DESIGN AND ANALYSIS OF TURBOCHARGER IMPELLER FOR DIESEL ENGINE

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Abstract— When people talk about race cars or high-performance sports cars, the topic of turbocharger usually comes up. Turbocharger also appear on large diesel engines. A turbo can significantly boost an engine's horsepower without significantly increasing its weight, which is the huge benefit that makes turbocharger so popular.

Turbochargers are a type of forced induction system. They compress the air into the engine. The advantage of compressing air is that it lets the engine squeeze more air into a cylinder, and more air means more fuel can be added. Therefore, getting more power from each cylinder.

Here in this project we are designing the compressor impeller by using Creo and doing analysis by using FEA package. The main aim of the project is to increase the life of compressor wheel for this we are changing the material and also we are changing the existing design. By comparing the result we will get the best model from this data we suggests the design modifications to the company to improve the life of the compressor impeller.

Keywords— Turbocharger Impeller, Titanium alloy, Aluminum Alloy, CFD, ANSYS.

I. INTRODUCTION

A turbocharger is a turbine driven forced induction device that increases an internal combustion engines efficiency and power output by forcing extra air into the combustion chamber. This improvement over a naturally aspirated engines power output is due to the fact that the compressor can force more air and proportionately more fuel into the combustion chamber than atmospheric pressure. Turbochargers were originally known as turbo superchargers when all forced induction device classified as superchargers. Nowadays the terms supercharger applied only to mechanically driven forced induction device. The difference between a turbocharger and a conventional supercharger is that a supercharger is mechanically driven by the engine, often through a belt connected to the crankshaft, whereas a turbocharger is powered by a turbine driven by the engine's exhaust gas. Turbochargers are commonly used on truck, train, car, aircraft, and construction equipment engines.

Turbocharger are widely used in car and commercial vehicles because they allow smaller capacity engines to have improved fuel economy, reduced emission, higher power and considerably higher torque. [18]

II. LITERATURE SURVEY

D. Ramesh Kumar, B. Shanmugasundaram, P. Mohanraj et, al., [2017] in this work the author used different material for the turbine and compressor impeller and investigation has been done by ANSYS and CATIA software. The variation of stresses, strains, and deformation profile of the turbine and compressor impeller has been determined by using the ANSYS software. The authors are used different analysis, to investigate stresses, strains and displacements of the turbine used structural analysis, to investigate the frequency and deflection of the turbine and compressor impeller used modal analysis, to investigate total heat flux and direction heat flux used thermal analysis. The turbine and compressor impeller of a turbocharger will be recommend based on the better material results. They used different material for turbine and compressor, Inconel alloy N06230 and Incoloy alloy A-286 respectively, replace of existing material, Inconel alloy 740 and Incoloy alloy 909 respectively. They concluded that for turbine impeller the minimum von-mises stress, maximum frequency and maximum total heat fluxes is obtained for the Inconel alloy N06230, and for compressor impeller the minimum von-mises stress and maximum frequency is obtained for the Incoloy alloy A-286. So the Incoloy alloy A-286 and Inconel alloy N06230 is the best material for turbocharger impeller to get better efficiency and performance of it. [1]

Shujie Liu, Chi Liu, Yawei Hu, SIbo Gao, Yifan Wang, Hongchao Zhang et, al., [2016] studied about the fatigue life assessment of centrifugal compressor impeller has a critical issue in the industrial practise as well as automotive application. In this study, both centrifugal load and aerodynamic load have beern considered in the analysis of the impeller life using finite element analysis(FEA). The impeller working under an alternating cycle loads and a dynamic load caused by the centrifugal loads, aerodynamic loads, exciting loads, etc. All this loads are combined with impact loads from collision with particles in the medium, the impeller blade suffers multiple failure modes and this failure modes include abrasion, erosion, stress fatigue, and others. This research shown that the fatigue cracking and fractures of impeller blades are the main factors leading to almost fifty percent of the centrifugal compressor operational failure. There are two methods to ascertain the fatigue life of mechanical components. One is to conduct an experiment representing the actual working condition which give obviously accurate result but it is costly and complex process. The other method is the numerical method in which the simulation model and the fatigue parameters are combined to calculate the fatigue life with lower cost and high efficiency. The author concluded that compared to the working condition that set for the simulation, the real operational condition of the FV520B impeller blade is far more complex. And also conclude that there could be much more noise and uncertainties in the fatigue lab experiment that produced error in data, and hence a well designed experiment and data analysis procedure to reduce the error in lab experiment results are highly recommended. [2]

