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Analysis of Turbine Blade for Automobile Turbocharger by Changing Material and Number of Blades

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Abstract -- Turbocharger is a class of turbo machinery that increases the power of internal combustion engines. A turbocharger uses waste energy from the exhaust system to compress the air entering the cylinder. Thus, increase the power of internal combustion engine. This research is to analyse the stress on turbine blade of turbocharger which is used in automotive diesel engine (118 kW). Firstly, the three different materials of turbine blades are analysed by comparing the von-Mises stress, equivalent elastic strain and deformation. The minimum von-Mises stress 2.6313 MPa and the minimum equivalent elastic strain 1.5374×10^{-5} are found to be a suitable material. So, the suitable material is structural steel. Secondly, the turbine wheel is reduced the number of turbine blade from 11 to7. The suitable number of turbine blades is 9. The model of turbine blade is generated by ANSYS 16.0 software and Solid Works software. Then, this turbine blade is analyzed by ANSYS 16.0 software.

Indexed Terms: Number of turbine blades, Power, Structural analysis, Turbine, Turbocharger

I. INTRODUCTION

A turbocharger is an air pump designed to operate on the normally waste energy in engine exhaust gas. Turbocharger is a class of turbo machinery that increases the power of internal combustion engines. This is accomplished by increasing the pressure of intake air, allowing more fuel to be combusted. A turbocharger uses waste energy from the exhaust system to compress air entering the cylinder, thus increasing engine power. Turbo charging system is turbine drives the compressor which is driven by the exhaust gas (residual gas) from the cylinder. These gases drive the turbine wheel and shaft which is coupled to a compressor wheel which when rotating provides high volume of air to the engine combustion chamber [7].

The main components of turbocharger are a compressor, a turbine and canter housing. Compressor is spun by the rotation force created by exhaust gas flowing through the turbine. Clean air from the air cleaner is drawn into the compressor housing and wheel where it is compressed and delivered through a pipe to the engine air intake manifold. Canter housing is comprised of "journal" or "ball bearings" depending upon the application, as well as oil lubrication and drains. The turbine is a section of turbocharger where the exhaust gases of the engine are forced through to cause the turbine wheel to spin. The turbine converts some of the energy contained in the hot engine exhaust gas into mechanical work the pressure and temperature of the exhaust gas decreases. Exhaust gas from the engine enters the turbine and expends, performing work on the turbine shown in Fig. 1[5].

K. Kumar, S. L. Ajit Prasad and Shivarudraiah studied the strength evaluation in turbo machinery blade disk assembly at constant speed. In this work, 3D Finite Element Analysis of low pressure turbine blade disk assembly is carried out at constant speed loading condition. Special investigations were performed based on Neuber formulae. This can be reduced the local peak stresses at the blade and disk root fillet using linear analysis. And the equivalent non-linear stress values are identified by the strain energy distribution. In this research, the turbine wheel model is generated and analysed the von-Mises stress, equivalent elastic strain and deformation with same rotational speed, tangential and radial forces [3].

Fig. 1: Turbine Wheel for Automobile Turbocharger

II. ANALYSIS OF TURBINE BLADE

Firstly, turbine blade is analyzed by using three different materials (aluminum alloy, structural steel and copper alloy). And then, it is selected the suitable material using in turbine blade. And analyze the three different number of turbine blades. Finally, choose the most suitable material and number of blades. A Specification data of the turbine wheel are shown by TABLE I.

