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RESEARCH ARTICLE

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DESIGN AND ANALYSIS OF TURBOCHARGERS

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ABSTRACT

In these days of technological advancements in Automobile sector where mans penchant is to develop technologies that can improve the power and mileage of the vehicle. TURBOCHARGER is one such exotic gadget. Any engine needs air for combustion of fuel. It is the Air-Fuel ratio that decides the performance of an engine. Hence supply of air is an important task.. A TURBO CHARGER is basically an exhaust gas driven air compressor which compresses the ambient air and sent this pre compressed air into the cylinder during suction stroke. It consists of two basic parts, the exhaust gas driven turbine and its housing, and the air compressor and its housing. The exhaust air from the engine spins the turbine and leaves while the compressor wheel, connected to the common shaft of turbine and compressor, compresses the ambient air and feeds it to the engine. Modern turbochargers are complex assemblies of various accessories attached to it like waste gate, blow off valves, oil and water plumbing,. Modeling and Analysis of the turbine and compressor wheel of a turbocharger is presented in our project. For modeling, we have used the real time modeling package Pro Engineer (Pro-E) and for analysis we have used the prevalent FEM analysis package ANSYS 10.Our Analysis includes both Structural and Thermal Analysis of the turbine and compressor wheel. Special focus on the results part has been given in order to help designers. Various contour plots has been studied and presented so as to acquire proper idea about the deflections and stress distributions on the turbine blade. In case of thermal Analysis, Nodal temperatures and the distribution of the temperature across the turbine blade has been obtained and explained. An attempt is also made to suggest the best material for an impeller of a turbocharger by comparing the results obtained for three different materials (wrought aluminum alloy 2011, incoloy alloy 909, wrought aluminum copper alloy for compressor and inconel alloy 740, inconel alloy 783, wrought aluminum alloy 2219 for turbine impeller. Based on the results best material is recommended for the impeller of a turbocharger.

KEY WORDS: Turbo chargers,Pro E,Ansiys ,Compressor

I. INTRODUCTION TO TURBOCHARGERS

A turbocharger, or turbo, is an air compressor used for forced-induction of an internal combustion engine. Like a supercharger, the purpose of a turbocharger is to increase the mass of air entering the engine to create more power. However, a turbocharger differs in that the compressor is powered by a turbine driven by the engine's own exhaust gases. Their total design, as in the other turbo machines, involves different types of analyses such as mechanical, thermal and acoustical. Engineers and researchers are still searching for ways to improve their designs while keeping the balance between the needs and costs.

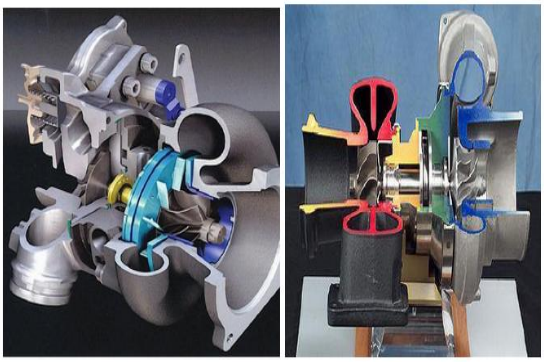


Fig. 1.1.1: Turbo charger cross section

Turbochargers are a class of turbo machinery intended to increase the power of internal Combustion engines. This is accomplished by increasing the pressure of intake air, allowing more fuel to be combusted. In the late 19th century, Rudolf Diesel and Gottlieb Daimler experimented with pre-compressing air to increase the power output and fuel efficiency. The first exhaust gas turbocharger was completed in 1925 by the Swiss engineer Alfred Buchi who introduced a prototype to increase the power of a diesel engine by a reported 40%. The idea of turbo charging at that time was not widely accepted. However, in the last few decades, it has become essential in almost all diesel engines with the exception of very small diesel engines. Their limited use in gasoline engines has also resulted in a substantial boost in power output and efficiency. Turbocharger is a very unique product. One of the main problems with turbocharger is the angle of curvature at the inlet of curve inducer blades is hard to produce using advanced machining technique. It needs sharp edge and strength to sustain it life. To sustain turbocharger life, material selection is very important. Different material provides different characteristic of turbocharger.

Turbo-charging lost its edge towards the end of the '80s and today this technology is used only in select performance cars. Porsche, for example, is all set to build a turbo-charged version of its all-new 911(water-cooled) with added performance. Turbo engines were banned in Formula One too with the idea of restricting the performance of the cars (and thereby making them safer too). There are many who consider this a backward step in the world of Formula One, which is considered to represent the 'tomorrow' of automotive technology.

To increase the power of an engine, it is possible to increase either the cubic capacity or engine speed. Another method consists of feeding it more fuel. This is the solution, known as supercharging, which is performed by the turbocharger. However, this cannot be achieved by simply increasing the quantity of petrol or diesel fuel injected during each cycle. For the engine to operate correctly, it is important for it to maintain the very precise proportioning of the air/fuel mix. If this does not happen, combustion is incomplete, which results in a sharp increase in the rate of unburned components and a fall-off in engine efficiency. Such consequences would be completely at odds with the required objective.