CH.Satyasai Manikanta, S.D.V.V.S.B.Reddy, A.Sirishabhadrakali et, al.,[2016] presents structural analysis of the turbocharger impeller by using different material under different static and dynamic condition to obtaining the stress values and strain values and deformation range. In this study the authors consider design for 30000 rpm of the impeller. The design has mainly focused to reduce the blade size according to the requirements and geometrical modeling is used when designing this impellers of turbocharger. The authors using four different material namely AISI 4063 STEEL, INCONEL 718, TECHNITIUM, TITANIUM 2646. Turbocharger impeller has to withstand high centrifugal loads and high pressures and temperatures when working, So these materials are selected in this paper for impeller depending on their properties. The design was made in CATIA (computer aided three dimensional interactive application) and analysis done in ANSYS workbench software. The author concluded after design and analysis of impeller that Titanium Ti 2646 gives better life for impeller because its having less stress and displacement values compared to Technatium. Its mass properties is half to the base material Inconel 718, So decreased mass and increased impeller life. [3]

M.F. Moreira et, al., [2016] studied about the aluminum compressor wheel used in the turbocharged diesel engine which are made with machined AA2618 T652 alloy and installed in light truck engines. The premature failure of the wheels happened after life between 40000 km and 300000 km, while the expected life was about 1000000 km. This particular wheel presents 14 blades, 7 full blades and 7 small blades. The goal of this study is to check whether the material of the faiure wheels was in accordance with standards, and to identify the fracture mechanisms involved in the premature failure of the wheels. The nine different impeller or compressor wheels were submitted to chemical analysis, microstructural characterization, X-ray diffraction, hardness testing and fractographic examinations. The conclusion of this study is that a fatigue process was trigged by intergranular corrosion on the upper surface of the AA 2618 T652 aluminum alloy compressor wheel. [4]

B.P.Terani, Dr. K.S.Badarinarayan, Prakasha.A.M et, al., [2015] stated that turbocharger are very essential to incorporate in diesel engine. Turbocharger will feed compressed air to engine which produce more power and torque than natural aspirated engine, this process to obtained more power from engine is called engine downsizing. This study is to analyses impellers structural, modal and thermal stability with various boundary conditions and blade parameters. In order to achieve boost the turbocharger needs power and this is provided by the exhaust gas which will spin the turbine impeller and with common shaft compressor wheel will compress air and feeds it in to same engine. Turbocharger spins speed up to 15000rpm (revolution per minute) that is about 30 times faster than car engine. Impeller wheel has to with stand high exhaust gas temperature and stress induced force and external pressure. The author studied about the difficulties in manufacturing and testing of turbocharger, for that the CAE is very useful to analyze. Also studied that various iterations of turbine impeller with varied blade thickness, varied blade number are made and they are compared with stock model. Author concluded that Structural analysis of impeller to find stress deformation and strain, modal analysis to find natural frequency and finally thermal analysis is carried out for effect of exhaust gases on impeller turbine. [5]

V.R.S.M. Kishore Ajjarapu1, K. V.P.P.Chandu, D.M.Mohanthy Babu et, al., [2015] In these work impeller was designed with three different materials. The investigation can be done by using CATIA and ANSYS software. The CATIA is used for modeling the impeller and analysis is done in ANSYS. ANSYS is dedicated finite element package used for determining the variation of stresses, strains and deformation across profile of the impeller. This work is about to investigate the effect of temperature, pressure and induced stresses on the impeller. There are several way to reduce the price of the turbochargers, easiest way is to keep the design as simple as possible and hence 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. Author get result that the compressor material is withstand up to the (482.61 HZ) 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. [6]