Table 1: Specification Data

Physical Properties	Symbol	Value	Unit
Brake Power	B.P	118	kW
Turbine inlet stagnation temperature	T_{03}	402	˚C
Turbine outlet stagnation temperature	T_{04}	317	˚C
Compressor inlet stagnation temperature	T_{01}	68	˚C
Compressor outlet stagnation temperature	T_{02}	148	˚C
Ambient pressure	P_1	1.013	bar
Ambient temperature	T_1	298	K
Turbine speed	N	9500	rpm

A. Theoretical Calculation of von-Mises Stress and Effective Strain on the Turbine Wheel:

The moment of the inertia can be calculated as

$$J = \frac{\pi D_4^{\ 4}}{32} \tag{1}$$

Shear stress can be calculated as

$$\tau_{xy} = \frac{Tr_4}{J} \tag{2}$$

The centrifugal stress can be calculated as

$$\sigma_c = \frac{\rho\omega^2}{2}\left(r_t^{\ 2} - r_r^{\ 2}\right) \tag{3}$$

where, ρ = density of material (kg/m^3)
ω = angular velocity (rad/s)
r_t= blade tip radius (m)
r_r= blade root radius (m)

The gas bending stress can be calculated by

$$\sigma_{gb} = \frac{\dot{m}\left(V_{\omega in} + V_{\omega out}\right)h_R}{2n_R z_m c_R^{\ 3}} \tag{4}$$

where, $V_{\omega in}$ = inlet whirl velocity, m/s
$V_{\omega out}$= outlet whirl velocity, m/s
h_R= blade height, m
n_R = number of blades
z_m= section modulus, m^3/m chord
c_R = chord length of blade, m

The principal stress can be calculated as

$$\sigma_1, \sigma_2 = \frac{\sigma_x + \sigma_y}{2} \pm \frac{1}{2}\sqrt{\left(\sigma_x - \sigma_y\right)^2 + 4\tau_{xy}^{\ 2}} \tag{5}$$

The von-Mises stress can be calculated as

$$\sigma_v = \frac{1}{2}\sqrt{\left(\sigma_1 - \sigma_2\right)^2 + \left(\sigma_2 - \sigma_3\right)^2 + \left(\sigma_3 - \sigma_1\right)^2} \tag{6}$$

The effective strain can be calculated as

$$\bar{\varepsilon} = \left[\frac{2}{3}\left(\varepsilon_1^{\ 2} + \varepsilon_2^{\ 2} + \varepsilon_3^{\ 2}\right)\right]^{\frac{1}{2}} \tag{7}$$

B. Theoretical Results of von-Mises Stress and Effective Strain on the Turbine Wheel:

Table 2: Specification Data

Materials	von-Mises Stress, σ_v(MPa)	Effective Strain, $\bar{\varepsilon}$
Aluminium Alloy (2014-T6)	2.6718	3.7778×10^{-5}

Copper Alloy	2.7581	2.6484×10^{-5}
Structural Steel	2.7418	1.6738×10^{-5}

Theoretical results of von-Mises stress and effective strain on the turbine wheel with three different materials are described by TABLE II. The von-Mises stresses for three different materials are not exceeded than yield strength of three materials. So, the design of turbine blades is satisfied. Structural steel is minimum von-Mises stress and effective strain than other two materials. So, the suitable material for turbine wheel is Structural steel.

C. Structural Analysis of Turbine Wheel:

In this research, structural behaviors (von-Mises stress and effective strain) of turbine wheel using the three different materials are analyzed by using ANSYS 16.0 software. The turbine wheel is modeled by using Blade Gem and Solid Works software. The model of the turbine wheel was added to the geometry by using ANSYS software package as shown in Fig.2

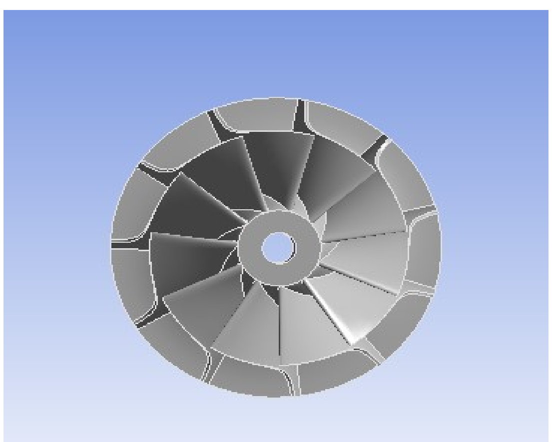

Fig. 2: Geometry of Turbine Wheel

The generated mesh is done by fine position to obtain the good quality of the mesh. The mesh model of the turbine wheel is as shown in Fig. 3.

