Design and Analysis of Spiral Wheel Rim for Four Wheeler

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---**ABSTRACT**--
Alloy wheels are automobile wheels which are made from an alloy of aluminum or magnesium metals or sometimes a mixture of both. Alloy wheels differ from normal steel wheels because of their lighter weight, which improves the steering and the speed of the car. Alloy wheels will reduce the unstrung weight of a vehicle compared to one fitted with standard steel wheels. The benefit of reduced unstrung weight is more precise steering as well as a nominal reduction in fuel consumption. Alloy is an excellent conductor of heat, improving heat dissipation from the brakes, reducing the risk of brake failure under demanding driving conditions. At present four wheeler wheels are made of Aluminum Alloys. In this project a parametric model is designed for Alloy wheel used in four wheeler by collecting data from reverse engineering process from existing model. Design is evaluated by analyzing the model by changing the design of rim styles to be strong and balanced. Its material should not deteriorate with weathering and corrosion.

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I.   1.INTRODUCTION

The importance of wheels and tyres in the automobile is obvious. Without the engine the car may be towed but even that is not possible without wheels. The wheel along with tyre has to take the vehicle load, provide a cushioning effect and cope up with the steering control. The various requirements of an automobile wheels are:

1.   It must be strong enough to perform the above functions.

2.   It should be balanced both statically as well as dynamically.

3.   It should be as light as possible so that the unsprung weight is least.

4.   It should be possible to remove or mount the wheel easily.

5.   Its material should not deteriorate with weathering and age. In case the material is susceptible to corrosion, it must be given suitable protective treatment.

II.   WHEEL RIMS

2.1Magnesium alloy rims

Some magnesium rims are weak and unsuitable for heavy off-road operations, for example magnesium fitted to the Mercedes-G. But many are quite strong enough for most uses. Their disadvantage comes only if when they are bent, when they are much more difficult to repair and a hammer and a tree trunk aren't going to bend them straight: It will just break them more. Steel is the better, but heavier and uglier choice.

2.2 Steel rims

Steel rims are constructed in two parts: a pressed steel centre boss and a rolled circular bed for the tyre. These parts are either riveted or welded together, riveted types being the strongest and most reliable. Steel rims are sometimes of inferior quality and in some cases severely warped rims are supplied with new vehicles, making perfect balancing impossible.

2.3Split rims

Some older vehicles were fitted with split rims of a two part design. This facilitates the removal of the tyre from the rim. It is imperative that the tyre be totally deflated prior to splitting the rim as air pressure remaining in the tyre will cause the rim to split with explosive force which could cause serious injury. Also, when a tube is fitted onto a split rim, a protective gaiter consisting of a ring of shaped rubber must be inserted between the rim and the tube, without which tube will get damage.

III. OBJECTIVE

The objective of this project is to test the wheel according to the specifications given by the industrial standards.
Two kind of test is performed
1. Bending endurance test

2. Radial endurance test
a. Pressure loading

b. Centrifugal loading

c. Vertical loading
3.1 Bending test
The bending moment to be imparted in the test shall be in accordance to the following formula:

$$M = ((\mu * R) + d) * F * S$$

Where
M = Bending moment in 'Nm'
μ = Friction Coefficient between the tyre and the road surface (no units)
R = Radius of the tyre applicable to the wheel in 'm'
d = Offset of the wheel in 'm'
F = Maximum load acting on the tyre in 'N'
S = Coefficient specified according to the standards.
According to the industrial standards:
μ = 0.7
d = 37 mm
  = 0.037 m
F = 1400 lbs
  = 1400 * 0.453 = 634.2 kg
  = 634.2 * 9.81
  = 6221.5 N
S = 1.5
Bending moment M = $((\mu * R) + d) * F * S$
                 = ((0.7 * 0.3689) + 0.037) * 6221.5 * 1.5
                 = 2755.16 Nm

3.2 Radial endurance test:
The radial load to be imparted in the test shall be in accordance with the following formula:

Fr = F * k
Where
Fr = Radial load in N
F = the maximum load coming on to the tyre in N
K = Coefficient according to the industrial standards

 According to the industrial standards
 F = 1400 lbs
   = 1400 * 0.453 = 634.2 kg
   = 634.2 * 9.81
   = 6221.5 N
 k = 2.25
Radial load Fr = F * k
               = 6221.5 * 2.25
               = 13998.375 N