Alain Batailly, Mathias Legrand et, al., [2015] stated that the contribution addresses the vibratory analysis of unilateral contact induced structural interactions between a bladed impeller and is surrounding flexible casing. This study shows that the linear interaction condition, commonly considered for the safe design of impellers and casing in turbomachinery, may be advantageously combined with the presented numerical strategy in order to assess the actual importance of predicted critical speeds. This study involved the casing flexibility allows for broadening the scope of simulated interactions from rubbing phenomena to modal interaction and detecting critical angular speeds for each type of interaction. It is concluded that the linear interaction condition, which stands as an important guideline for the design of impeller and casings, may be advantageously complemented by the numerical strategy exposed. And also concluded that critical speed may be predicted for free vibration modes that are not geometrically compatible. [7]

Neelambika, Veerbhadrappa et, al., [2014] this work is about detailed CFD analysis was done to predict the flow pattern inside the impeller which is an active pump component. The optimum inlet and outlet vane angles are calculated for the existing impeller by using the empirical relations. In the first case, outlet angle is increased by 5˚.Improved efficiency by changing the outlet angle the efficiency of the impeller is improved to 59%. In the second case inlet angle is decreased by 10˚, and efficiency of the impeller in this case is 61%. From this analysis it is understood that the changes in the inlet vane angle did not changes the efficiency of the impeller as much as the changes in outlet angle. The existing impeller, the head and efficiency are found out to be 19.24 m and 55% respectively. The impeller 1, the percentage increase in the head and efficiency are 3.22% and 7.27% respectively. The impeller 2, the percentage increase in the head and efficiency are 10.29% and 10.91% respectively. The impeller 3, the percentage increase in the head and efficiency are 13.66% and 18.18% respectively. Based on the above, it is concluded that impeller 3 gives better performance than the impeller 1 and impeller 2. [8]

Shaikh Mohammad Rafi, N. Amara Nageswara Rao, et. Al.,[2014] this study is about structural analysis of turbocharger compressor wheel. In this research they work on different material and changing design of compressor wheel. Using Pro-E they design the compressor wheel and analysis is done by using FEA package. The main aim of this study is to increase the performance of the compressor wheel. They studied on three different materials steel, alloy706, and alloy718. After completion of the analysis they get the result that Inconel 706 alloy material is better than other two alloy, 718 alloy and steel. And changed model is also found safe because result of modified are nearly equal to the actual turbocharger wheel. From that they conclude that stress are minimized then the performance maximized. [9]

Seiichi Ibaraki, Tetsuya Matsuo, Keiichi Shiraishi, Koichiro Imakiire, et. al., [2013] studied about the optimization of the compressor performance for high pressure turbocharged diesel engines. The objective is to develop optimized compressors that realize a wider operating range, high efficiency and relatively robust performance with respect to changes in engine operating conditions in the high pressure region. At the same time, optimized compressors must maintain high performance and sufficient surge margin at low engine loads. The authors developed new compressor impeller having relatively large backward swept blades and examined its performance. As a result authors achieved a wider operating range at high loads and good characteristics at low loads. This compressor design has been applied in the Mitsubishi MET 42SH turbocharger for the Mitsubishi 18KU30B high power diesel engine. The author concluded that the performance of newly developed impeller is more than the conventional impeller, in pressure ratio, operating range and characteristics at low speeds. The shape of the suction surface of the blade leading edge was improved, such that the compressor efficiency was increased. [10]

