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ANALYSIS OF A GAS TURBINE BLISK WITH ALTERNATE MATERIALS USING FEM

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ABSTRACT
This thesis is primarily focused on Static Structural Analysis and Harmonic Analysis of the turbine blisk. A blisk is designed utilizing the data obtained from the literature survey and used to obtain the static and harmonic responses when subjected to certain boundary and loading conditions. Another design was proposed and the similar analysis is done to compare both the designs. To design the model of turbine blisk, CATIA software is used and then it is imported to ANSYS software, to perform the Static Structural and Harmonic Analysis. Two different materials namely as Inconel740, and Ti6 Al 4V alloy.The best suitable material with Ti6 Al 4V alloy has the less Stress and Strain when compared to the Inconel 740

INTRODUCTION
A blisk is a turbomachine component that includes both the rotor disc and the blades. It is made up of a single piece rather than an assembly comprising a disc and individual, replaceable blades. Blisk can be additively built, integrally cast, machined from a solid piece of material, or welded to a rotor disc. The phrase is mostly used in aeronautical engine design. Blisk rotors are also known as integrally bladed rotors.

Since the mid-1980s, blisk manufacturing has been used. Sermatech-Lehr (now GKN Aerospace) employed it for the compressors of the T700 helicopter engine for the first time in 1985. Since then, its utilization in significant applications such as compressors and fan blade rotors has increased. The Rocketdyne RS-68 rocket engine and the General Electric F110 turbofan are two examples.

The F-35B Joint Strike Fighter type employs blisk to perform short take-off and vertical landing.

CFM International's Leap-X demonstration engine programme, which has undergone full-scale rig testing, employs blisk technology in the compressor portion. The Sukhoi Superset 100s' Power Jet SaM146 engines are also outfitted with blisk.

Aircraft engines are high-tech goods that require new manufacturing procedures. Furthermore, aero-engines must constantly improve their technical skills in order to achieve improved efficiency in terms of lower fuel consumption, increased reliability, and safety while meeting stringent environmental regulations (External Advisory Group for Aeronautics of the European Commission, 2000).

A blisk (bladed disc) is a single engine component made up of a rotor disc and blades that can be cast or machined from a solid piece of material or created by welding individual blades to the rotor disc. The phrase is mostly used in aeronautical engine design. The term is a combination of the words blade and disc, which are the two components it replaces in turbo equipment.

According to the literature review, there is a critical requirement for an efficient use of the Finite Element Method (FEM) technique so that the accuracy of the result can be verified/maintained for improved analytical treatment. The project's goals are as follows:

- Model a sector of a turbine blisk using ANSYS 14.5.
- Using three different materials, estimate the heat flow and thermal stresses encountered by the component.
- Choosing the optimal material for future turbine blisk production.

Gas Turbine

Gas turbines generate energy by burning high-pressure gas. These turbines are not used to generate energy, but rather to propel jet engines. Gas turbines are the most recent turbine types. Their structure is more advanced, but the principle remains the same. A gas turbine is a type of internal combustion engine. It is also known as a combustion turbine. It consists of an upstream spinning compressor connected to a downstream turbine and a combustion chamber in the middle.

The basic operation of a gas turbine is similar to that of a steam power plant, except that instead of water, air is employed. Fresh ambient air is compressed as it passes through a compressor. The energy is then added by spraying fuel into the air and burning it, resulting in a high-temperature flow from the combustion. This high-temperature, high-pressure gas enters a turbine and expands to exhaust pressure, resulting in shaft work output. The turbine shaft work is used to power the compressor and any other devices that may be attached to the shaft, such as an electric generator.

Applications of Gas Turbine:

- Land applications include central power plants.
- Space applications include turbojets and turboprops.
- Applications in the marine environment.

Introduction of CAD:

A Computer Assisted Design (CAD) package has three parts, as shown in the sketch: Design, analysis, and visualization are the first three. Below is a quick breakdown of these elements.

a) Design: Design refers to geometric modelling, which involves drafting, part development, drawing creation with numerous views of the part, component assembly, and other activities. This encompasses both 2-D and 3-D modelling.

b) Analysis: Examples of analysis include finite element analysis, optimization, and other numerically intensive engineering analyses. A geometric model is often created initially, and then it is evaluated for loads, stresses, moment of inertia, volume, and other factors.

c) Visualization: Computer graphics can be used to render models, produce pie charts and contour plots, shade models, scale them, add animation, and more.

Introduction of CATIA:

CATIA, or Computer Aided Three-dimensional Interactive Application, is a software package developed by Desalt Systems, a French company. This package includes mechanical, form, style, product synthesis, equipment and systems engineering, NC production, analysis and simulation, and industrial plant design. CATIA Knowledge ware is extremely user-friendly software since it allows massive user communities to easily capture and communicate knowledge, rules, and other intellectual property assets.

Introduction to ANSYS:

Swanson Analysis Systems Inc. developed and maintains the ANSYS programme. It is a stand-alone general-purpose finite element programme. The application has a large number of interrelated routines that all work together to solve engineering issues using the finite element method.

Engineers can use ANSYS finite element analysis software to do the following:

- Create computer models.

- Use operating loads.
- Investigate physical responses.
- Reduce production costs by optimising a design.
- Conduct prototype testing.

MATERIAL PROPERTIES

Inconel740:

Special Metals Corporation developed the austenitic nickel-chromium-based super alloys known as Inconel740. Super alloys are high-performance alloys that function well in extremely hot environments. When a gamma-prime second phase precipitates, an age-hardenable nickel-chromium-cobalt alloy known as INCONEL 740 is formed.

Material Properties:

Density- 8000 kg/m3

Young's Modulus- 2.1GPa

Poisson's Ratio- 0.3

Applications: INCONEL 740 is mainly used in advanced power production boiler tubes and diesel engine exhaust valves.

Ti6 Al 4V Alloy:

Commonly abbreviated in English as Ti-6AL-4V (or Ti 6-4), this nomenclature alludes to the material's chemical make-up, which includes 0.25 percent (maximum) iron, 0.2% (maximum) oxygen, and nearly 90% titanium. It is heat treatable, has a good weld ability, strong corrosion resistance, low elastic modulus, and great strength.