3.3 Centrifugal load:
Angular velocity is calculated by using the following formula. From the relation

$$V = r * \omega$$

Where
V = velocity of the car in m/s
 r = radius of the tyre in m
ω = Angular velocity in rad/s

Maximum speed of the car is 80 km/ hr = 22.22m/s
        V = r * ω
    22.22 = 0.3689 * ω
        ω = 60.23 rad/s

IV.   THEORITICAL ASPECTS OF A PROBLEM
4.1 STEPS
4.1.1The geometry of the wheels
The solid model of the wheel rim is created in catia and it's as shown in the figure 3.4. This shows the complete solid rim with 9 flectures and 5 bolts. The wheel is modeled according to the standards.

4.1.2Producing a mesh
After creating a model the wheel is transferred to the ANSYS using IGES translator, it is then meshed using auto mesh by parts. Throughout the model 10-noded tetrahedral solid elements are used. The figure 9.2 shown gives the complete mesh in detail.

4.1.3Element groups and material properties used
Aluminum alloy is used for the wheel. Appropriate material properties have been used for the elements in these areas. In the case of bending test, three types of element groups are defined,
8-noded tetrahedral solid element
3D elastic beam
Right bar element
In the case or radial test 10-noded tetrahedral solid element is used.

V.   MATERIAL PROPERTIES
Material used
Aluminum Alloy A 356.2

Mechanical properties:
Ultimate strength - 228 MPa
Density - 2.7 gm/cm3
Yield strength - 166 MPa
Composition:
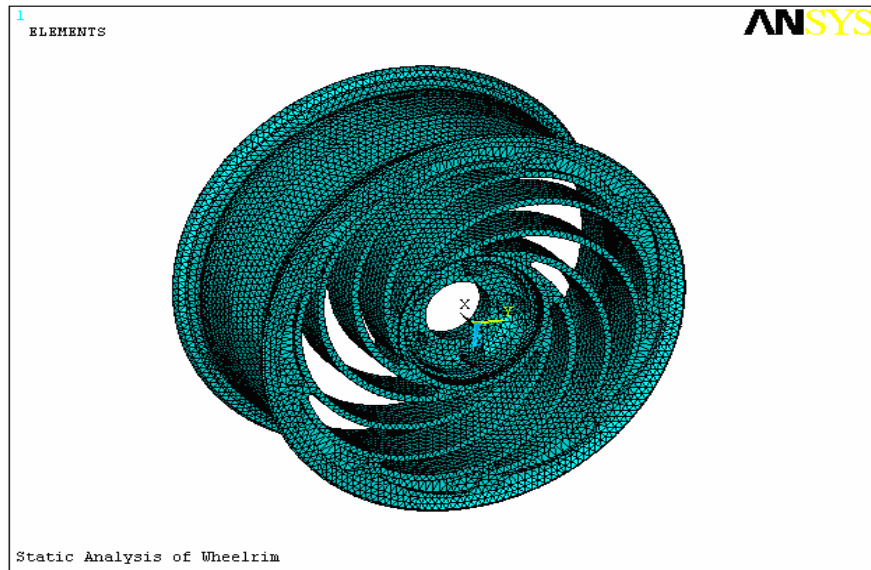Silicon- 6.5-7.5%
Iron- 0.12%
Manganese -0.05%
Magnesium- 0.3-0.45%
Zinc- 0.50%
Titanium -0.20%
Copper- 0.10%
Others- 0.15%
Remaining Aluminum.

Static Analysis of Wheelrim

VI.   DESIGN CALCULATION

6.1 Bending test
The bending moment to be imparted in the test shall be in accordance to the following formula:

$M = ((\mu*R) + d)* F * S$

M = Bending moment in 'Nm'

μ = Friction Coefficient between the tyre and the road surface (no units)

R = Radius of the tyre applicable to the wheel in 'm'

d = Offset of the wheel in 'm'

F = Maximum load acting on the tyre in 'N'

S = Coefficient specified according to the standards.