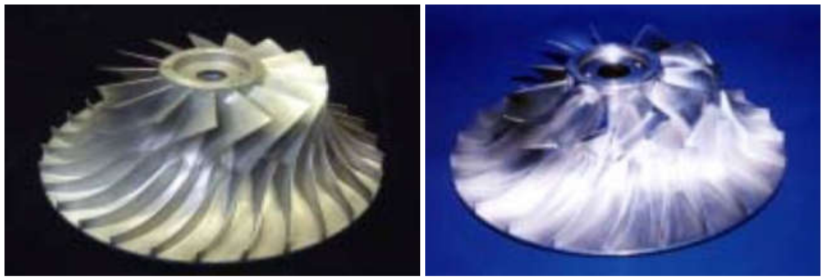

Fig. 1 New impeller Vs. Conventional impeller

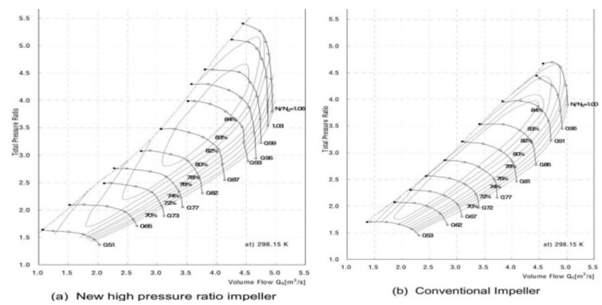

Fig. 2 Comparison of compressor characteristics

B.Mohan, B.E.Kumar et, al., [2011] in this study the axial composite impeller has been developed using commercial tools pro-e. They have chosen the suitable material for this study, namely Kevlar-49, carbon and S-Glass with a standard epoxy resin for the composite matrix. Static and dynamic behaviour of the component were analyzed using finite element analysis commercial tool ANSYS 14.5. They have analyzed the stress distribution and displacements on the composite impeller in static analysis. The stress concentration region was identified in this analysis. For transient analysis, they applied dynamic force at various operating speeds of the impeller and analyzed the deflections and stress concentration regions. [11]

Changhee Kim, Horim Lee, Jangsik Yang, Changmimn Son et, al., [2016] study about the series of aero-thermo-mechanical analysis which were carried out to predict the running tip clearance and the effect of impeller deformation on the performance using the two different compressor. In operation, the impeller deformation due to the combination of centrifugal force, aerodynamic pressure and thermal load result in non uniform tip clearance profile. The results show that the maximum displacement occurs at the leading edge tip of the impeller blade but maximum stress takes place at the blade root of the impeller. A significant reduction of the tip clearance height has occurred at the leading edge and the trailing edge of the impeller. Due to the reduction of the tip clearance, the tip leakage flow has decreased by 19.4% and 16.2% in the blade type A and B, respectively. The polytropic efficiency of blade type A and B at operating condition has increased by 0.72% and 1.81%, respectively. Conclusion of this study is that the largest deformation occurred at the leading edge tip of the impeller and the maximum stress took place at the blade root. There is constant cold build tip clearance to the non uniform tip clearance due to the impeller deformation during operation and after that the largest tip clearance has occurred at the leading and tailing edges of the impeller. Thus, the impeller deformation changes the blade flow structure reliability. They also concluded that polytropic efficiency and pressure ratio also increase due to reduction in the tip clearance over entire range. [12]

Isaias Hernandez-Carrillo, Christopher J Wood, Hao Liu et, al.,[2017] studied about the advanced material for the impeller in microturbine, for that there are different materials are selected a composite polyether-ether-ketone with 30% glass fiber filling (PEEK-GF30), Acrylonitrile Butadiene Styrene (ABS):thermoplastic and aluminum A354 is used as reference material. .The work is divided in the five component namely, heat and mass balance, mean line turbine design, 3D blading, fluid structure interaction (FSI), and prototyping. The working fluid is R245, Impeller diameter of 49mm and rotational speed of 36000rpm considered. Three situations are evaluated, full load operation, rotor blocked and 27% over speed. As a result they get that in over speed PEEK-GF30 is structurally 11% stronger than Aluminum whereas ABS is 40% weaker than Aluminum and both materials are sufficiently strong for the application. Author concluded that the thermoplastic materials cost effective alternative and also use at chemical resistance and lower inertia. Whereas the polymeric materials are more expensive than aluminum but the overall cost could be reduced by introducing leaner mass production process. With the coupled of CFD and FEA simulation it is confirmed that PEEK-GF30 and ABS are feasible substitutes for aluminum in ORC microturbine impellers to be used with low temperature resources. [13]