Material Properties:

Density- 4512 kg/m3

Young's Modulus- 1.19GPa

Poisson's Ratio- 0.37

Applications:

· High corrosion resistance
· High fatigue strength
· High performance index
· High strength at elevated temperatures

METHODOLOGY

Engineering Design:

A variety of tools are provided by CATIA V5 to allow the creation of an entire digital depiction of the object being developed. The ability to produce geometry for other integrated design disciplines, such as industrial and standard pipe work and comprehensive wiring specifications ,is available in addition to the tools for general geometry .Collaborative development tools are also accessible. The product's engineering process can then employ a variety of concept design tools that offer first Industrial Design concepts. These can be extensive freeform surface tools, reverse engineering using point cloud data, or creative industrial design drawings.

DESIGN IMAGES OF GAS TURBINE BLADE:

EXISTING DESIGN

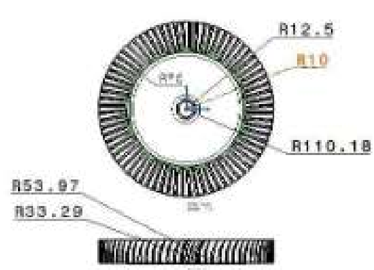


Figure 3.1 Dimensions of existing design

PROPOSED DESIGN

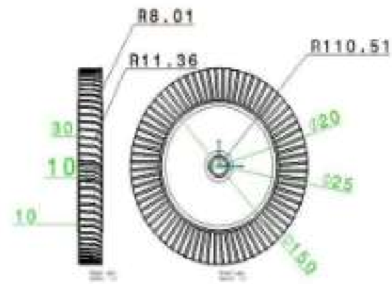


Figure 3.2Dimensionsof the Proposed model

Different Modules in CATIA

- Sketcher
- Part Modelling
- Surfacing
- Sheet Metal
- Drafting
- Manufacturing
- Shape designs

Performing a typical ANSYS analysis:

From a straightforward linear static analysis to a challenging nonlinear transient dynamic analysis, the ANSYS software includes a wide range of finite element analysis capabilities .The ANSYS documentation set's analysis guide guides detail particular methods for carrying out analysis for various engineering specialties.

Atypical ANSYS analysis has three distinct steps:

- Build the model
- Apply loads and obtain the solution
- Review the results

The following table shows the brief description of steps followed in each phase

Pre-processor	Solution Processor	Postprocessor
Assigning Element Type	Analysis definition	Read results
Geometry Definition	Constant definition	Plot results on graphs
Assigning real constants	load definition	view animated results
Material Definition	Solve	
Mesh Generation		
Model Display		

Pre-processor:

A pre-processor is used to generate the input data for an ANSYS analysis. The general pre-processor (prep 7) includes powerful solid modelling and mesh generation tools, as well as the ability to create any additional analytical data with the benefit of data base definition and customization.

Solution processor:

Here we create the environment to the model, i.e., Applying constraints & loads. This is the main phase of the analysis, where the problem can be solved by using different solution techniques. Here three major steps involved:

- The desired solution type, such as static, modal, or transient, is chosen.
- Load definition
- The pre-solver, mathematical-engine, and post-solver are the three primary processes.
-

Post processor:

Post processing describes the results of an analysis. This part of the study is perhaps the most important because we want to comprehend how the applied loads effect the design, how thick your finite element mesh is, and other aspects.

Post processors, which can display deformed geometries, stress and strain contours, flow fields, safety factor contours, contours of potential field discover, vector field displays mode forms, and time history graphs, are used to exhibit the study's results. In addition to algebraic operations, the post processor can be used for database management, differentiation, and integration. Dynamic analysis can be used to create response spectra. Axis metric constructions that are harmonically burdened can be caused by a variety of loads.

Review the results:

We can use the Ansys post processor to evaluate the results after the solution has been computed. The two post processors are Post 1 and Post 26. We analyse the results at one subset for the entire model or a particular area of the model using post 1, the generic post processor. To analyse and assess the analysis's findings, we might acquire tabular listings, deform forms, and contour representations. The remaining components of post 1 include route operations, load case combinations, computation among results data, and error estimate.

Meshing:

Before meshing or even generating the model, it is critical to decide whether a free mesh or a mapped mesh is appropriate for the study. No limits on constituent forms or predetermined patterns are present in a free mesh. A mapped mesh is constrained in terms of the element shapes it contains and the mesh pattern compared to a free mesh. While a mapped volume mesh only comprises hexahedron components, a mapped area mesh includes either quadrilateral or simply triangular elements. If we wish to use this kind of mesh, we must construct the geometry as a collection of somewhat regular volumes and or regions that can accommodate a mapped mesh.

4. FINITE ELEMENT ANALYSIS(FEM):

Static structural analysis

A static analysis calculates the effects of observed loading conditions on a structure while discounting inertia and damping effects, such as those caused by time-varying loads. However, constant inertia loads and time-varying loads that may be roughly classified as similar static loads can be included in a static analysis. To calculate the displacements, stresses, strains, and forces in structures or components brought on by loads with minimal inertia and damping effects, static analysis is utilized. In other words, it is believed that the loads acting on the structure and its reactions would change gradually over time under steady loading and response circumstances.

There are several loading types that may be used in static analysis:

- Externally applied forces and pressures.
- Steady state inertial forces.
- Imposed displacement.
- Temperatures.
- Fluencies(fornuclearswelling).

Harmonic Analysis:

A number of structure types can be subjected to base acceleration in harmonic analysis using ANSYS Mechanical APDL and Mechanical Workbench. Be it for figuring out the sinusoidal steady-state response to sinusoidal changing loads acting all at a certain frequency. A phase off set can be used to apply some load types.