Tyre specification Radial 255/60-R17

255 is the section width in millimeters

60 is the Aspect ratio in percentage

R is the construction type i.e., Radial

17 is the rim diameter in inches

Aspects ratio = section height **/** section width

Section height = Section width * Aspect ratio

    = 255 * 0.60

    = 153 mm

    = 0.153 m

Rim diameter = 17 inches

    = 17 * 2.54 = 43.18 cm

Rim radius = 21.59 cm

    = 0.2159 m

Tyre radius = Rim Radius + Section height

    = 0.2159 + 0.153 = 0.3689 m

According to the industrial standards:

μ = 0.7

d = 37 mm

  = 0.037 m

F = 1400 lbs

   = 1400 * 0.453

   = 634.2 kg

   = 634.2 * 9.81

   = 6221.5 N

S = 1.5

Bending moment M = ((μ*R) + d)* F * S
$$= ((0.7 * 0.3689) + 0.037) * 6221.5 * 1.5$$
$$= 2755.16 \text{ Nm}$$

6.2 Radial endurance test
The radial load to be imparted in the test shall be in accordance with the following formula:
Fr = F * k
Where
Fr = Radial load in N
F = the maximum load coming on to the tyre in N
K = Coefficient according to the industrial standards
According to the industrial standards
F = 1400 lbs
= 1400 * 0.453 = 634.2 kg
= 634.2 * 9.81
= 6221.5 N

VII. LOAD CASE EXPLANATION
7.1 Load Case Bending
 In the case of bending test a vertical load of 2755.16 N is applied at a distance of 1 m from the center of the hub. Before applying the load the model should be meshed property. There are six degrees of freedom of which there are three translations and three rotations. The type of constraints depends upon the type of model. In our case we have arrested all the six degrees of freedom.

In case of wheel outer rim is constrained for all six degrees of freedom. The outer rim is selected by means of a selection set and displacement is defined by means of node by obeying the conditions as mentioned above. After the constrained are made by using appropriate commands it can be screened by using the command DPLOT. The load is applied to the node in Y direction (downward direction) after the constraints are specified for the model. The forces are plotted on the screen using the command FPLOT. Before running the analysis the model should be feed with sufficient data such as material property, real constants and element group. Under material property, the property such as density, Poisson's ratio, Young's modulus should be given as data for material, which have been selected for the model. Aluminum alloy (A 356.2) is selected as material for our model with density 2700 kg/m^3, Poisson's ratio 0.3 and Young's modulus of 67500 kg/m^2. Under element group it is necessary to check the attributes of elements mentioned in the model and then the data's are checked using DATA CHECK command. To verify that all needed attributes for an element are being defined, RUN CHECK does more elaborate checking including element connectivity. With the use of analysis option, the desired analysis (RUN STATIC ANALYSIS) is made to run for the model and the necessary results are plotted.

7.2 Load Case Pressure
In case of pressure loading, the pressure of 3.5 kg/cm2 is applied through the circumference of the wheel. Before applying the load the model should be constrained properly. The type of constrain depends upon the type of model. In our case we have constrained all the six degrees of freedom.

In the case of pressure loading, bolts are constrained for all six degrees of freedom. The bolt is selected by means of a selection set and displacement is defined by means of nodes by obeying the conditions as mentioned above. After the constrained are made by using appropriate commands it can be screened by using the command DPLOT. The load is applied to the node in Y direction (downward direction) after the constraints are specified for the model. The forces are plotted on the screen using the command FPLOT. Before running the analysis the model should be feed with sufficient data such as material property, the property such as Density, Poisson's ratio, Young's modulus should be given as data for material, which have been selected for the model. Aluminum alloy (A 356.2) is selected as a material for our model with density 2.7E-6 kg/ mm3, Poisson's ratio 0.3 and young's modulus of 0.675E5kg/mm2. Under element group it is necessary to check the attributes of elements mentioned in verify that all needed attributes for an element are being defined, RUN CHECK does more elaborate checking including element connectivity. With the use of analysis option, the desired analysis (RUN STATIC ANALYSIS) is made to run for the model and the necessary results are plotted.

7.3 Load Case Centrifugal

In the case of centrifugal loading, the wheel is constrained at the bolts and is constrained for all 6 degrees of freedom. In the case of centrifugal loading the wheel has to be transferred to the global axis i.e., keeping the axis at the center of the wheel assuming it to be revolved with reference to that axis. Cosmos has got a special feature of calculating the centrifugal load if we specify the angular velocity.

