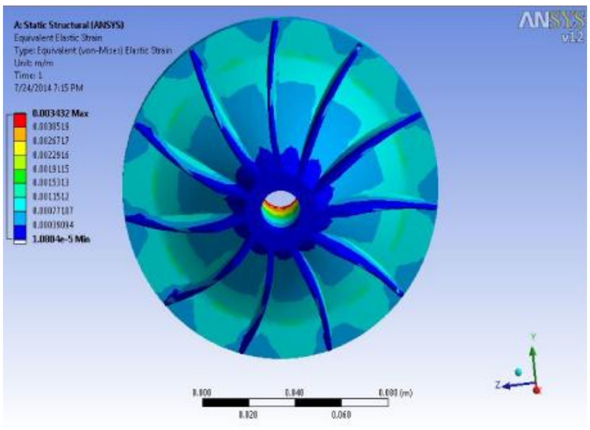


Figure 13: Stress Analysis of Stainless Steel at 50000 rpm

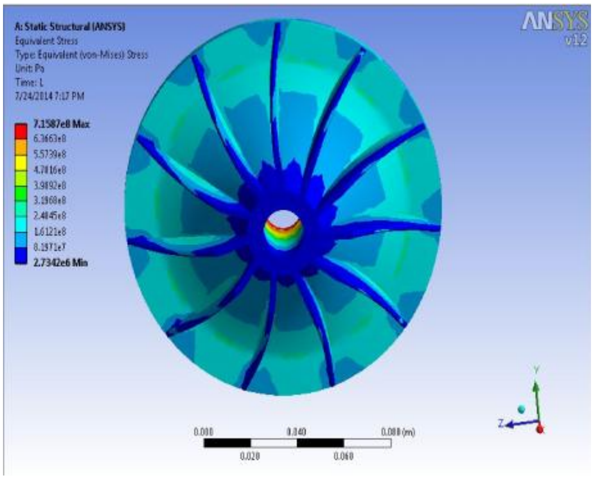
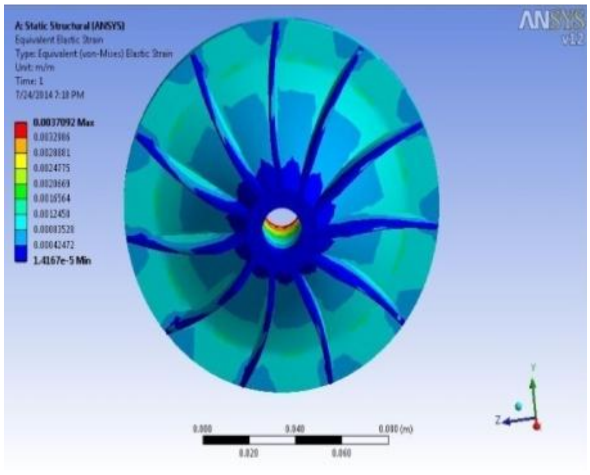


Figure 14: Strain Analysis of Stainless Steel at 50000 rpm



The Aluminium alloy material at 60000 rpm creates maximum strain of 0.0034 m/m and minimum strain of 1.80×10^{-5} m/m.

The Stainless Steel alloy material at 50000 rpm creates maximum stress of 7.16×10^{8} Pa and minimum stress of 2.73×10^{6} Pa.

The Stainless Steel material at 50000 rpm creates maximum strain 0.0037 m/m and minimum strain of 1.42×10^{-5} m/m.