The purpose of the turbo is therefore to feed more air into the cylinders in order to maintain the correct proportions of the mix, by “just” compressing it. This is equivalent to giving the engine a “virtual” cubic capacity higher than its real cubic capacity. Turbo-charging, simply, is a method of increasing the output of the engine without increasing its size. The basic principle was simple and was already being used in big diesel engines .For example, one can buy chips that can boost power by 100 bhp for some Japanese Cars, such as the Nissan Skyline. Moreover, on-road speeds were being restricted all over the world. Though most of the sports cars today are capable of doing more, they are restricted electronically not to exceed 250kmph even in autobahn-blessed Germany.

The basic principle was simple and was already being used in big diesel engines. European car makers installed small turbines turned by the exhaust gases of the same engine. This turbine compressed the air that went on to the combustion chamber, thus ensuring a bigger explosion and An incremental boost in power. The fuel injection system, on its part, made sure that only a definite quantity of fuel went into the combustion chamber.

It works like this - on starting, exhaust gases spin the turbine and thus activate a compressor that pressurizes the air. This pressurized air from the turbocharger is then sent through a duct to an aircooled intercooler, which lowers the temperature of the intake charge and thus increases its density. The air-cooled intercoolers receive air through separate intakes and that explains the small scoops and louvers usually found on the hoods of turbo-charged cars. Modern turbo-diesel engines also make use of a temperature sensitive, motor-driven fan which boosts airflow at low engine speeds or when the intake air temperature is high.

II. INTRODUCTION TO PRO-E

The feature-based parametric modeling technique enables the designer to incorporate the original design intent into the construction of the model. The word parametric means the geometric definitions of the design, such as dimensions, can be varied at any time in the design process. Parametric modeling is accomplished by identifying and creating the key features of the design with the aid of computer software. The design variables, described in the sketches and features, can be used to quickly modify/update the design. In Pro/ENGINEER, the parametric part modeling process involves the following steps:

1. Set up Units and Basic Datum Geometry.
2. Determine the type of the base feature, the first solid feature, of the design. Note that Extrude, Revolve, or Sweep operations are the most common types of base features.
3. Create a rough two-dimensional sketch of the basic shape of the base feature of the design.
4. Apply/modify constraints and dimensions to the two-dimensional sketch.
5. Transform the two-dimensional parametric sketch into a 3D feature.
6. Add additional parametric features by identifying feature relations and complete the design.
7. Perform analyses/simulations, such as finite element analysis (FEA) or cutter path generation (CNC), on the computer model and refine the design as needed.
8. Document the design by creating the desired 2D/3D drawings.

STARTING Pro/E

To start Pro/E on a Windows machine, there may be an icon on your desktop or you may have to look in the Start menu at the bottom left of the screen on the Windows taskbar. The program takes a while to load, so be patient. The start-up is complete when your screen looks like the following figure, which is a default Pro/E screen.

Fig. 1.2.1: Default Pro/E Wildfire screen

Now, look for the icon under your menu to start a new application. Press the icon; or you may use the menu **FILE > New**. Either way, you should be able to launch the following window

Fig. 1.2.2: The pop-up window to start a new application

You may type the name [housing] to replace the default name "prt0001". In this section, we are going to create the first feature of a part called "housing", which is one of the components of a disc brake assembly that we are going to create in the lab. The focus of this section, however, is on the introduction of Pro/E environment rather than the modeling techniques. More modeling techniques will be described in later sections. After clicking the OK button, you should see the window shown inFigure , which is pretty much self-explanatory. You are encouraged to move your mouse cursor on top of each shortcut button and read the description from the command description window. The filter setting selection is for the convenience of picking a feature on the main graphics screen. The default (or the lazy way) is to leave it as smart

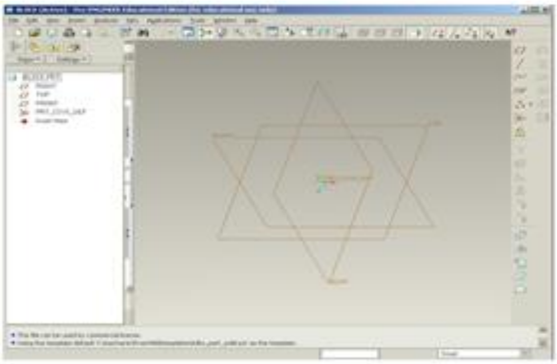


Fig. 1.2.3: Pro/E screen

BEGIN TO WORK IN Pro/E

The main graphics windows shows three orthogonal planes, named TOP, FRONT and RIGHT, and a coordinate system. These planes are called datum planes, representing the 3-D world. These planes are very useful as reference planes when creating features and assembling components. Their advantages are not obvious when modeling simple parts, and in fact new users find these planes annoying. Whatever you feel now, my advice is to get yourself used to these "annoying" planes from above figure

MOUSE FUNCTIONS

Before we start with the hard job (modeling), you should know about some tricks of the mouse. Wildfire is meant to be used with a 3-button mouse. If it has a middle scroll, it is actually better and you are lucky. If your mouse is a 2-button one, try to use the <shift> key plus the left mouse button (LMB) simultaneously as an equivalent to the middle mouse button (MMB). If it doesn't work, talk to your system administrator.

