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Stress analysis and shape optimization of wheel rim

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Abstract*— Automobile have number of components which are important for good performance of the vehicle. Testing component with the help of various software is economical as compared to laboratory testing. The computational power is also increasing day by day which help researchers to evaluate the performance of various components to see their effect on the overall system Wheels are one of such component. They are not just imperative component that must meet fatigue, effect and ride quality determinations; however their weight is of prime importance because of the both rotational and translational forces present at the wheel [1]. This paper describes the use of structural analysis tool for wheel rim stress analysis and weight reduction. The wheel along with the wheel rim plays an important role in vehicle dynamic performance. That performance is indirectly dependent upon various load acting on the wheel rim. These loads acting on the wheel rim are air pressure, engine torque, vehicle weight. An attempt is made to design the wheel rim which is identical to ford ecosport. Two major dimensions which are section height and section width are considered for wheel rim design. Corresponding stress result is shown in this paper along with the relevant diagrams obtained from the structural analysis tool available in ansys. Weight optimization is also done using the shape optimization tool available in the ansys workbench. At each and every stage stress analysis is done. These weights are applied at the respective location on the wheel rim. Finally the resultant wheel rim design is compared with its original design in terms of weight and strength.

Keywords*— shape optimization, stress analysis, weight reduction, wheel rim, fuel economy

I. INTRODUCTION

Structural optimization of various component of automobile has shown that vehicle performance is greatly affected by component weight. Because of the understanding of wheels contribution to the overall vehicle performance this topic is chosen for the research by the author. In constantly expanding interest to decrease the item cost and to build the item strength and unwavering quality, the utilization of simulation tools is done here in this paper. Simulation tool used here is ansys (structural analysis). As computational power available is also increasing day by day the researchers are putting extra efforts to optimize the tool by using large number of iterations. To have the success in the optimization of wheel rim; we should use the correct loads which acts on the wheel rim during actual operation cycles. The wheel rim modelled using pro engineer is shown in following Fig 1. For the sake of simplicity for analysis only the half part of the wheel rim is considered; because the remaining half part of the wheel rim will show the same stress behavior.

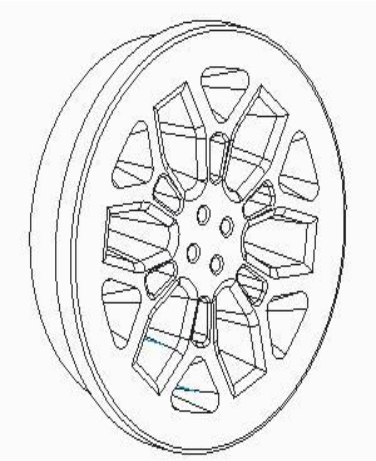

Fig. 1 Solid model of wheel rim

The wheel rim is shown in above figure is modelled using the tire dimension available on the tire of ford ecosport in the form of

code as 205/60R16 92H. For the designing of the wheel rim the main dimension taken from the code is section height and section width which are 205 millimetres and 60 millimetres respectively. The dimensions for the spoke design are assumed as per the convenience. There are total 4 variants available in the ford ecosport. Materials used for the wheel rims of all the four variants are summarized in the following Table I.

TABLE I
Variants of Ford Ecosport [4]

SR. NO.	VARIANT	MATERIAL
1	1.5l petrol Ambiente MT	Structural steel
2	1.5l petrol trend MT	Structural steel
3	1.5l petrol Titanium MT	Steel alloy
4	1.5l petrol Titanium AT	*Steel alloy*

II. STRUCTURAL OPTIMIZATION STUDIES

The structural optimization studies are performed on the component which is under study. Because of the optimization process the weight alteration can be done on the component without altering its strength such that component will perform really well under actual operating conditions. The process of the optimization can be summarized as shown in the following Fig 2 [2].

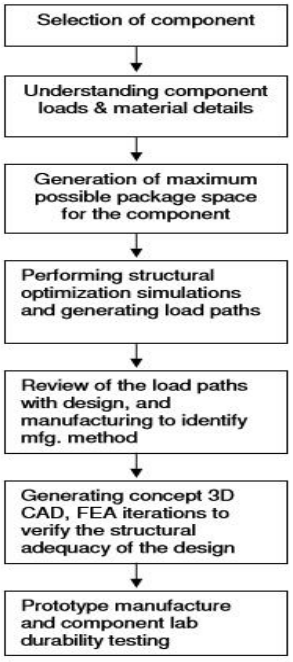

Fig. 2 Structural optimization process flow chart

III. STRUCTURAL ANALYSIS AND WEIGHT OPTIMIZATION

The material used here from the engineering data available in the library is structural steel. The structural analysis and weight

optimization are carried out using the structural analysis tool available in ansys in various stages for weight optimization as discussed below

A. Geometry Import

The basic step to start the analysis is to import the file in .stp format as shown in Fig 3. The file generated after designing the wheel rim in Creo software is of .prt format. But Ansys workbench cannot work on the model file of >prt format. Therefore we have to change the file format which Ansys workbench can read. Among the different format like .igs, .stp author have chosen .stp format for the import operation of the model file into Ansys workbench.