Table 4: Analysis Result of 50000 rpm

	Titanium Alloy	Aluminium Alloy	Stainless Steel Alloy
Maximum Stress (Pa)	4.332×10^8	2.461×10^8	7.159×10^8
Maximum Strain (m/m)	0.00425	0.00343	0.00371

Safety Factor of this compressor model is:

Titanium Alloy Material (Ti-b-120UCA) = UTS/Fmax

$= 1147 \times 10^6$ Pa/4.332×10^8 Pa

= 2.65

Aluminium Alloy Material (AL-a7079 = UTS/ Fmax

$= 558 \times 10^6$ Pa/2.461×10^8 Pa

= 2.27

Stainless Steel Alloy Material (STLAISI-304) = UTS/Fmax

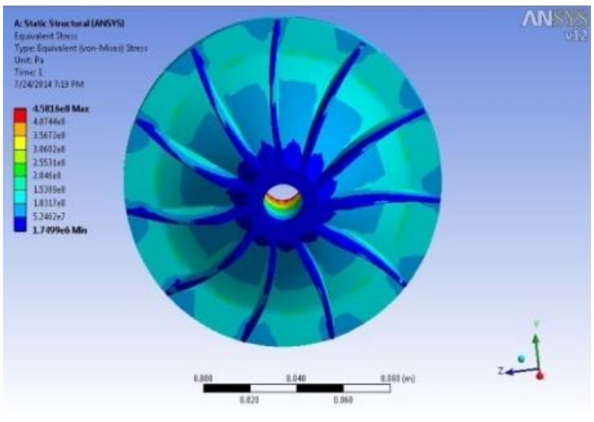
$= 1675 \times 10^6$ Pa/7.159×10^8 Pa

= 2.34

Analysis Result of 40000 rpm

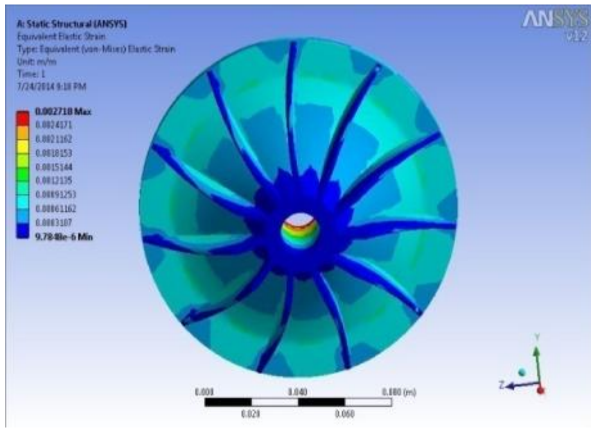
The Titanium alloy material at 40000 rpm creates maximum stress of 4.58×10^8 Pa and minimum stress of 1.75×10^6 Pa.

Figure 15: Stress Analysis of Titanium Alloy at 40000 rpm



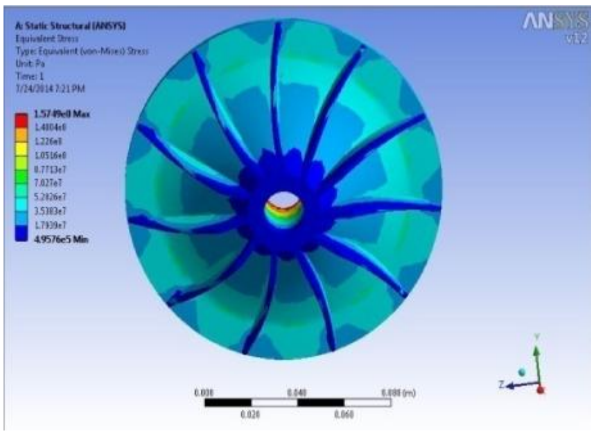
The Titanium alloy material at 40000 rpm creates maximum strain of 0.0027 and minimum strain of 9.78×10^{-6} m/m.

Figure 16: Strain Analysis of Titanium Alloy at 40000 rpm



The Aluminium alloy material at 50000 rpm creates maximum stress of 1.57×10^8 Pa and minimum stress of 4.96×10^5 Pa.

Figure 17: Stress Analysis of Aluminium Alloy at 40000 rpm



The Aluminium alloy material at 40000 rpm creates maximum strain of 0.0021m/m and minimum stress of 6.91×10^{-6} m/m.

The Stainless Steel material at 40000 rpm creates maximum stress of 4.58×10^8 Pa and minimum stress of 1.75×10^6 Pa.