Most selections of menu commands, shortcut buttons, and so on are performed by clicking the left mouse button (LMB). In this tutorial, whenever you "select", "click", or "pick" a command or entity, this is done with the LMB unless otherwise directed. The functions controlling the view of the object in the graphics window are all associated with the MMB. These are the important Spin, Pan, and Zoom functions.

WORKING PRINCIPLE

A turbocharger, often called a turbo, is a small radial fan pump driven by the energy of the exhaust flow of an engine. A turbocharger consists of a turbine and a compressor on a shared shaft. The turbine inlet receives exhaust gases from the engine causing the turbine wheel to rotate. This rotation drives the compressor, compressing ambient air and delivering it to the air intake manifold of the engine at higher pressure, resulting in a greater mass of air entering each cylinder.

A naturally aspirated automobile engine uses only the downward stroke of a piston to create an area of low pressure in order to draw air into the cylinder through the intake valves. Because the pressure in the atmosphere is no more than 1 bar, there ultimately will be a limit to the pressure difference across the intake valves and thus the amount of airflow entering the combustion chamber. This ability to fill the cylinder with air is its volumetric efficiency. Because the turbocharger increases the pressure at the point where air is entering the cylinder, greater oxygen makes it possible to add more fuel, increasing the power and torque output of the engine. Because the pressure in the cylinder must not go too high to avoid detonation and physical damage, the intake pressure must be controlled by controlling the rotational speed of the turbocharger.

In the automotive industry a turbocharger is widely used among car fanatics to improve engine efficiency. A car turbocharger works by having exhaust gases from the engine drive the turbine which powers a compressor that takes clean ambient air back into the engine to increase volumetric efficiency. Since turbochargers are massed manufactured, the cost is relatively inexpensive and exhibits high efficiency given the correct working conditions.

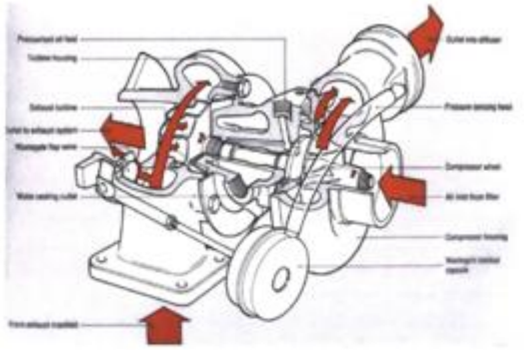


Fig. 3.1.1: Section view of Engine with Turbo charger

As the compressor spins, it raises the pressure of the incoming air from the air intake. The high pressure air is often directed through a charged air cooler (also known as an intercooler) to further raise the density of the air. The high density air is then ducted into the cylinder and combustion occurs as normal. The larger mass of air, however, allows for more fuel to be burned in the same volume, and thus more power to be extracted by the piston during the power stroke, transmitting more power to the crankshaft and eventually the wheels. The cycle of an automotive Turbocharger follows closely to that of an aircraft turbine engine and thus allows for the correlation between an aircraft engine and that of the automotive based turbine engine to be created and thus implemented in the Propulsion course at Cal Poly San Luis Obispo.

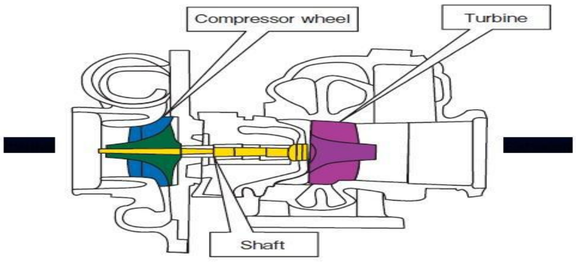


Fig. 3.1.2: Compressor and Turbine of the Turbochager

Turbocharged engines made a comeback during the oil shortage in the early 70's due to their inherent increase in fuel efficiency. The advances in rotor dynamic analysis using up-todate computation technology have made the dynamics of a turbocharger's rotor-bearing system a rich area for investigation. Vendors are now looking for more dynamically stable turbochargers to benefit business and increase customer satisfaction. More contributions are needed to have optimum design stability, while assuring continued low cost production.

They also require a high level of reliability and efficiency in order to be cost-effective. There are several ways to reduce the price of turbochargers; the easiest way is to keep the design as simple as possible. A common design assembly in an automotive turbocharger consists of a simple inboard bearing mounting arrangement with a radial outflow compressor and a radial inflow turbine on a single shaft.

Future Scope

1. The Efficiency of the engine can be increased.
2. The Emissions from the engine can be controlled.
3. Fuel consumption is less when compared to ordinary vehicle.
4. Experimental Analysis of the Engine with Turbo charger.
5. A proto type of the turbocharger could be fabricated by suitable processes and tested by properly installing it to a two -wheeler.