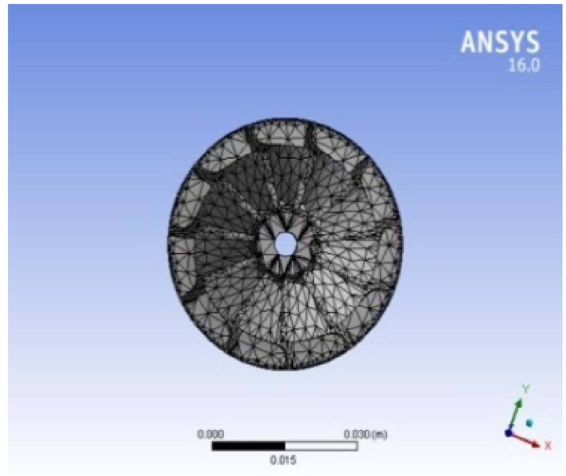

Fig. 3: Meshing of Turbine Wheel

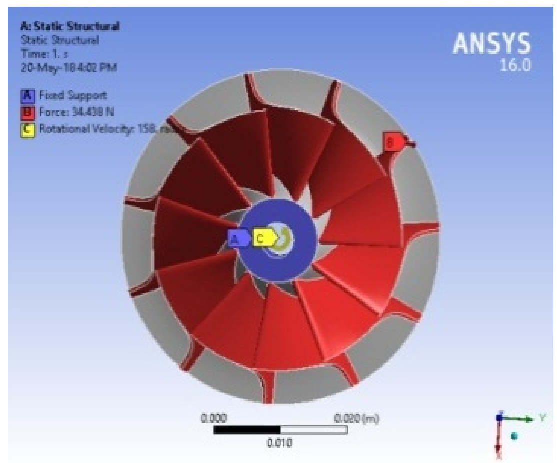

Fig. 4 Boundary Condition of Turbine Wheel

The boundary condition are applied on the turbine wheel after finishing the mesh of the disc which fixed at the tip of the turbine wheel and surface of shaft, the tangential and radial forces are applied to the surface of blades and rotational speed are applied on the surface of shaft. The boundary condition of the turbine wheel is as shown in Fig. 4.

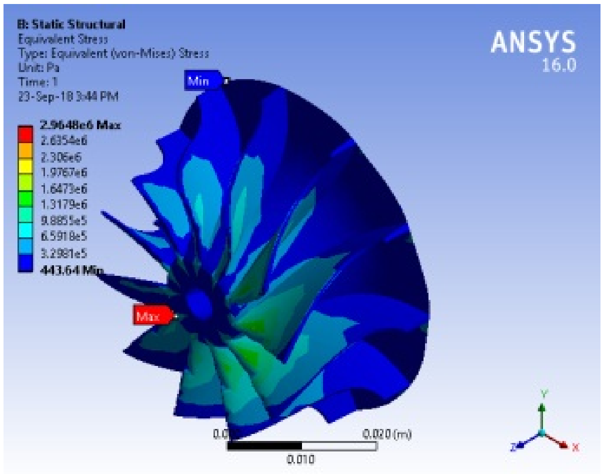

Fig. 5 von-Mises Stress on Turbine Wheel using Aluminum Alloy (2014-T6)

Fig. 5 shows the simulation results of von-Mises stress of the turbine wheel. The maximum von-Mises stress of the turbine wheel using aluminum alloy is 2.9648 MPa.