4.1 FINITEELEMENTANALYSISONEXISTINGMODEL

USINGINCONEL 740MATERIAL:

Static Structural Analysis

Stress

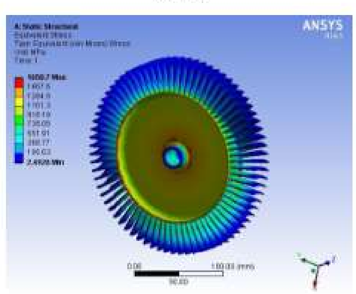


Figure 4.1.1 Equivalent Stress For Inconel740

Strain

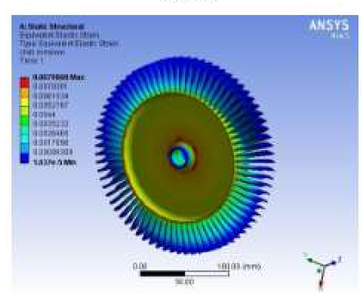


Figure 4.1.2 Equivalent strain for Inconel740

Figure 4.1.1 shows the stress impact on the turbine and the color blue indicates the min stress on the blade of the value 2.4926MPa and red color indicates the max stress on the center of theturbine with the value of 1650.7MPa.

Figure 4.1.2 shows the strain impact on the turbine and the color blue indicates the min stress on the blade of the value 1.637e-5 and red color indicates the max stress on the center of the turbine with the value of 0.0079068

Total deformation	Directional deformation

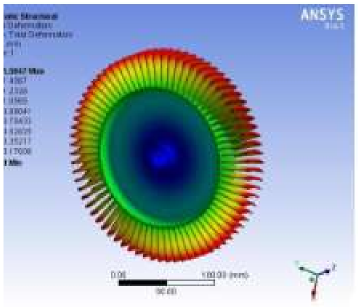
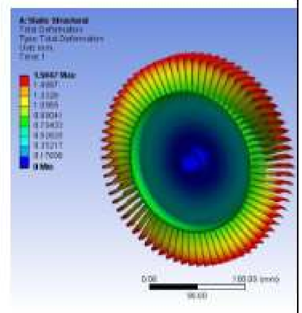

	

Figure 4.1.3 TotalDeformation for Inconel740	Figure 4.1.4 Directional Deformation For Inconel740

Figure 4.1.3 shows the total deformation impact on the turbine and the color blue indicates the min deformation impact of the value 0.17608mm and red color indicates the max total deformation impact on the outer surface of the turbine blade with the value of 1.5847 mm.

Figure 4.1.4 shows the directional deformation along X axis impact on the turbine and the color blue indicates the min directional deformation impact of the value -0.9810 mm and red color indicates the max directional deformation impact of the turbine blade with the value of0.98619 mm.

Harmonic Analysis:

Max Shear Stress:

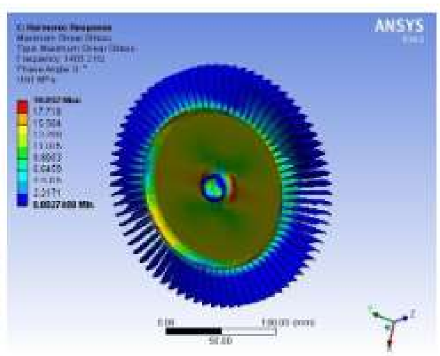


Figure 4.1.5:Maximum shearstressforInconel740

Figure 4.1.5 shows the max shear stress with respect to harmonic response analysis on the turbine and the color blue indicates the min deformation impact on the blades of the turbine of the value 0.002408MPa at 1485.2 Hz and red color indicates the max total deformation impact on the centre of the turbine blades with the value of 19.932 Mpa at 1485.2 Hz.

Frequency Response Directional Deformation:

Figure4.1.6 shows graphs of frequency Samplitude and frequencyVSphaseangle

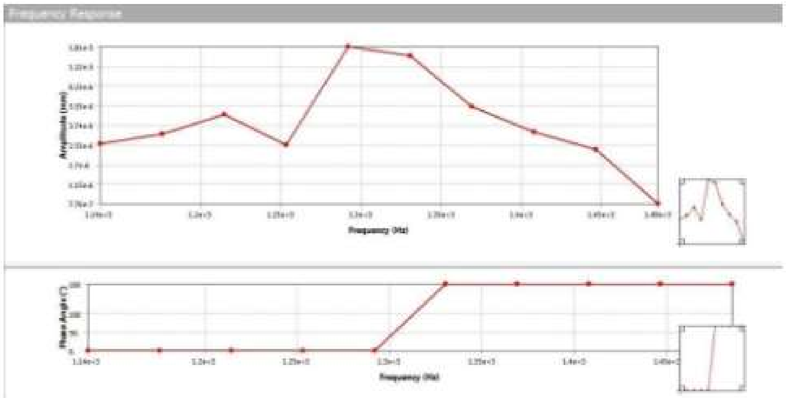


Figure 4.1.6: Frequency SAmplitude and Phase angle rIncon el740

Frequency Response Stress:

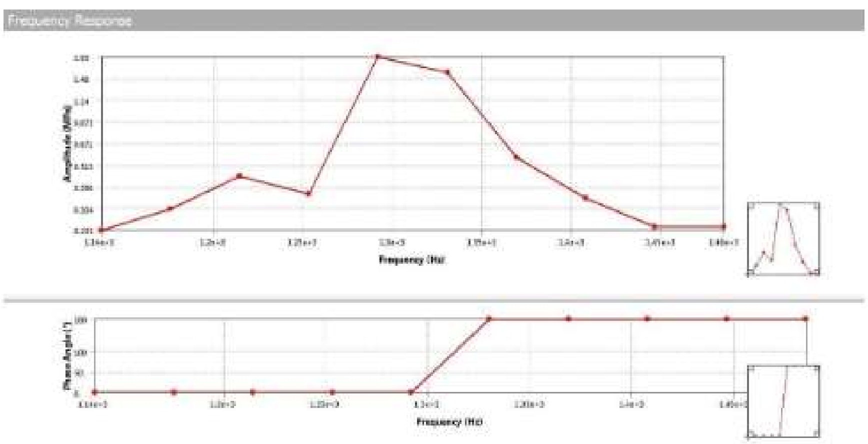


Figure 4.1.7: Frequency vs Amplitude and Phase angle for Inconel740

Figure4.1.7 shows graphs of frequency vs amplitude and frequency vs phase angle

USINGTI6 AL4V ALLOY MATERIAL:

Stress

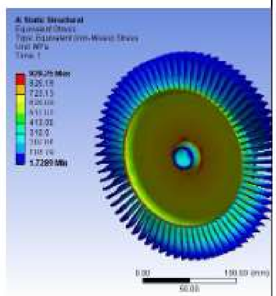


Figure 4.1.8 Equivalent Stress for of Ti6Al 4V

Strain

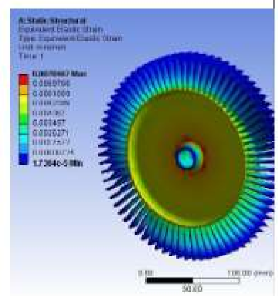


Figure 4.1.9 Equivalentstrain forTi6Al 4V

Static Structural Analysis:

Figure 4.1.8 represents the result of the stress impact on the turbine and the color blue indicates the min stress on the blade of the value 1.729MPa and red color indicates the max stress on the turbine center location with the value of 929.25MPa.