ANALYSIS OF TURBOCHARGER

For this work, the geometry was built in Pro-E CAD software, which can be seen in the below Figure. This geometry was imported into ANSYS modeling environment by converting CAD file into IGES format. Cyclic symmetry was utilized to decrease the computational requirement for analyses. Complete turbine was divided into 14 cyclic symmetric sectors according to the number of blades in the turbine.

For Compressor impeller 3 materials investigation is done using structural analysis and modal analysis for turbine impeller 3 materials investigation is done using structural analysis, modal analysis and thermal analysis. The variation of von mises stress, Von mises strain, and deformation for three different materials of compressor impellers, using structural analysis.

Fig. 4.1.1: Model of the Turbo Charger

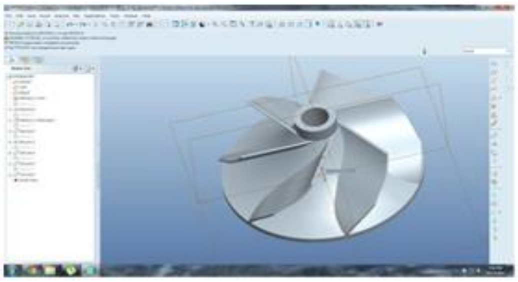


Fig. 4.1.2: Actual model of turbocharger compressor wheel

Properties	Wrought Aluminum alloy 2011	Incoloy alloy 909	Wrought aluminum copper alloy 2014
Von mises stress (MPa)	42.366	32.981	49.294
Von mises strain (MM)	0.0005967	0.00020743	0.00044813
Deformation (MM)	0.1226	0.013233	0.088051

Table 4.1.1: Structural analysis for compressor impeller

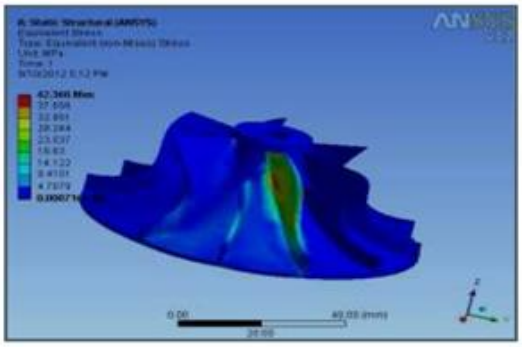


Fig. 4.1.3: Wrought aluminum alloy 2011 Von mises stress

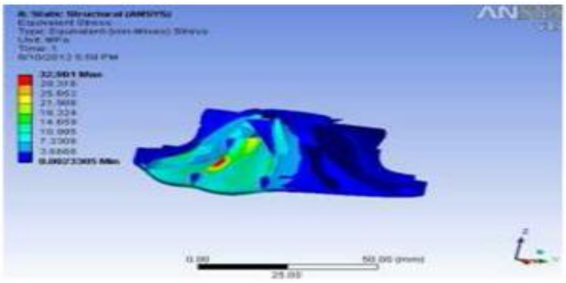


Fig. 4.1.4: Incoloy alloy 909 Von mises stress

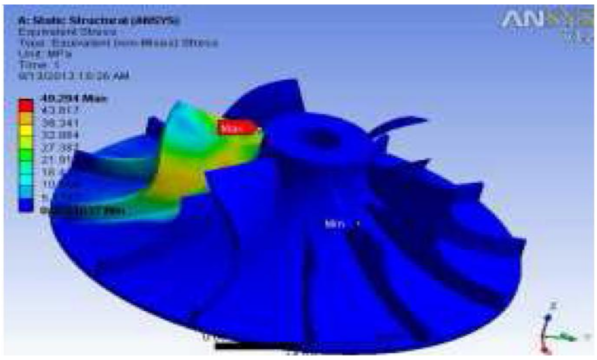


Fig. 4.1.5: Wrought aluminum copper alloy 2014 von mises stress

The variation of frequency and deflection for three different materials of compressor impeller using modal analysis.

Table 4.1.2: Modal analysis for compressor impeller

Type of material	Frequency (Hz)			Deflection (mm)		
	1	2	3	1	2	3
Wrought aluminum alloy 2011	400.3	400.35	400.41	49.451	31.441	47.733
Incoloy alloy 909	482.6	483.65	619	30.873	30.612	29.037
Wrought aluminimum copper alloy 2014	319	319.02	410.78	1.4484	1.4332	1.4102