Figure 18: Strain Analysis of Aluminium Alloy at 40000 rpm

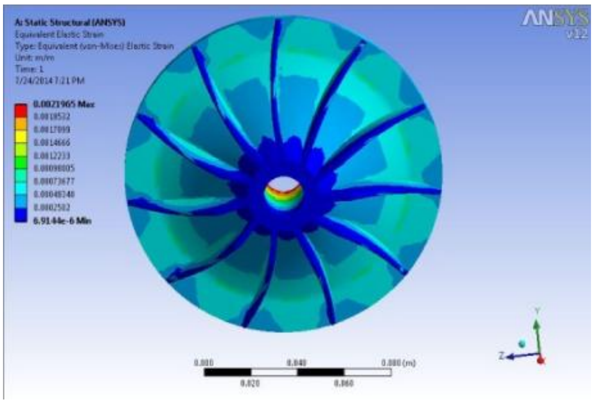


Figure 19: Stress Analysis of Stainless Steel at 40000 rpm

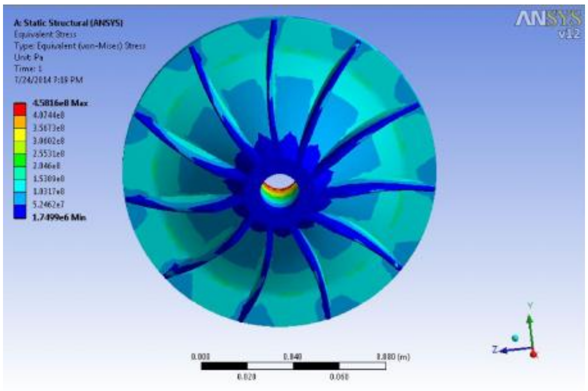
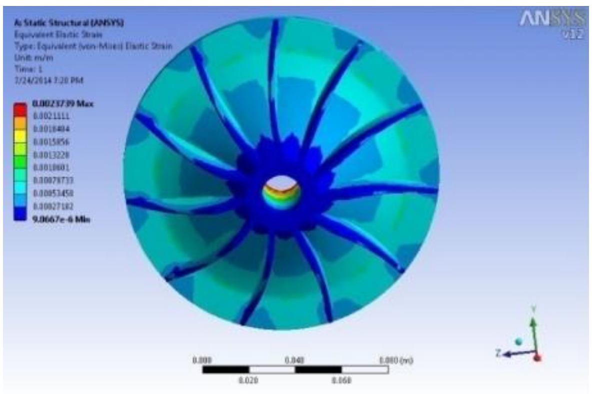


Figure 20: Strain Analysis of Stainless Steel at 40000 rpm



The Stainless Steel material at 60000 rpm creates maximum stress of 0.0024 m/m and minimum strain of 2.22×10^{-6} m/m.

Table 5: Analysis Result of 40000 rpm

	Titanium Alloy	Aluminium Alloy	Stainless Steel Alloy
Maximum Stress (Pa)	2.772×10^8	1.575×10^8	4.582×10^8
Maximum Strain (m/m)	0.00272	0.00220	0.00240

Safety Factor of this compressor model is:

Titanium Alloy Material (Ti-b-120UCA) = UTS/Fmax

$= 1147 \times 10^6$ Pa$/2.772 \times 10^8$ Pa

$= 4.138$

Aluminium Alloy Material (AL-a7079) = UTS/Fmax

$= 558 \times 10^6$ Pa$/1.575 \times 10^8$ Pa

$= 3.54$

Stainless Steel Alloy Material (STLAISI-304) = UTS/Fmax

$= 1675 \times 10^6$ Pa$/4.582 \times 10^8$ Pa

$= 3.66$

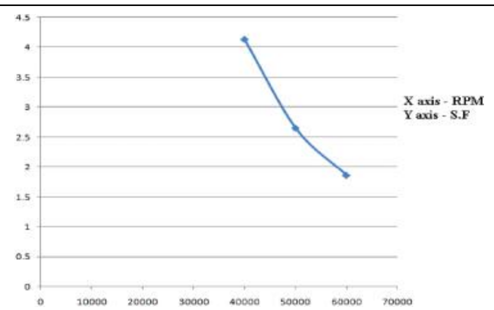
Various Rotational Speed Results

Titanium Alloy Analysis

Table 6: Analysis Result of Titanium Alloy

Speed	40000	50000	60000
Maximum Stress (Pa)	2.772×10^8	4.332×10^8	6.177×10^8
Safety factor	4.13	2.65	1.86