Figure 4.1.9 shows the strain impact on the turbine and the color blue indicates the min stress on the blade of the value 1.73e-5 and red color indicates the max stress on the center of the turbine with the value of 0.0078467

Total deformation

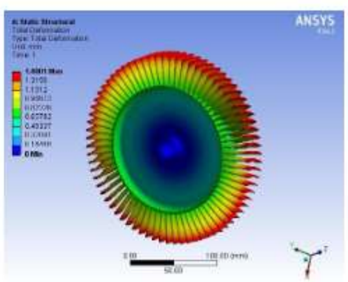


Figure 4.1.10 Total Deformation of Ti6 Al 4V

Directional deformation

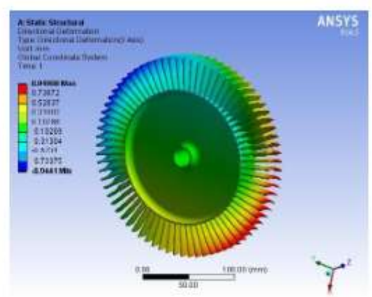


Figure 4.1.11 Directional Deformation For Ti6Al4V

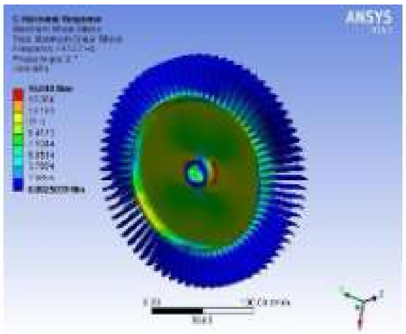
Figure 4.1.10 shows the total deformation impact on the turbine and the color blue indicates the min deformation impact of the value 0.16446mm and red color indicates the max total deformation impact on the outer surface of the turbine blade with the value 1.4801 mm.

Figure 4.1.11 shows the directional deformation along the X axis impact on the turbine and the color blue indicates the min directional deformation impact of the value -0.9441 mm and red color indicates the max directional deformation impact of the turbine blade with the value of0.9491 mm.

Harmonic analysis :

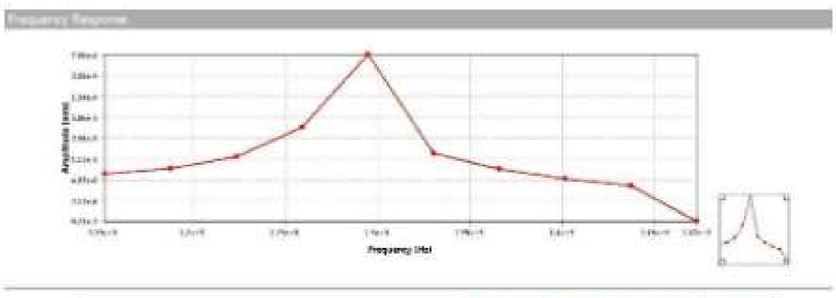
Max Shear Stress:

Figure 4.1.12 shows the max shear stress with respect to harmonic response analysis on the turbine and the color blue indicates the min deformation impact on the blades of the turbine of the value 0.0025039MPa at 1472.7 Hz and red color indicates the max total deformation impact on the center of the turbine blade with the value of16.949MPaat 1472.7 Hz.

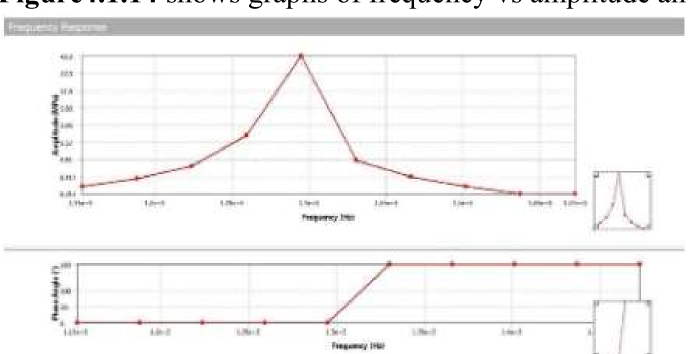


Frequency response directional deformation:

Figure4.1.13 shows graphs of frequency amplitude and frequency vs phase angle



Frequency Response Stress:
Figure4.1.14 shows graphs of frequency vs amplitude and frequency vs phase angle



4.2 FINITE ELEMENT ANALYSIS ON PROPOSED MODEL

USING INCONEL 740 MATERIAL:

Static Structural Analysis

Stress

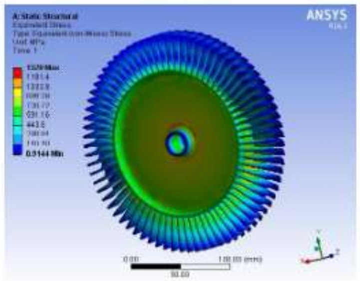


Figure 4.2.1 Equivalent Stress Of Inconel740

Strain

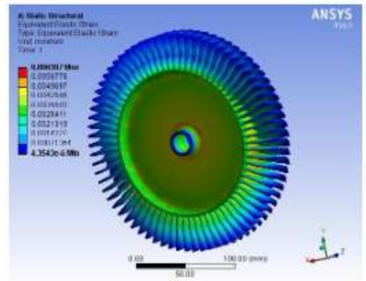


Figure 4.2.2 Equivalent Strain of Inconel740

Figure 4.2.1 shows the stress impact on the turbine and the color blue indicates the min stress on the blade of the value 0.9144Mpa and red color indicates the max stress on the center of the turbine with the value of 1329MPa.