Fig. 3 Step format import of wheel rim

B. Meshing

After completing the geometry import step the next and vary important step is meshing of the wheel rim. To have a good result and accuracy we should use the fine meshing as shown in the following Fig 4.

Fig. 4 Meshing of wheel rim

C. Analysis setting

In this we introduce the various forces and moment acting on the wheel rim. Those forces and moments acting on the wheel rim are summarized in the following Table II. Torque acting during the first gear and the vehicle weight are greater on front wheels as compared to the rear wheels therefore the stresses generated will be maximum in the any one of the wheel rim of the front wheels.

Therefore we are considering front wheel rim for the analysis. Here in the calculation of various forces and moments acting on the wheel rim, we have considered the above four forces/moments. The curb weight of the ford ecosport is 1290 Kg [4]. And as the ford ecosport is front wheel drive therefore this weight will be distributed in the ratio of 60:40. That means 60 part of the total weight on front axle and the 40 part of the total weight on the rear axle. Therefore the weight on the front axle is 3870N. Because of this weight the ground will exert the equal and opposite reaction on the wheel rim at bead seating. As we all know the torque generated in the first gear will be maximum and that's why the moment acting on the wheel
rim will be maximum while vehicle is in the first gear. In the calculation of moment we have to consider the first gear ratio and the differential gear ratio. After multiplying by both of these gear ratios we will get the final torque acting on the wheel rim. The air pressure in the front wheels is generally 32 psi that means 0.20679 Mpa.

TABLE
Forces and moments

Named selection	Force/moment	Amount
Bead_seating	Force due to vehicle weight	3870N
Bead_seating	Moment due to torque	1215200 N-mm
Wheel_inner	Air pressure	0.20679 Mpa
Hub_mount	Fixed support	0

The wheel rim is attached at hub mount therefore we have given fixed support at the hub mount. These all the forces and the moment acting on the wheel rim can be seen in the following Fig. 5.

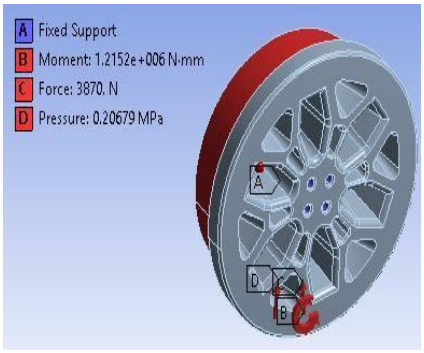

Fig. 5 Various forces acting on the wheel rim

D. Solution and the results

In this part the stress generated can be calculated by using the appropriate setting of solvers and having large number of iterations to have good accuracy. The stress profile generated can be seen in the Fig. 6. The maximum stress generated is 74.812 Mpa and the weight of the wheel rim is 15.192 Kg which is high. Therefore there is a need to do the weight optimization of the wheel rim

without affecting the life of the wheelrim.

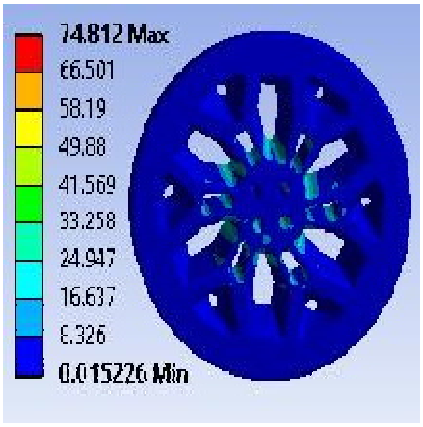

Fig. 6 Stress profile of wheel rim

E. Weight Optimization

For this we can use the shape optimization tool available in the ansys workbench. The structural steel which can be used in wheel rim is of various grades as shown in Table III.

1) *Stage one:* In this stage we will perform the first iteration for the weight optimization. The material to remove is shown in following Fig. 7.