Figure 21: Graph Showing Analysis Result of Titanium Alloy

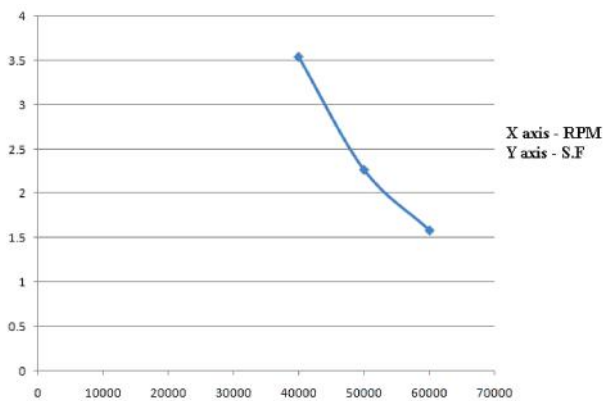


Aluminium Alloy Analysis

Table 7: Analysis Result of Aluminium Alloy

Speed	40000	50000	60000
Maximum Stress (Pa)	1.575×10^8	2.461×10^8	3.509×10^8
Safety factor	3.54	2.27	1.59

Figure 22: Graph Showing Analysis Result of Aluminium Alloy

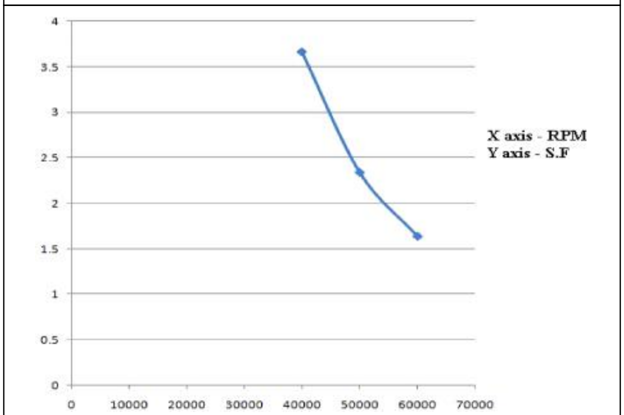


Stainless Steel Alloy Material Analysis

Table 8: Stainless Steel Alloy Material Analysis

Speed	40000	50000	60000
Maximum Stress (Pa)	4.582×10^8	7.159×10^8	1.021×10^9
Safety factor	3.66	2.34	1.64

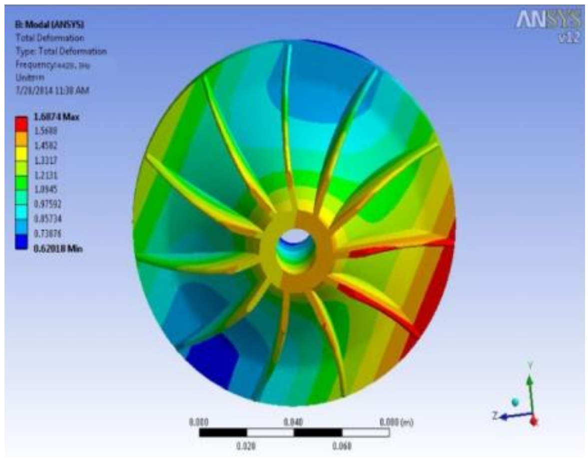
Figure 23: Graph Showing Analysis Result of Stainless Steel Alloy