The element group and material properties are defined appropriately and the analysis is made to run. The normal stress is plotted along Y- axis and is shows very negligible amount of stress coming on to the wheel.

7.4 Load Case Vertical

In case of vertical loading, a vertical load of 13998.375 N is applied vertically from downwards. Before applying the load the model should be constrained properly. The type of constrain depends upon the type of model. In our case we have constrained all the six degrees of freedom.

In the case of Vertical loading, bolts are constrained for all six degrees of freedom. The bolt is selected by means of a selection set and the displacement is defined by means of nodes by obeying the conditions as mentioned above. After the command DPLOT, the load is applied to the node in Y direction (downward direction) after the constraints are specified for the model.

After plotting the nodes a temporary point is created at the center of the hub. This point is extruded in such a way that it passes on to 60 degree on both sides from the center of the wheel. The nodes are selected on either side of the wheel in the selection set and the load is applied only to that portion where the tyre is getting seated. The forces are plotted on the screen using the command FPLOT before property, real constants and element group. Under material property, the property such as Density, Poisson's ratio, Young's modulus should be given as data for material, which have been selected for the model. Aluminum alloy (A 356.2) is selected as a material for our model with density 2.7E-6 kg/mm2, Poisson's ratio 0.3 and Young's modulus of 0.675E5kg/mm2. Under element group it is necessary to check the attributes of elements mentioned in the model and then the data's are checked using DATA CHECK command.

To verify that all needed attributes for an element are being defined, RUN CHECK does more elaborate checking including element connectivity. With the use of analysis option, the desired analysis (RUN STATIC ANALYAIS) is made to run for the model and necessary results are plotted.

7.5 Combined Load Case

In this load case the combination of pressure, Centrifugal, and vertical loads are applied to appropriate nodes as such in individual load case. The constraints remain the same as individual loads case. The load cases number should be specified by picking from Results menu. And the remaining parts of the analysis are carried out as in normal load case.

$$k = 2.25$$
Radial load $Fr = F * k$
$$= 6221.5 * 2.25$$
$$= 13998.375 \text{ N}$$

7.6 Centrifugal load

Angular velocity is calculated by using the following formula. From the relation
$$V = r * \omega$$
Where
V = velocity of the car in m/s
r = radius of the tyre in m
ω = Angular velocity in rad/s
Maximum speed of the car is 80 km/ hr = 22.22m/s
$$V = r * \omega$$
$$22.22 = 0.3689 * \omega$$
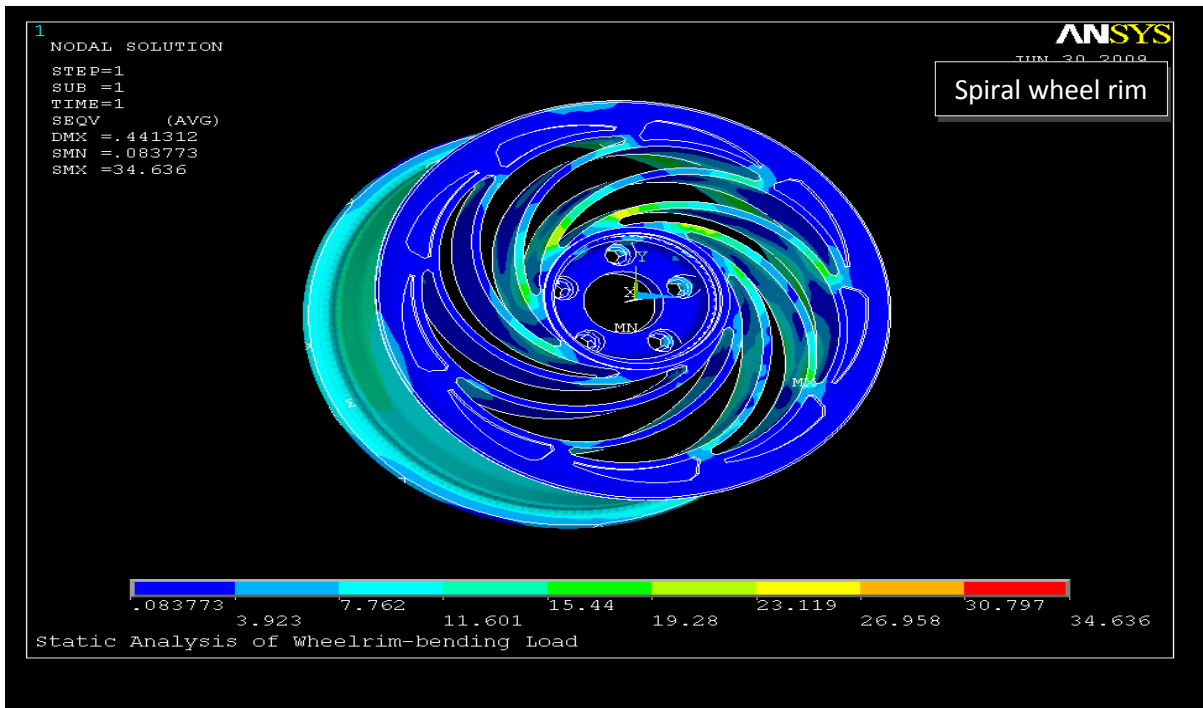$$\omega = 60.23 \text{ rad/s}$$