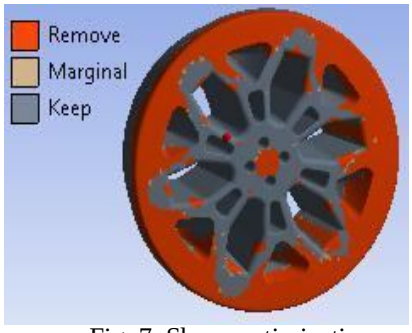

Fig. 7: Shape optimization

The weight of wheel rim is reduced two 10.7 kg after this stage. We will then try to find out the stress generated in the wheel rim which is formed after the first weight optimization. The stress generated is shown with help of stress profile diagram as shown below in Fig. 8. As we can see generated stress is far below the maximum applicable stress of 90 Mpa therefore we can further reduce the weight by using shape optimization tool.

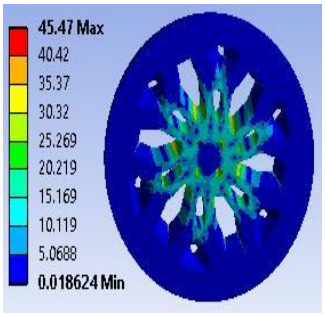

Fig. 8 Stress profile

2) *Stage Two:* In this stage we will again do the shape optimization. The material to remove is shown in Fig. 9.

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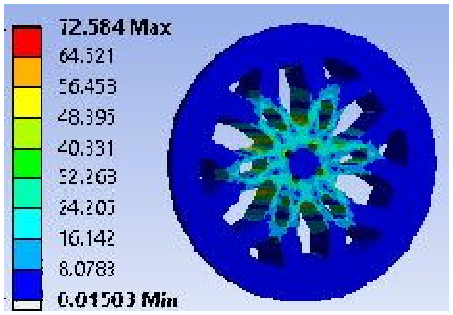

Fig. 9 Shape optimization

The weight of the wheel rim is reduced form the 10.7kg to 6.5977kg. The stress profile for the wheel rim is shown in the Fig. 10. The maximum stress generated is 72.584Mpa which is less than 90Mpa therefore we can again do the shape optimization of the wheel rim.

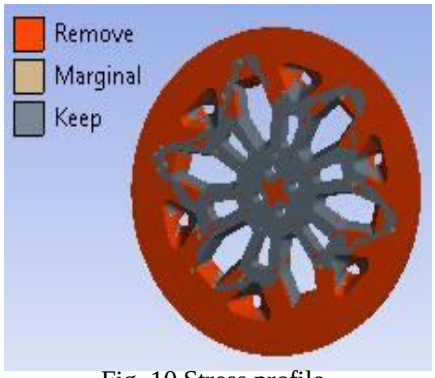

Fig. 10 Stress profile

3) *Stage Three:* To have the more accurate result and to reduce number of stages for the shape optimization this time the weight reduction percentage is kept 30%. The material to be removed is shown in the following figure.

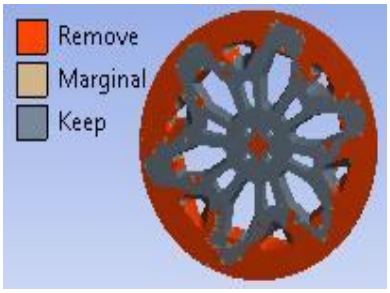

Fig. 11 Shape optimization

Weight of the wheel rim is reduced from 6.5977Kg to 5.1195Kg .The stress profile for the corresponding wheel rim is shown in the Fig. 12.

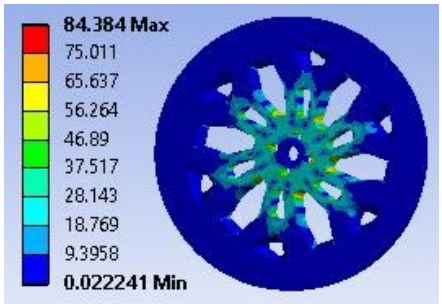

Fig. 12 Stress profile

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Table III
Grades of structural steel

Grade	Yield strength (N/mm2)	Tensile strength (N/mm2)
S235	235	510
S275	275	530
S355	355	630

Among them S275 is very common grade of structural steel used for Ford eco sport wheel rim [4]. And as shown in the above table S275 have the yield strength of 275 N/mm2.By considering the factor of safety 3 we can do the weight optimization till maximum generated stress is 90Mpa. Weight optimization is done in various stages which are explained below one after another.

4) *Stage Four:* As the stress generated is now close to the maximum applicable stress of 90 Mpa so this time we will have 15% weight reduction. The material to be removed is shown in Fig. 13.

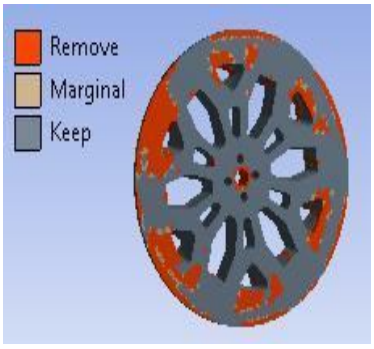

Fig. 13 Shape optimization

As we can see material to remove is very less and the maximum stress generated is close to maximum applicable stress so we will stop here our shape optimization process. The data which we have obtained is summarized in the following Table IV.