S. Mayakannan, V. Jeevabharathi, R. Mani, M.Muthuraj et, al., [2016] studied about the design of impeller of centrifugal pump to increase its power and efficiency. They uses the six blade turbine, comparing with old material of a turbine and investigate can be done by SOLIDWORKS and ANSYS work bench software. The modeling is done in SOLIDWORKS and analysis is done in ANSYS work bench. It is determine that the variation of heat flux and directional deformation across profile of the impeller in ANSYS. This study for an attempt is made to suggest the best material for an impeller of turbine for an impeller of a turbine by comparing the results obtained for two different materials inconel alloy 783, inconel alloy 740 for centrifugal is to made it. It is concluded from the analysis that heat flow rate of inconel alloy740($6.6*10^{-9}$) is greater than the inconel alloy783($1.18*10^{-9}$) and stainless steel 2324($1.3*10^{-9}$). The inconel alloy 783 will produced more deflection under tangential and axial load temperature. At last from analysis, Titanium alloy blade material provides the less heat losses as compared to other materials. But as a view of structural and thermal behaviour other material inconel alloy 783 and inconel alloy 740 is better than the Titanium alloy. [14]

Rachel Schwind and Shaaban Abdallah et, al., [2015] in this study analysis will focus on different impeller blading designs including splitter bladed impellers, tandem bladed impellers, and tandem bladed impellers with a casing blade. There are different advantages associated with each impeller design. Author get result that the tandem bladed impeller have a low efficiency and pressure ratio as compared with the backswept and splitter bladed design and also get that the operating range is increases with the tandem design due to lower surge margin. Surge occurs when there is a low flow rate at a relatively high pressure ratio causing flow reversal. Surge can lead to catastrophic failure. Light surge with smaller flow reversal areas not necessarily cause a failure of the system and the compressor may still operate, but the performance will suffer. While it may not completely catastrophic failure, it could result in engine misfires if not enough air is fed into the combustion chamber. Hence the surge margin can be harmful to the performance of both the turbocharger and the engine. The authors concluded that while the tandem impeller design shows an improvement in operating range, it also shows a decrease in overall efficiency. For the turbocharger application, a large operating range is extremely desirable so it may be worth sacrificing some efficiency to achieve. [15]

Santosh Shuklaa, ApurbaKumar, Royband KaushikKumar et, al., [2015] in this paper the authors highlight to minimize the stress developed and deformation. The 3D model of mixed flow pump impeller blade was developed using CATIA and with four different materials (Copper alloy, Bronze, Stainless steel, and Titanium alloy) analysis was done in ANSYS 11.0 with similar loading and support condition. The results obtained were compared. It was observed that Titanium alloy can be considered as the constructional material for the blades as it gave minimum deformation (at tip) and Stress (at base). [16]

III. RESULT AND DISCUSSION

Geometry 3-D model

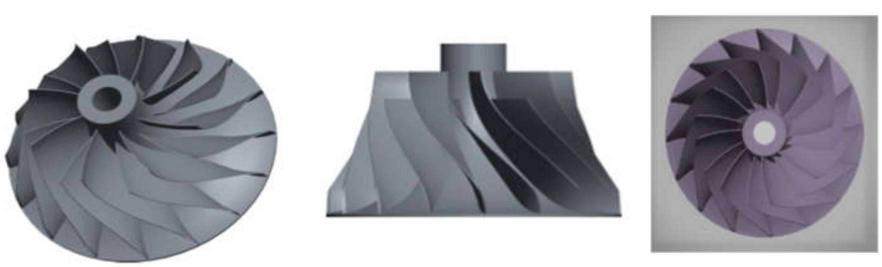

Fig 3 Geometry 3-D model of impeller

Meshing of impeller

Fig 4 meshing of impeller

Structural analysis of Titanium Alloy

Fig 5 (a) Total Deformation (b)Equivalent Elastic Strain (c) Equivalent stress

Properties	Minimum (MPa)	Maximum (MPa)
Total Deformation	0	0.51254
Equivalent elastic strain	3.4474e-7	0.0060839
Equivalent stress	3.3087e-002	583.45