Figure 4.2.2 shows the strain impact on the turbine and the color blue indicates the min stress on the blade of the value of 0.006387 value 4.354e-6 and red color indicates the max stress on the center of the turbine with the value of 0.006387

Total Deformation:

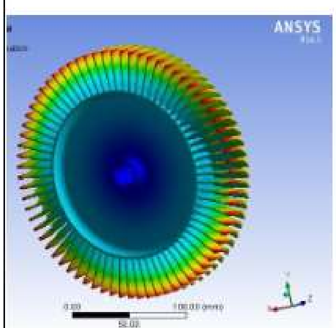


Figure 4.2.3TotalDeformation of Inconel740

Directional Deformation:

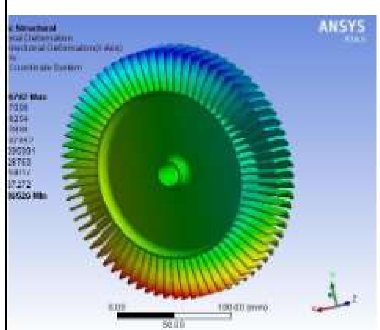


Figure 4.2.4 Directional Deformation of Inconel740

Figure 4.2.3 shows the total deformation impact on the turbine and the color blue indicates the min deformation impact of the value 0.097498mm and red color indicates the max total deformation impact on the outer surface of the turbine blade with the value of0.87748mm.

Figure 4.2.4 shows the directional deformation along the X axis impact on the turbine and the color blue indicates the min directional deformation impact of the value -0.86526 mm and red color indicates the max directional deformation impact of the turbine blade with the value of 0.86762 mm.

Harmonic Analysis

Max shear stress:

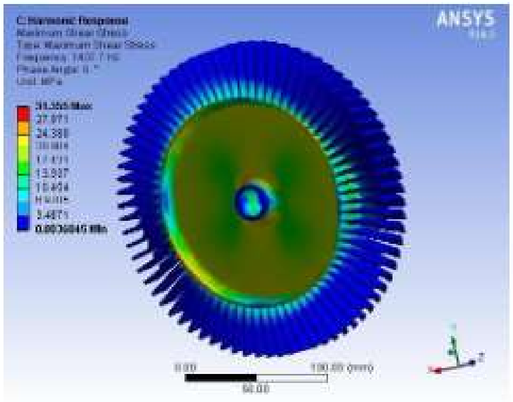
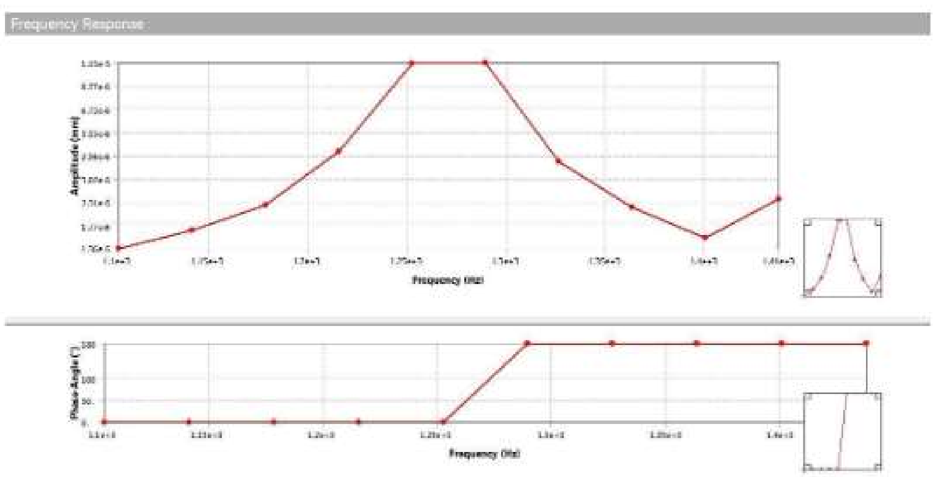


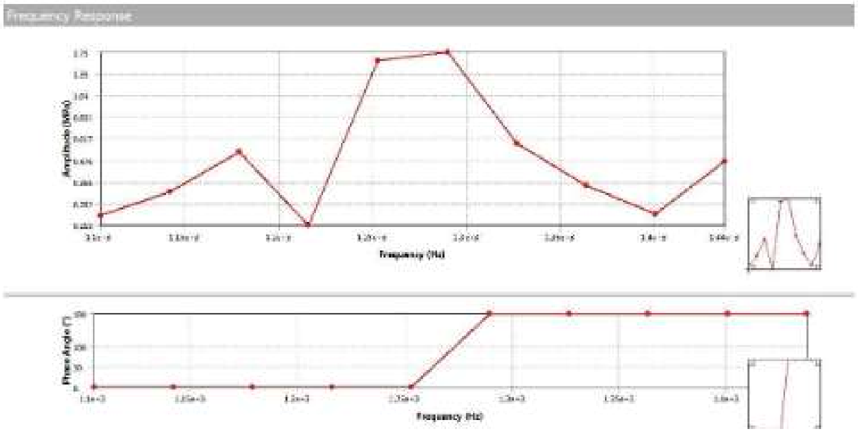
Figure 4.2.5:Maximum shear stress for Inconel740

Figure 4.2.5 shows the max shear stress with respect to harmonic response analysis on theturbine and the color blue indicates the min deformation impact on the blades of the turbine of the value 0.0036045MPa at 1437.7 Hz and red color indicates the max total deformation impact on the center of the turbine blade with the value of 31.355Mpaat 1437.7 Hz.

Frequency Response Directional Deformation:

Figure4.2.6 shows graphs of frequency vs amplitude and frequency vs phase angle.





Frequency Response Stress:

Figure 4.2.7: Frequency vs Amplitude and Phase angle for Inconel 740 Figure 5.22 shows graphs of frequency vs amplitude and frequency vs phase angle.

USINGTI6 AL4V ALLOY MATERIAL:

Static Structural Analysis:

Figure 4.2.8 represents the result of the stress impact on the turbine and the color blue indicates the min stress on the blade of the value 0.5814MPa and red color indicates the max stress on the turbine center location with the value of 722.06 Mpa.