Table IV
Comparison of weight

Stage No	Original weight (Kg)	Reduced weight (Kg)	Stress generated (MPa)
1	15.192	10.7	45.47
2	10.7	6.5977	72.584
3	6.5977	5.1195	84.384

IV. CONCLUSION

Now days the priority of automotive industries is to reduce the weight of automotive components for better performance and fuel economy. This research work optimized wheel rim design to achieve weight reduction. The goal of weight optimization has achieved. The weight of the wheelrim is reduced from 15.192 Kg to 4.9404 Kg. The strength of the final part is 84.384 MPa which is well near to 90 MPa as per the factor of safety criterion.

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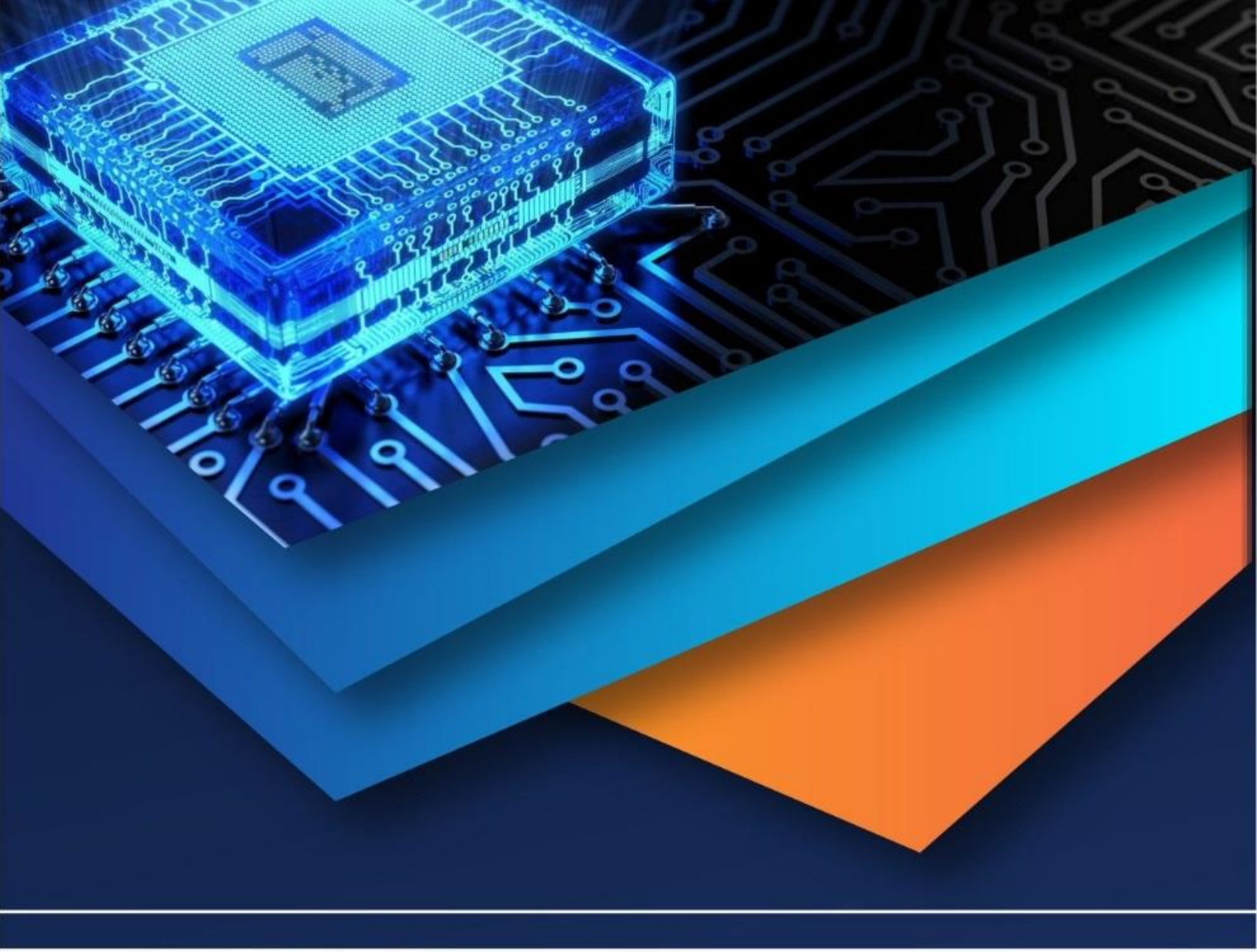

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