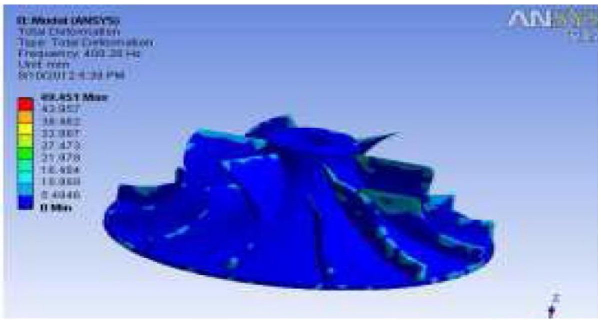


Fig. 4.1.6: Wrought aluminum alloy 2011 frequency deflection

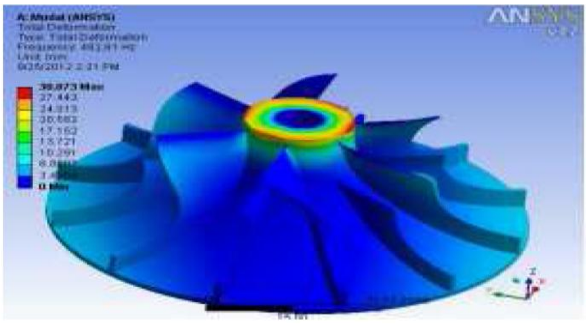


Fig. 4.1.7: Incoloy alloy 909 frequency deflection

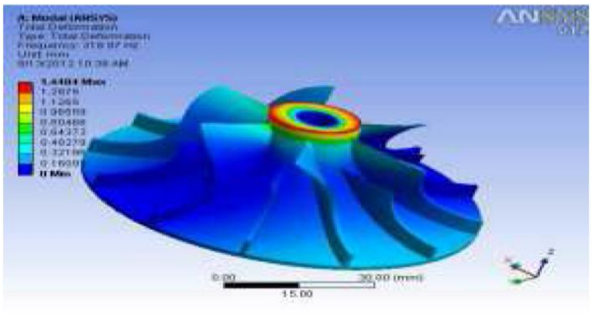
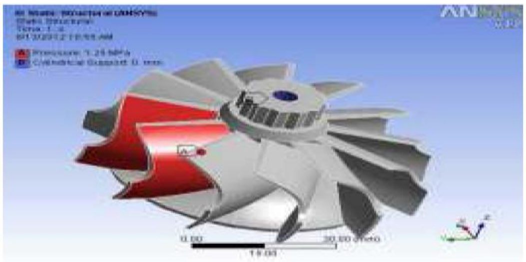


Fig. 4.1.8: Wrought aluminum copper alloy 2014 frequency deflection

The variation of von mises stress, Von mises strain, and deformation for three different materials of turbine impeller, using structural analysis.

Table 4.1.3: Structural analysis for turbine impeller

Properties	Inconel alloy 740	Inconel alloy 783	Wrought aluminum copper alloy 2219
Von mises stress (MPa)	171.01	283.7	204.73
Von mises strain (MM)	0.002443	0.001419	0.0009749
Deformation (MM)	0.35753	0.21337	0.12693



Fig, 4.1.9: Structural analysis for turbine impeller

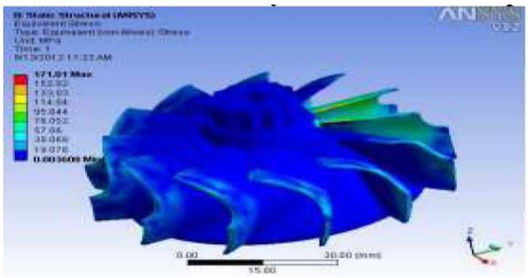


Fig. 4.1.10: Inconel alloy 740 von mises stress

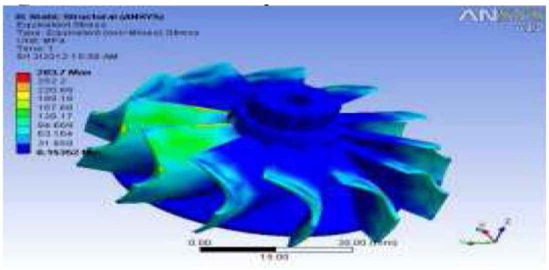


Fig. 4.1.11: Inconel alloy 783 von mises stress

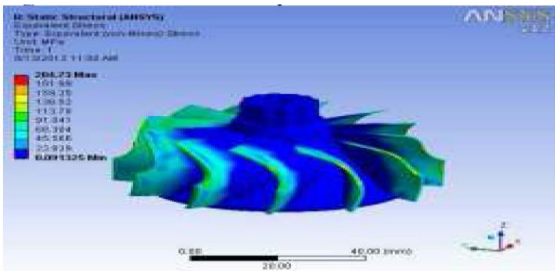


Fig. 4.1.12: Wrought aluminum alloy 2219 von mises stress

The variation of frequency and deflection for three different materials of turbine impeller using modal analysis.

Table 4.1.4. Modal analysis for turbine impeller

Type of material	Frequency (Hz)			Deflection (mm)		
	1	2	3	1	2	3
Inconel alloy 740	773.58	775.22	783.5	235.53	254.67	305.8
Inconel alloy 783	679.12	680.56	687.842	206.77	223.57	268.46
Wrought aluminium copper alloy 2219	887.16	889.04	898.55	270.12	292.06	350.7

The variation of total heat flux and direction heat flux for three different materials of turbine impeller

Table 4.1.5: Thermal analysis for turbine impeller

Properties Units: w/mm^2		Inconel alloy 740	Inconel alloy 783	Wrought aluminium 2219
Total heat flux		0.70635	1.1219	11.773
Direction heat flux	Axis			
	X	0.63139	1.0028	10.523
	Y	0.49816	0.7912	8.3027
	Z	0.38801	0.61625	6.4668