Figure 4.2.9 shows the strain impact on the turbine and the color blue indicates the min stress on the blade of the value 4.8857 e-7 and red color indicates thema stress on the center of the turbine with the value of 0.0061072

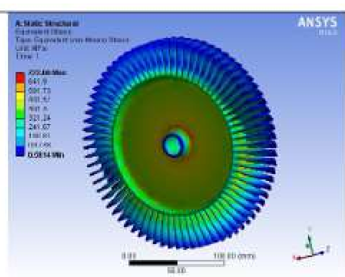


Figure 4.2.8: Equivalent stress for Ti6 Al 4V

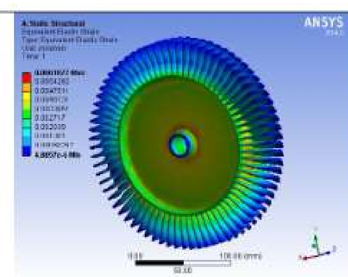


Figure 4.2.9: Equivalent strain for Ti6 Al 4V

Total deformation

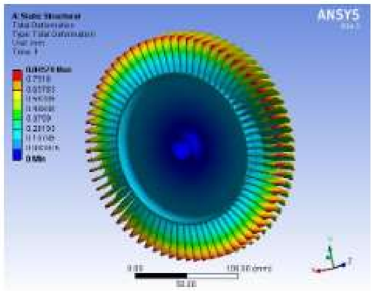


Figure 4.2.10: Total Deformation for blisk of Ti6 Al 4V

Directional deformation

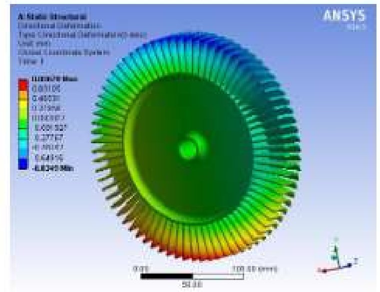


Figure 4.2.11: Directional Deformation for blisk of Ti6 Al 4V

Figure 4.2.10 shows the total deformation impact on the turbine and the colour blue indicates the min
deformation impact of the value 0.093975mm and red colour indicates the max total deformation
impact on the outer surface of the turbine blade with the value of 0.84578 mm.
Figure 4.2.11 shows the directional deformation along X axis impact on the turbine and the colour
blue indicates the min directional deformation impact of the value -0.8349 mm and red colour indicates
the max directional deformation impact of the turbine blade with the value of 0.83679 mm.

Harmonic Analysis:

Max shear stress:

Figure 4.2.12 shows the max shear stress with respect to harmonic response analysis on the turbine and the colour blue indicates the min deformation impact on the blades of the turbine of thevalue 0.011848MPa at 1425.8 Hz and red colour indicates the max total deformation impact on the
centre of the turbine blade with the value of 54.703MPa at 1425.8 Hz.

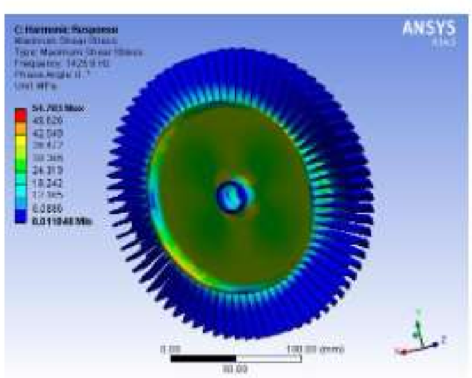


Figure 4.2.12: Maximum shear stress for blisk of Ti6 Al 4V

Frequency response directional deformation:

Figure 4.2.13 shows the graphs of frequency vs amplitude and frequency vs phase angle.

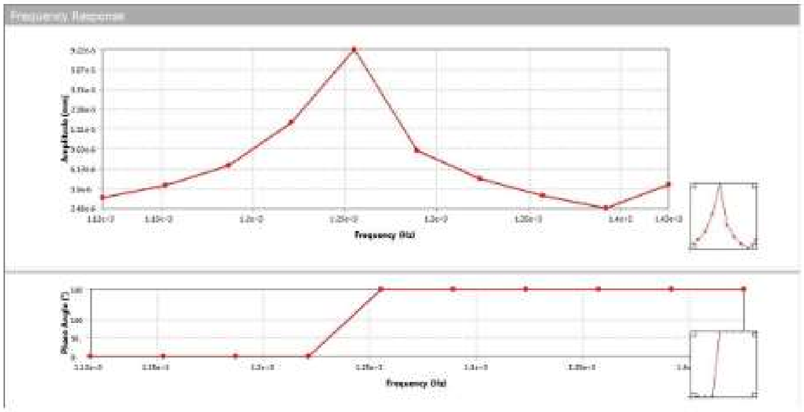
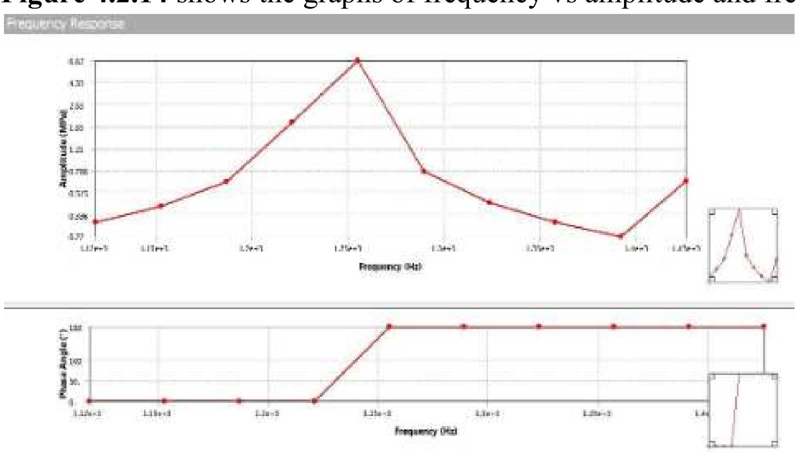


Figure 4.2.13: Frequency vs Amplitude and Phase angle for Ti6 Al 4V

Frequency response stress:

Figure 4.2.14 shows the graphs of frequency vs amplitude and frequency vs phase angle.