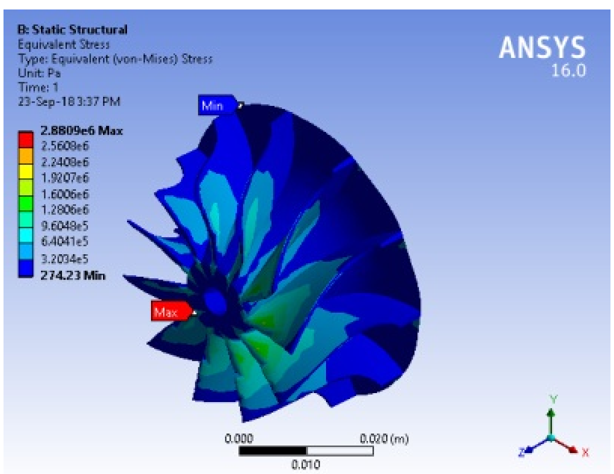

Fig. 6 von-Mises Stress on Turbine Wheel using Copper Alloy (Manganese Bronze)

According to the Figure 6, the maximum von-Mises stress of turbine wheel for copper alloy (manganese bronze) is 2.8899 MPa.

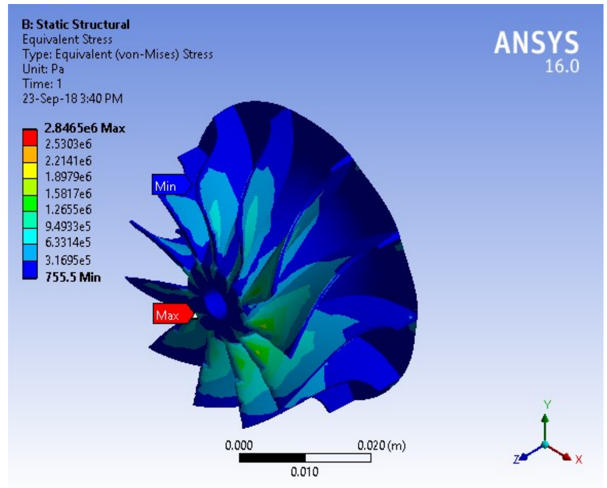

Fig. 7 von-Mises Stress on Turbine Wheel using Structural Steel

Fig. 7 shows the maximum equivalent (von-Mises) stress on the turbine wheel for the structural steel is 2.8465 MPa. The maximum von-Mises stress occurred at the engage between the surface of cone and blade edges. TABLE III shows the results of von-Mises stress and effective strain for three different materials.

Table 3: Comparison of von-Mises stress and equivalent elastic strain with three different materials

Properties	Aluminium Alloy	Copper Alloy	Structural Steel	Unit
Von-Mises Stress	2.9648	2.8899	2.8465	MPa
Effective Strain	4.1764 $\times 10^{-5}$	2.6195 $\times 10^{-5}$	1.4235 $\times 10^{-5}$	-

D. Modified the Number of Turbine Wheel:

In this portion modify the turbine wheel, the various number of turbine wheels (7, 9 and 11) are created by blade gem and Solid Works. And, the turbine wheels are inputted into ANSYS 16.0. Then, mesh the model by fine situation. And then, the three boundary conditions are applied on the turbine wheel. Finally, the turbine wheel is analyzed by ANSYS 16.0 software.

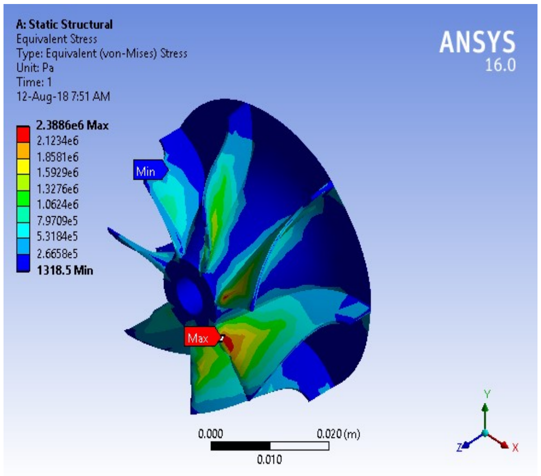

Fig. 8 von-Mises stress on 7 turbine blades for Structural Steel

Fig. 8shows the von-Mises stress on 7 turbine blades by using structural steel. The maximum von-Mises stress is 2.3886 MPa.