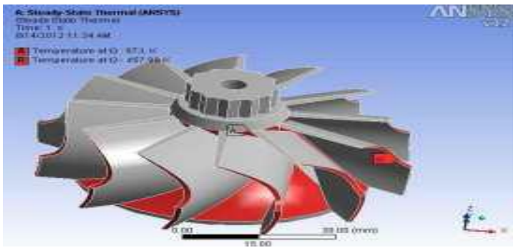


Fig. 4.1.13: Thermal analysis for turbine impeller

RESULTS AND DISCUSSIONS

5.1 COMPRESSOR

Effect of von mises stresses on compressor impeller materials

The comparison of von mises stresses with respect to compressor materials .the maximum von mises stresses are induced in wrought aluminum copper alloy 2014,when compared to the wrought aluminum alloy 2011 and incoloy alloy 909.where a maximum value of von mises stresses 49.294 Mpa was noticed to wrought aluminium copper alloy 2014 and minimum value of von mises stresses 32.981 MPA was noticed for incoloy alloy 909.

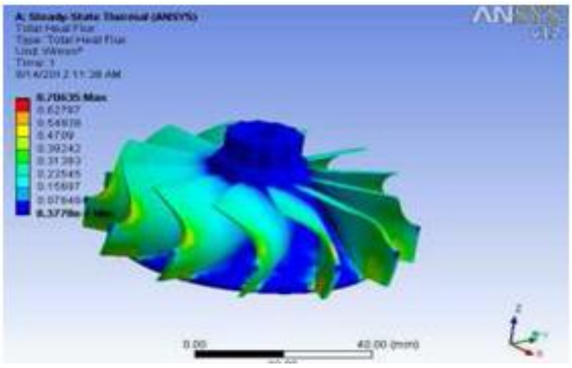


Fig. 4.1.14: Inconel alloy 740 Total heat flux

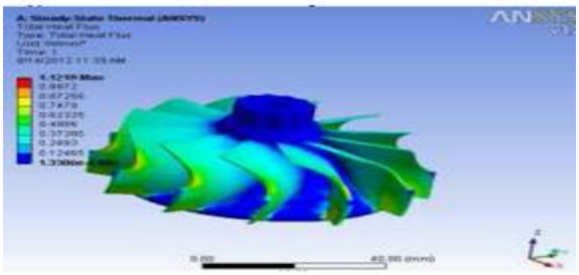


Fig. 4.1.15: Inconel alloy 783 total heat flux

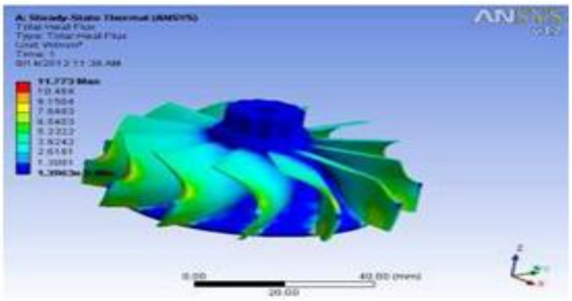
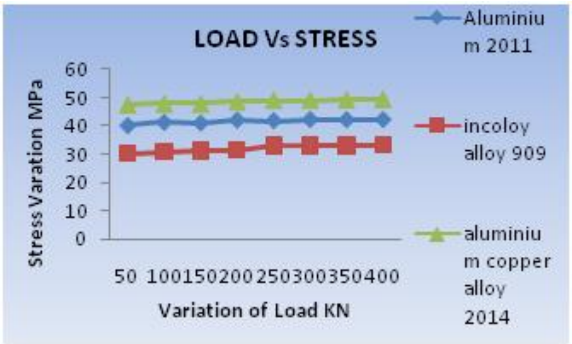


Fig. 4.1.16: Wrought aluminum alloy 2219 total heat flux

Table 5.1.1: Stress with respective load for compressor material

Sl. No	Load	Aluminium 2011	incoloy alloy 909	aluminium copper alloy 2014
1	50	40.236	30.265	47.258
2	100	41.369	30.569	47.652
3	150	41.123	31.125	47.695
4	200	42.147	31.256	48.365
5	250	41.987	32.911	48.897
6	300	42.366	32.923	48.951
7	350	42.3	32.935	49.125
8	400	42.345	32.981	49.294



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3	150	41.123	31.125	47.695
4	200	42.147	31.256	48.365
5	250	41.987	32.911	48.897
6	300	42.366	32.923	48.951
7	350	42.3	32.935	49.125
8	400	42.345	32.981	49.294

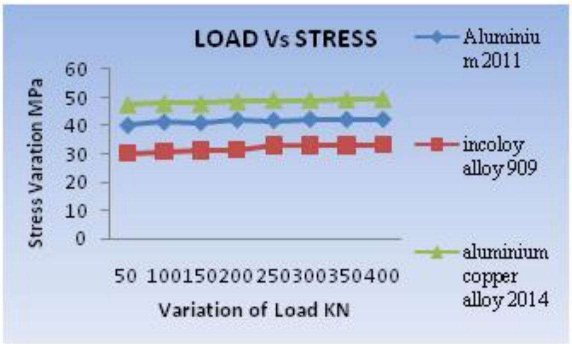


Table 5.1.2: Strain with respective load for compressor material

Sl. No	Load	Aluminium 2011	incoloy alloy 909	aluminium copper alloy 2014
1	50	0.000515	0.000159	0.000378
2	100	0.000527	0.0001659	0.000388
3	150	0.000538	0.0001728	0.000398
4	200	0.00055	0.0001798	0.0004081
5	250	0.000562	0.0001867	0.0004181
6	300	0.000573	0.0001936	0.0004281
7	350	0.000585	0.0002005	0.0004381
8	400	0.000597	0.0002074	0.0004481