RESULTS:

Static Structural Analysis:

Table 5.1:Equivalent Stress for both existing and proposed designs

S.no	**Material**	**Stress (MPa)**	
		Existing Design	**Proposed Design**
1	Inconel740	1650.7	1329
2	Ti6Al 4V alloy	929.25	722.06

Figure 5.1: Graphical comparison stress obtained for both existing and proposed designs

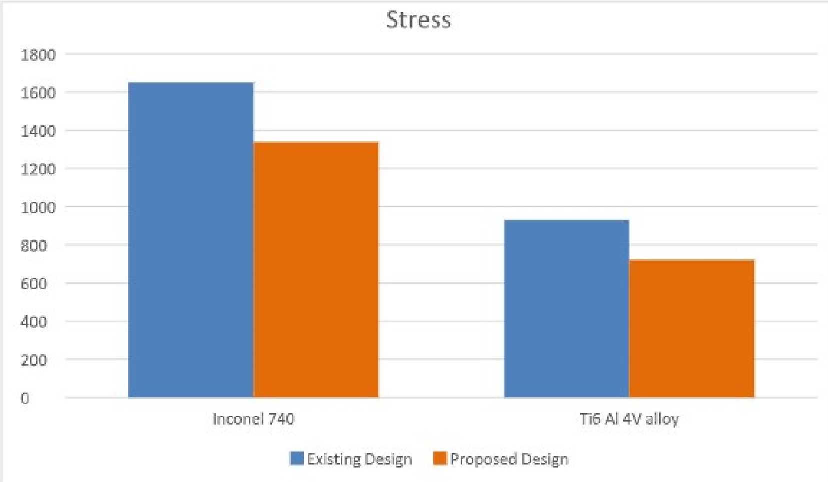


Table 5.2: Equivalent Strain for both existing and proposed designs

S.no	**Material**	**Strain**	
		Existing Design	**Proposed Design**
1	Inconel740	0.007068	0.006387
2	Ti6 Al 4V alloy	0.0078467	0.0078467

Figure 5.2:Graphical Comparison of strains obtained for both existing and proposed designs

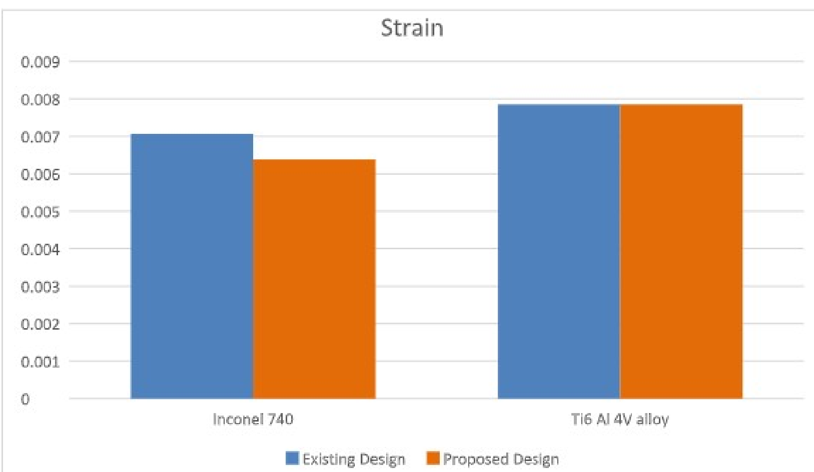


Figure 5.3 Total Deformation for both existing and proposed designs

S.no	**Material**	**Total Deformation(mm)**	
		Existing Design	**Proposed Design**
1	Inconel740	1.5847	0.87748
2	Ti6Al 4V alloy	1.4801	0.84578

Figure 5.3: Graphical comparison of total deformation obtained for both existing and proposed designs

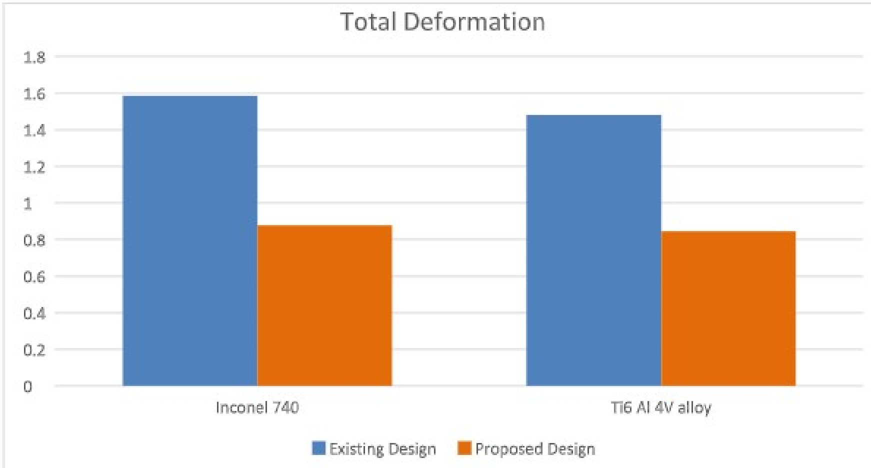
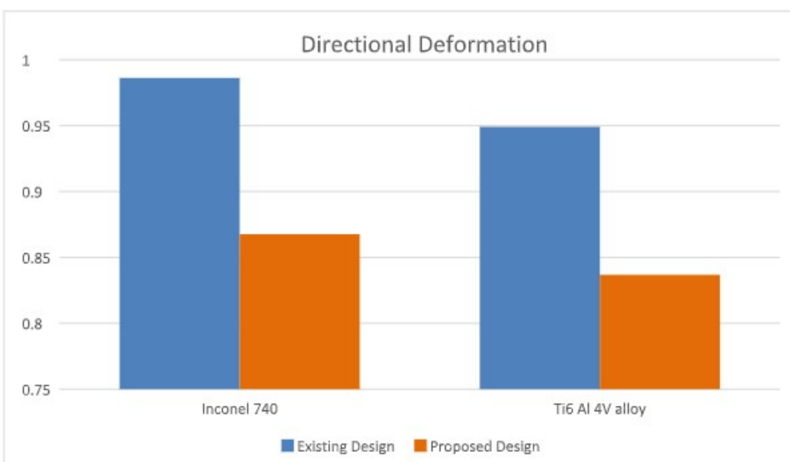


Table 5.4: Directional Deformation For both existing and proposed design

S.no	Material	Direction Deformation(mm)	
		Existing Design	**Proposed Design**
1	Inconel740	0.98619	0.86762
2	Ti6Al 4V alloy	0.94908	0.83679



Harmonic Analysis:

Study of vibrational response on two different designs of turbine blisk in which one design is considered from the data obtained from the literature survey and the other design has been developed for this analysis, subjected to an external excitation which is harmonic in nature has been conducted and the results obtained in the analysis represented as follows.