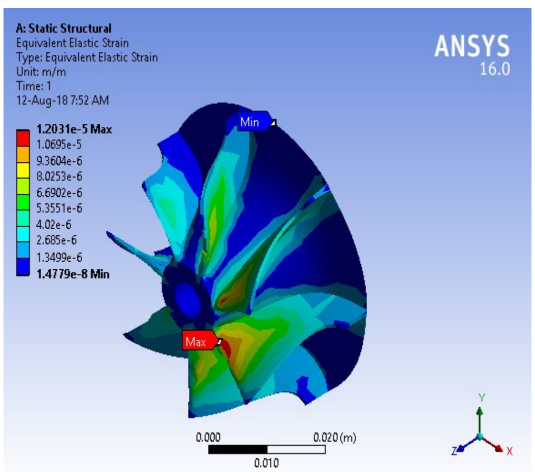

Fig. 9 Equivalent Elastic Strain on 7 Turbine Blades for Structural Steel

Fig. 9 shows the equivalent elastic strain of 7 turbine blades by using structural steel. The maximum equivalent elastic strain is 1.2031×10^{-5}.At this stage, the numbers of turbine blades (n=9) are created by blade gem and Solid Works software. Then, this turbine wheel is inputted into the ANSYS 16.0 software. And then, it is meshed by fine situation and inputted the boundary conditions. Finally, it is analyzed and the results are described.

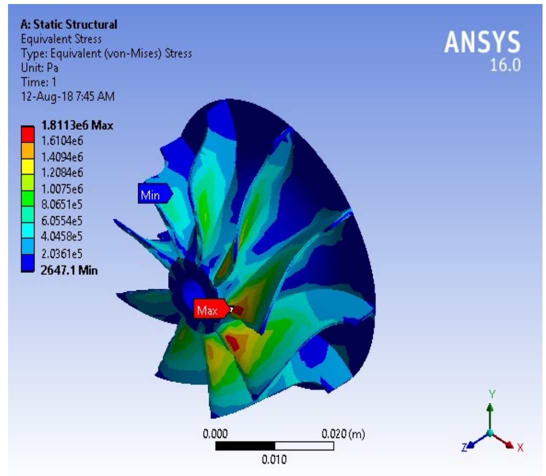

Fig. 10 von-Mises stress on 9 turbine blades for Structural Steel

Fig. 10shows the von-Mises stress on 9 turbine blades by using structural steel. The maximum Von-Mises stress is 1.8113 MPa.

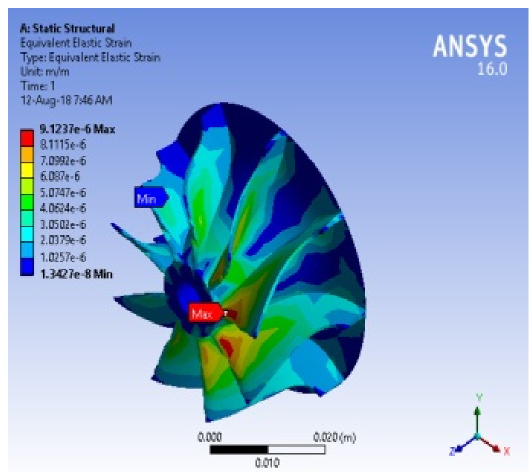

Fig. 11 Equivalent Elastic Strainon 9 Turbine Bladesfor Structural Steel

Fig. 11 shows the equivalent elastic strain of 9 turbine blades by using structural steel. The maximum equivalent elastic strain is 9.1237×10^{-6}.The comparison of structural analysis of three different number of turbine blades are shown in Table 4. According to the results of three different turbine blades of maximum stress distribution result is lower than that of the maximum tensile yield strength, so the design used for these three materials are satisfied.