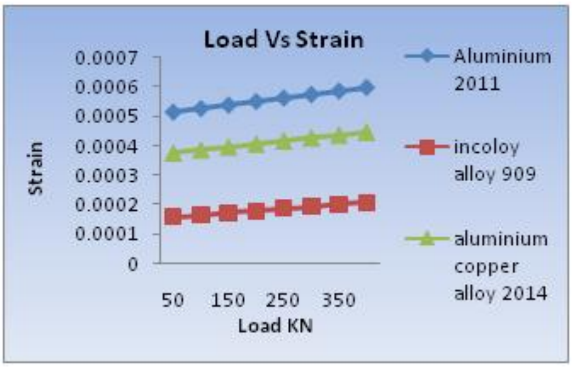


Table 5.1.3: Deformation with respective load for compressor material

Sl. No	load	Aluminium 2011	incoloy alloy 909	aluminium copper alloy 2014
1	50	0.1051	0.012477	0.081128
2	100	0.1076	0.012585	0.082117
3	150	0.1101	0.012693	0.083106
4	200	0.1126	0.012801	0.084095
5	250	0.1151	0.012909	0.085084
6	300	0.1176	0.013017	0.086073
7	350	0.1201	0.013125	0.087062
8	400	0.1226	0.013233	0.088051

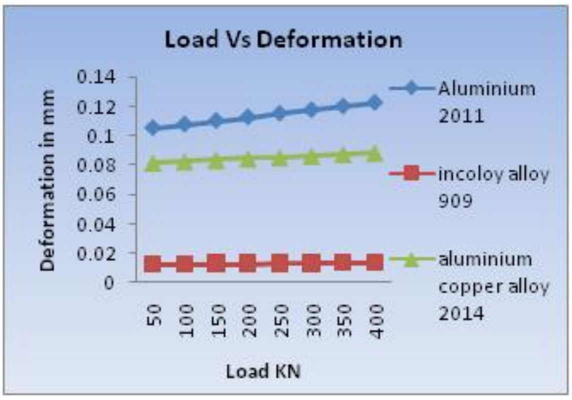


Table 5.1.4: Stress with respective load for Turbain material

Sl. No	load	Inconel alloy 740	Inconel alloy 783	Wrought aluminum alloy 2219
1	50	167.86	266.41	2219.54
2	100	168.31	268.88	197.71
3	150	168.76	271.35	198.88
4	200	169.21	273.82	200.05
5	250	169.66	276.29	201.22
6	300	170.11	278.76	202.39
7	350	170.56	281.23	203.56
8	400	171.01	283.7	204.73

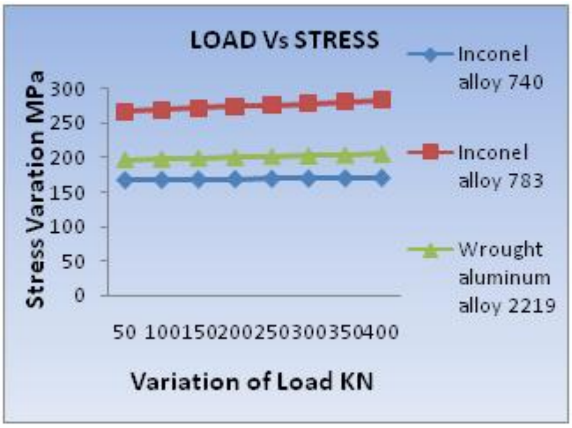
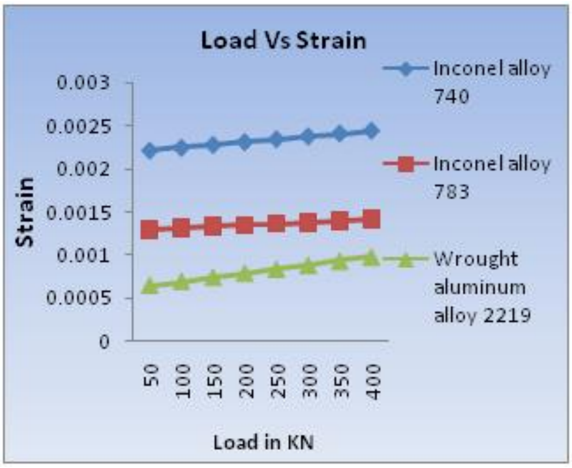