Table 1 Structural Analysis of Titanium Alloy

Structural analysis of Aluminum Alloy

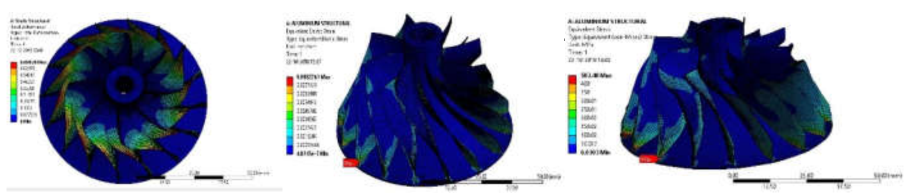

Fig 6 (a) Total Deformation (b)Equivalent Elastic Strain (c) Equivalent stress

Properties	Minimum (MPa)	Maximum (MPa)
Total Deformation	0	0.69838
Equivalent elastic strain	4.8745e-7	0.0082261
Equivalent stress	3.03e-002	583.48

Table 2 Structural Analysis for Aluminum Alloy

Modal analysis of Titanium Alloy

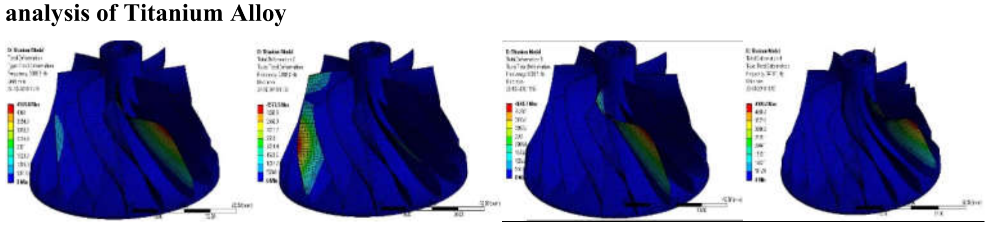

Fig 7 Total deformation at different frequency (Titanium alloy)

Modal analysis of Aluminum Alloy

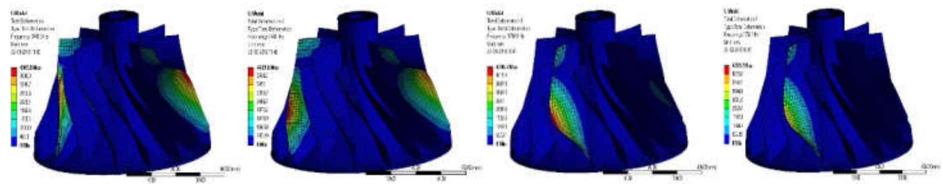

Fig 8 Total deformation at different frequency (Aluminum alloy)

Material	Frequency(Hz)				Deformation(mm)			
Titanium Alloy	1	2	3	4	1	2	3	4
	3388.8	3392.2	3401.7	3418.1	4569.8	4577.5	4645.7	4599.2
Aluminum Alloy	3736.5	3739.8	3750.8	3767.9	5915.1	5924.5	6033.7	5972.6

Table 3 Modal analysis for Compressor Impeller

- From Static analysis it is observed that total deformation and Equivalent Stress is less of Titanium Alloy than Aluminum Alloy.
- And from modal analysis maximum frequency is obtained for the titanium alloy.

IV. CONCLUSIONS

The analysis was carried out for Turbocharger impeller which was done using ANSYS. In the analysis part the model was created in Creo and saved files in to step after it was imported into ANSYS. The analysis is carried out on redesigned model with the different materials and results were compared. From the above result summary table we conclude that Titanium alloy was found better result than Aluminum alloy. And the changed model also safe to use because the result of the modified are near to the actual turbocharger impeller. So that we propose the new model to the company with new alloy material. From the above data we observed that minimum stress and deformation is obtained for the material titanium alloy. So we conclude that among these two different material titanium alloy is the best material.

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