Table 4: Comparison of structural steel for three different numbers of turbine blades

Blade Numbers, n	Simulation Results of von-Mises Stress, σ(MPa)	Simulation Results of Equivalent Elastic Strain, $\bar{\varepsilon}$	Simulation Results of Total Deformation
n =7	2.3886	1.2031×10^{-5}	1.3408×10^{-6}
n =9	1.8113	0.91237×10^{-5}	1.0413×10^{-6}
n =11	2.8465	1.4235×10^{-5}	1.3799×10^{-6}

According to the results of three different numbers of turbine blades, the minimum von-Mises stress and effective strain are occurred in 9 turbine blades. Moreover, the minimum deformation is also found in 9 turbine blades. Therefore, suitable number of turbine blades for Structural Steel is 9 turbine blades than the other two turbine blades.

III. CONCLUSIONS

This research paper has been studied the structural analysis of turbine wheel for turbocharged diesel engine. Simulation results of maximum von-Mises stress for three different materials are less than their yield strength. Then, minimum von-Mises stress (2.8465MPa) and minimum equivalent elastic strain(1.4235×10^{-5}) on the turbine wheelis occurred in structural steel. Therefore, structural steel is more suitable than the other two materials. And then, analyse and compare the results of the turbine wheel with the different number of blades (7, 9 and 11). The minimum von-Mises stress is 1.8113MPa but it does not exceed the yield strength of structural steel. The minimum equivalent elastic strain and deformation results are 0.9124×10^{-5} and 1.0413×10^{-6} respectively, which is occurred in 9 turbine blades. So, the suitable turbine blade is structural steel of 9 turbine blades.

REFERENCES

[1] Shailendra Kumar Bohidar, Prakash Kumar Sen, Ravi Bharadwaj, Study of Turbo Charging, 2015.

[2] Srinivasan. C, M. S. Sayooj, Increasing the Efficiency of an Engine by the use of Variable Geometry Turbochargers, 2014.

[3] Navajsharif Shailh, Prof. W. S, Rathod and Khalid Ansari. The Analysis of Turbocharger Turbine for Model and Harmonic Analysis, 2013.

[4] Gordon Krik, Synchronous Thermal Instability Evaluation of Medium Speed Turbocharger Rotor Bearing Systems, 2012.

[5] Oliver Velde, Geri Kreuzfeld, Ingolf Lehamann, Reverse Engineering of Turbocharger Compressor Design Based on Non-Parametric CAD Data, 2012.

[6] Paulson Ouseph A, T Mahender, Subramanyam Pavuluri, Design and Thermal Analysis of Radial Turbo Charger Using Finite Element Method, 2011.

[7] HIH Saravanamutto GFC Rogers, H Cohen PV Straznicky, Gas Turbine Theory, 2011.

[8] K. Kumar, S.L Ajit Prasas and Shivarudraiah, the Strength Evaluation in Turbo Machinery Blade Disk Assembly at Constant Speed, 2010.

[9] Tsutomu Adachi, Naohiro Sugita and Yousuke Yamada, Study on the Performance of a Sirocco Fan (Optimum Design of Blade Shape), 2010.

[10] Andreas Sidorow, Rolf Isermann, Francesco Cianflone, The Comparison of a Turbocharger Model Based on Isentropic Efficiency Maps with a Parametric Approach Based on Euler's Turbo-Machinery Equation, 2010.

[11] Jenelle Pope, Analysis of a Turbocharger System for a Diesel Engine, 2009.

[12] Khairul Anuar, Bin Ahmad.An Investigation of Turbine Blade Failure in Aircraft Turbine Engines, 2009.

[13] Arunachalam, Numerical Studied on the Effect of Impeller Blade Skew on Centrifugal Compressor Performance, 2008.

[14] Erain Baskharone, Principle of Turbo Machinery in Air Breathing Engines, 2006.