Table 5.1.5: Strain with respective load for Turbain material

Sl. No	load	Inconel alloy 740	Inconel alloy 783	Wrought aluminum alloy 2219
1	50	0.002219	0.001296	0.00064
2	100	0.002251	0.001314	0.000688
3	150	0.002283	0.001331	0.000735
4	200	0.002315	0.001349	0.000783
5	250	0.002347	0.001366	0.000831
6	300	0.002379	0.001384	0.000879
7	350	0.002411	0.001401	0.000927
8	400	0.002443	0.001419	0.000975

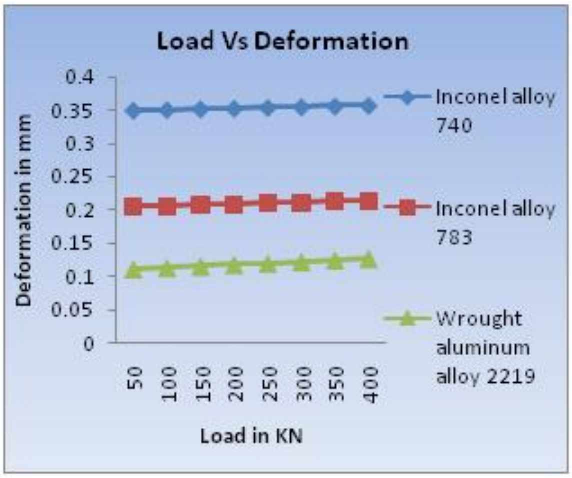


Effect of von mises strain on compressor impeller materials Von mises strain with respect to compressor materials.

It can be seen that the maximum von mises strain are induced in wrought aluminium alloy 2011.when compared to the incoloy alloy 909 and wrought aluminium copper alloy 2014. Where maximum value of von mises strain 0.0005967 mm was noticed for wrought aluminium alloy 2011 and minimum value of von mises strain 0.00020743 mm was noticed for incoloy alloy 909

Table 5.1.6: Deformation with respective load for a Turbain material

Sl. No	load	Inconel alloy 740	Inconel alloy 783	Wrought aluminum alloy 2219
1	50	0.35025	0.20497	0.11069
2	100	0.35129	0.20617	0.11301
3	150	0.35233	0.20737	0.11533
4	200	0.35337	0.20857	0.11765
5	250	0.35441	0.20977	0.11997
6	300	0.35545	0.21097	0.12229
7	350	0.35649	0.21217	0.12461
8	400	0.35753	0.21337	0.12693



Effect of displacement of the compressor materials

Comparison of displacement with respect to compressor materials. It can be seen that the maximum displacement are induced in wrought aluminium alloy 2011.when compared with incoloy alloy 909 and wrought aluminium copper alloy 2014.where a maximum value of displacement 0.1226 mm was noticed to wrought aluminium alloy 2011,and minimum value of displacement 0.013233 mm was noticed to incoloy alloy 909

TURBINE

Effect of von mises stresses on turbine material

The Comparison of von mises stresses with respect to turbine materials. It can be seen that the maximum von mises stresses are induced in inconel alloy 783. when compared with inconel alloy 740 and wrought aluminium alloy 2219 . Where a maximum value of von mises stresses 283.7 Mpa was noticed for inconel alloy 783 and minimum value 171.01Mpa was noticed for inconel alloy 740.

Effect of von mises strain on turbine material

The comparison of von mises strain with respect to turbine materials. it can be seen that the maximum von mises strain are induced in inconel alloy 740 when compared with inconel alloy 783 and wrought aluminium alloy 2219. Where a maximum value of von mises strain 0.002443 mm was noticed for inconel alloy 740 and minimum value 0.0009749 mm was noticed for wrought aluminium alloy 2219.

Effect of displacement of turbine materials

The comparison of displacement with respect to turbine materials .it can be seen that the maximum displacement are induced in inconel alloy 740 when compared with inconel alloy 783 and wrought aluminium alloy 2219.when a maximum value of displacement 0.35753 mm was noticed for inconel alloy 783 and minimum value 0.12693 mm was noticed for wrought aluminium alloy 2219.

Effect of total heat flux on turbine impeller

The total heat flux of a turbine impeller on three different materials .the maximum total heat flux occurred in wrought aluminum alloy 2219 and the value is 11.773 w/mm2,the minimum total heat flux occurred in inconel alloy 740 and the value is 0.70635 w/mm2.

CONCLUSION

For Compressor the minimum von mises stress (32.981 MPA) is obtained for the material incoloy alloy 909.And the maximum frequency (482.61 HZ) is obtained for the material incoloy alloy 909.For Turbine the minimum von mises stress (171.01MPA) is obtained for the material inconel alloy 740.And in the frequency comparing to the compressor maximum frequency (482.61 HZ) for incoloy alloy 909. And the turbine three materials frequencies inconel alloy 740 - (773.58 HZ); inconel alloy 783-(679.12 HZ); wrought aluminum alloy 2219 – (887.16 HZ); are more than compressor maximum frequency (482.61 HZ) . so that the compressor material is withstand up to the (482.61HZ) with the minimum stress (32.981 MPA) for the compressor material incoloy alloy 909 and the turbine material is withstand up to the (773.58 HZ) with the minimum stress (171.01 MPA) for the turbine material inconel alloy 740.

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