Vibrational Analysis

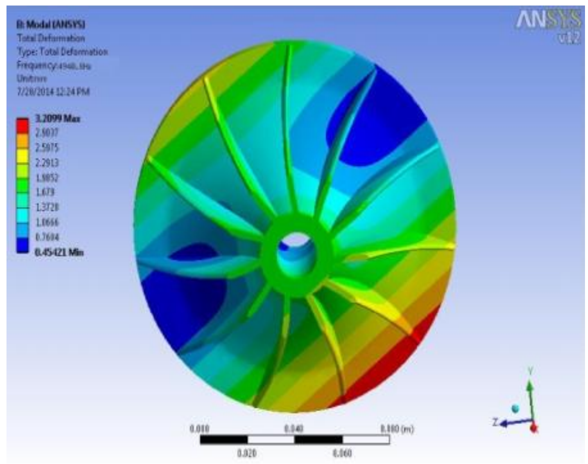
The Titanium alloy material at 4428.3 rpm creates vibration of 4428.3 Hz frequency and maximum deflection of 1.69 mm.

Figure 24: Vibrational Analysis of Titanium Alloy at 40000 rpm



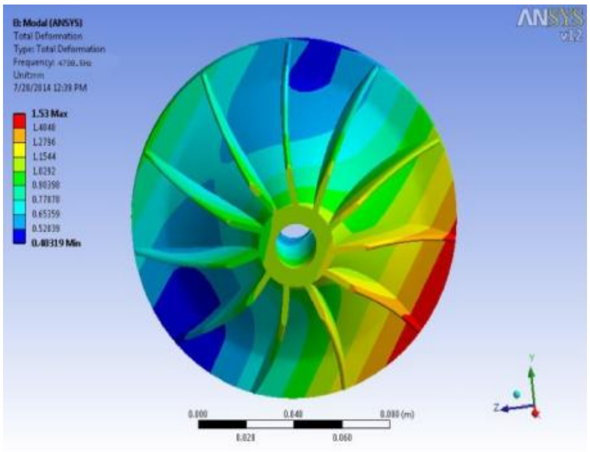
The Aluminium alloy material at 40000 rpm creates vibration of 4940.8 Hz frequency and maximum deflection of 3.20 mm.

Figure 25: Vibrational Analysis of Aluminium Alloy at 40000 rpm



The Stainless Steel alloy material at 40000 rpm creates vibration of 4940.8 Hz frequency and maximum deflection of 1.53 mm.

Figure 26: Vibrational Analysis of Stainless Steel at 40000 rpm



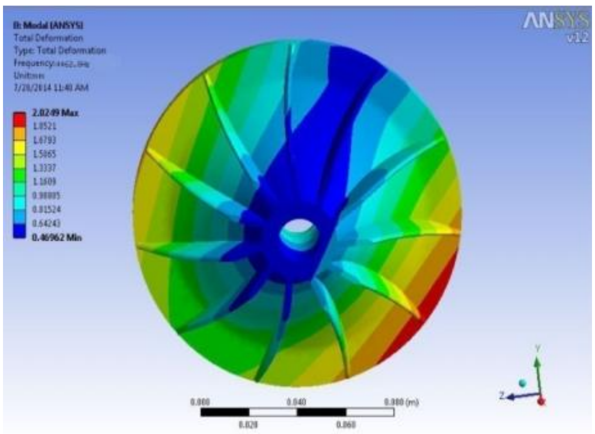
Comparison Table of Various Materials at 40000 rpm

The Titanium alloy material at 40000 rpm creates a low vibration of 4428.3 Hz frequency as compared to Aluminium Alloy and Stainless steel.