Table5.5depictsthenaturalfrequenciesalongsidetheirmaximumshearstressvaluesforboththeexistingand proposed designs and for four different materials considered.

Table 5.5: Maximum Shear Stress And Natural Frequencies

S.no	Material	Frequency(Hz)		Shear Stress (MPa)	
		Existing Design	**Proposed Design**	**Existing Design**	**Proposed Design**
1	Inconel740	1485.2	1437.7	19.932	31.355
2	Ti6 Al 4V alloy	1472.7	1425.8	16.949	54.703

CONCLUSION:

CAD model of turbine is generated using CATIA, and Static Structural and Modal Analysis is done in ANSYS Software on the different models and the results are tabulated and graphs are shown.

- The Static Structural study in the exiting model uses two different materials: Inconel740 and Ti6 Al 4V alloy..
- The material with Ti6 Al 4V alloy has the less Stress and Strain when compared to the Inconel 740.It can be observed that the material Ti6 Al 4V alloy has lower values of Total Deformation and Directional Deformation than the Inconel 740.
- It can be inferred from the above discussions that if the stresses, deformation and material cost are considered, then the proposed model utilizing Ti6 Al 4V alloy can be selected.

REFERENCES:

1. Theju V, Uday PS, PLV Gopinath Reddy, C.J. Manjunath, “Design and Analysis of Gas Turbine
Blade”, International Journal of Innovative Research in Science, Engineering and Technology (An
ISO 3297:2007 Certified Organization) Vol.3, Issue 6, June 2014.
2. Majid RezazadehReyhani, Mohammad Alizadeh, AlirezaFathi, HiwaKhaledi, Turbine blade temperature calculation and life estimation - a sensitivity analysis, Propulsion and Power Research, 2(2):148–161, 2013.
3. Arthur Holms, Richard D. Faldetta, Effect of Temperature Distribution and Elastuc properties of
materials on gas turbine disk stresses, Report no. 864,2008.
4. AmrElhefny, Guozhu Liang, Stress and deformation of rocket gas turbine disc under different loads
using finite element modelling, Propulsion and Power Research, 2(1):38–49, 2013.
5. David P. Gutzwiller, Mark G. Turner, Rapid low fidelity turbo machinery disk optimization, Advances in Engineering Software, 779–791, 2010.
6. M. B. Millenson and S S Manson, Determination of stresses in gas turbine disks subjected to
plastic flow and creep, Report no. 864,2010.
7. Amr M.S. El-Hefny, Mustafa Arafa, A.R. Ragab and S.M. El-Raghy,Stress analysis of a gas turbine rotor using finite element modelling, Production Engineering &Design For Development,

PEDD7, February 7 – 9, 2006
8. PrathapanayakaRajeevalochanam, S NAgnimitraSunkara, VeeraseshakumarChappati, BalaVenkata Ganesh Banda, BalamuruganMayandi and Kishor Kumar, Design of highly loaded
turbine stage for small gas turbine engine, ASME Turbo Expo, June 13- 17, 2016.
9. Naveen Kumar Sahi, Mrs. Jyoti Kale - Thermal Analysis Of Gas Turbine Rotor Blade Using Finite
Element Analysis
10. Nallappan M, Malarkannan ,Vinothkumar V.S - Structural & Thermal Analysis of Gas Turbine
Blade by Using Ansys, Annals of R.S.C.B., ISSN:1583-6258, Vol. 24, Issue 2, 2020, Pages. 1875
– 1891.
11. P.V.Durga Prasad,S.Polinaidu, R.Haranath, Ch.Venkata Rao - Model Analysis of Gas Turbine
Blade with Different Metals by Using Ansys 11.0, International Journal of Engineering, Science and
Mathematics Vol. 6 Issue 8, December 2017 (Special Issue) ISSN: 2320-0294.
12. Chaitanya Krishna Patsa , Subhani Mohammed-Structural Analysis of Super Alloy Gas Turbine
Blade using FEA,International Journal of Engineering Research & Technology (IJERT) Vol. 3 Issue
1, January – 2014, IJERT ISSN: 2278-0181.
13. Kalapala Prasad', B. Anjaneya Prasad, M. Anandarao "Numerical Analysis of Twisted Aerofoil Gas Turbine Blade.
14. Kalpala Prasad, B. Anjaneya Prasad and M. Anandarao, "Optimization of Twisted Aero-Foil Blade
Angle of a Structural Gas Turbine Assembly, International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 12, Number 15 (2017).
15. V. Nagabushan Rao, I.N.Niranjan Kumar, B. Vamsi Krishna, N. Madhulatha "Analytical comparative study of gas turbine blade materials used in marine
applications using FEA techniques", International Journal of Engineering Sciences & Management
Research
16. Michael T. Tong, Ian Halliwell, Louis J. Ghosn, A computer code for gas turbine engine weight and disk life estimation, ASME Turbo Expo, June 2012
17. S. Alka, Gunji, Suresh, Simhachalam, Naidul, "Modeling and Analysis on Gas Turbine Rotar Blade", International Journal of Engineering and Innovative Technology (IJEIT) Volume4, Issue 12, June 2015.
18. Mehdi TofighiNaeem, Seyed Ali Jazayeri, NesaRezamahdi, K. N. Toosi University of Technology,
"Failure Analysis of Gas Turbine Blades", Paper 120, ENG 108. Proceedings of the 2008 IJME International Conference ISBN 978-1-60643-379-9.

19. P.V. Krishnakanth, G. Narasaraju, R.D.V. Prasad, R. SaiSrinu, " Structural & Thermal analysis of Gas Turbine Blade by Using F.E.M", International Journal of Scientific Research Engineering & Technology (IJSRET), volume 2 Issue, May 2013
20. Haresh Pal Singh, Ashish Rawat, AviRajmanval computational analysis of a gas turbine blade with different materials.