Table 9: Comparison Table of Various Materials at 40000 rpm

	Titanium Alloy	Aluminium Alloy	Stainless Steel
Frequency (Hz)	4428.3	4940.8	4730.5
Deformation (mm)	1.69	3.21	1.53

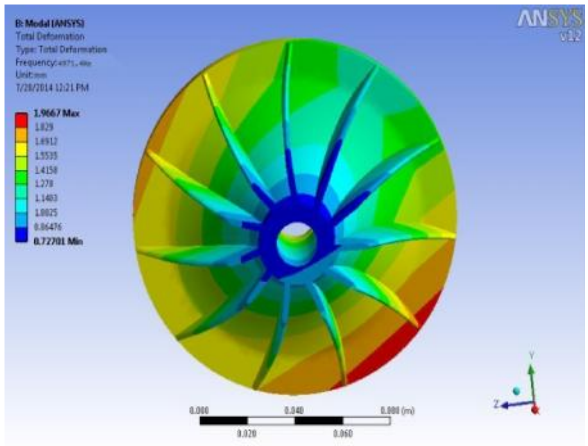
Figure 27: Vibrational Analysis of Titanium Alloy at 50000 rpm



The Titanium alloy material at 50000 rpm creates vibration of 4462.8 Hz frequency and maximum deflection of 2.02 mm.

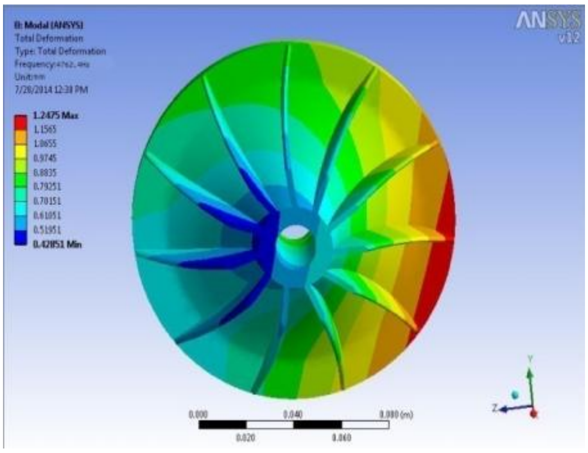
The Aluminium alloy material at 50000 rpm creates vibration of 4971.4 Hz frequency and maximum deflection of 1.97 mm.

Figure 28: Vibrational Analysis of Aluminium Alloy at 50000 rpm



The Stainless Steel alloy material at 50000 rpm creates vibration of 4462.4 Hz frequency and maximum deflection of 1.25 mm.

Figure 29: Vibrational Analysis of Stainless Steel at 50000 rpm



Comparison Table of Various Materials at 50000 rpm

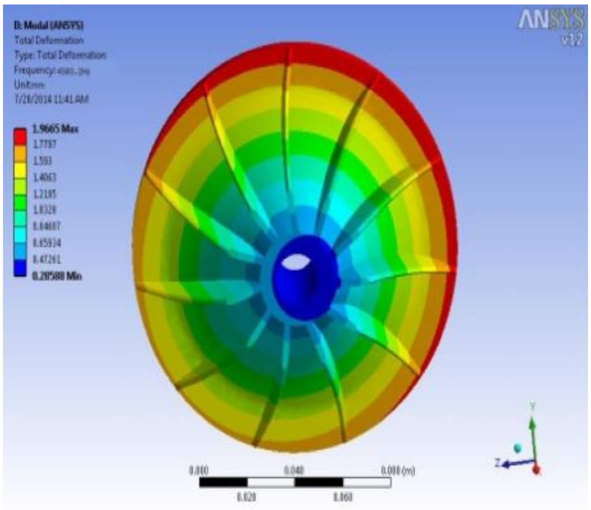
The Titanium alloy material at 50000 rpm creates a low vibration of 4462.8 Hz frequency as compared to Aluminium Alloy and Stainless steel.

Table 10: Comparison Table of Various Materials at 50000 rpm

	Titanium Alloy	Aluminium Alloy	Stainless Steel
Frequency (Hz)	4462.8	4971.4	4762.4
Deformation (mm)	2.02	2.66	1.25

The Titanium alloy material at 60000 rpm creates vibration of 4540.3 Hz frequency and maximum deflection of 1.97 mm.

Figure 30: Vibrational Analysis of Titanium Alloy at 60000 rpm



The Aluminium alloy material at 60000 rpm creates vibration of 5007.7 Hz frequency and maximum deflection of 2.66 mm.

The Stainless Steel alloy material at 60000 rpm creates vibration of 4792.9 Hz frequency and maximum deflection of 1.59 mm.

Figure 31: Vibrational Analysis of Aluminium Alloy at 60000 rpm

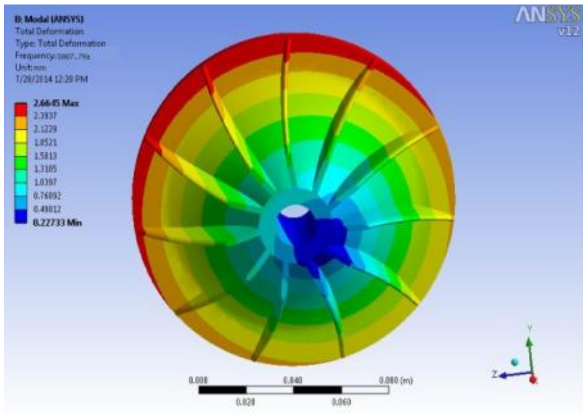
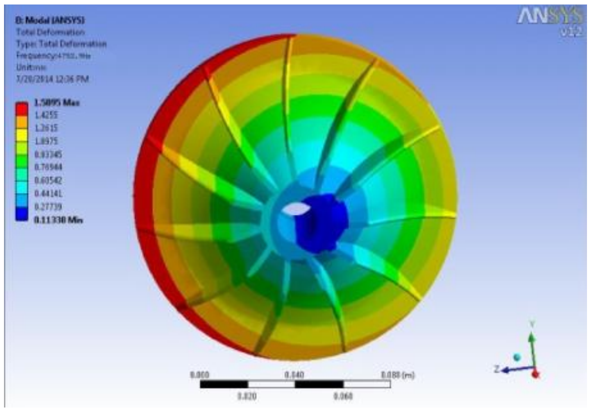


Figure 32: Vibrational Analysis of Stainless Steel at 60000 rpm



Comparison Table of Various Materials at 60000 rpm

Table 11: Comparison Table of Various Materials at 60000 rpm

	Titanium Alloy	Aluminium Alloy	Stainless Steel
Frequency (Hz)	4503.2	5007.7	4792.9
Deformation (mm)	1.97	2.66	1.59

The Titanium alloy material at 60000 rpm creates a low vibration of 4503.2 Hz frequency as compared to Aluminium Alloy and Stainless steel.

CONCLUSION

The compressor blade is modelled by using 3D modeling Software Solid works 2013. In this case stress analysis and vibrational analysis of different materials is carried out using analysis software ANSYS 12.

This analysis shows that Titanium alloy blade gives better safety factors compared to other alloys. The vibration characteristics from model analysis were also good for the same alloy. The simulation showed that the stresses are concentrated on the blade attachment to the hub. A better safety factor would be obtained when the rotational speed is decreased. The simulation showed that the stresses are concentrated on the blade attachment to the hub, caused by the centrifugal stresses. The counter measure for this problem is to apply the fillet radius thickening of the blade attachment to the hub.

Another point observed is that a higher rotational speed will result in greater stresses to be borne by the structure, which indicates that a better safety factor would be obtained when the rotational speed is decreased.

Considerations about the limiting rotational speed are also of importance. Because of the need to have a particular output power, the designated rotational speed needs to be predicted, since structural strength is limited by the various rotational speeds. Thus for this purpose, Titanium alloy, with a much higher ultimate tensile strength compare to Stainless Steel and Aluminium alloy, is thus the safe material to be used because they have the higher Young's modulus (E).

FUTURE SCOPE

Even though Titanium Alloy have better properties comparing with others when cost factor come into consideration then it is costly. For future works, new material or composite material has to be found out with low cost and more efficient.

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Hyderabad, INDIA. Ph: +91-09441351700, 09059645577
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