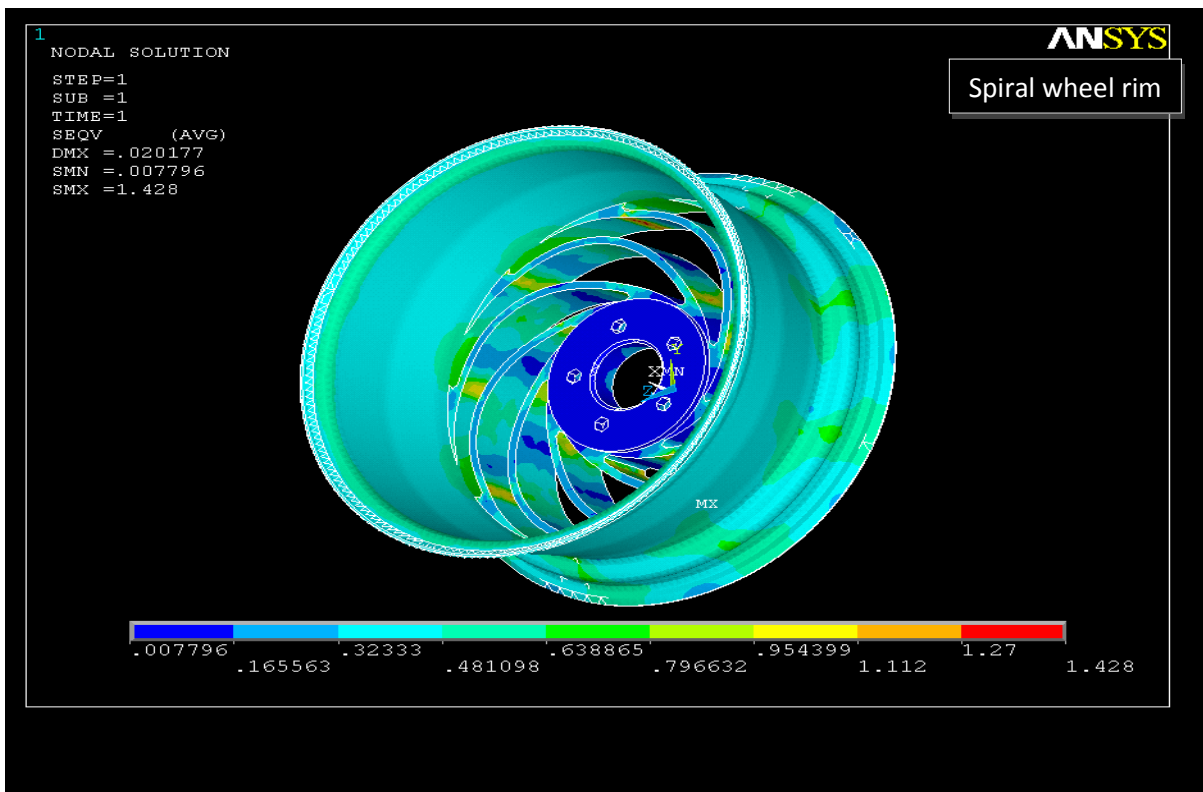**FIG 1. LOAD CASE BENDING VON-MISES STRESS DISTRIBUTION**

FIG 2. LOAD CASE CENTRIFUGAL VON-MISES STRESS DISTRIBUTION
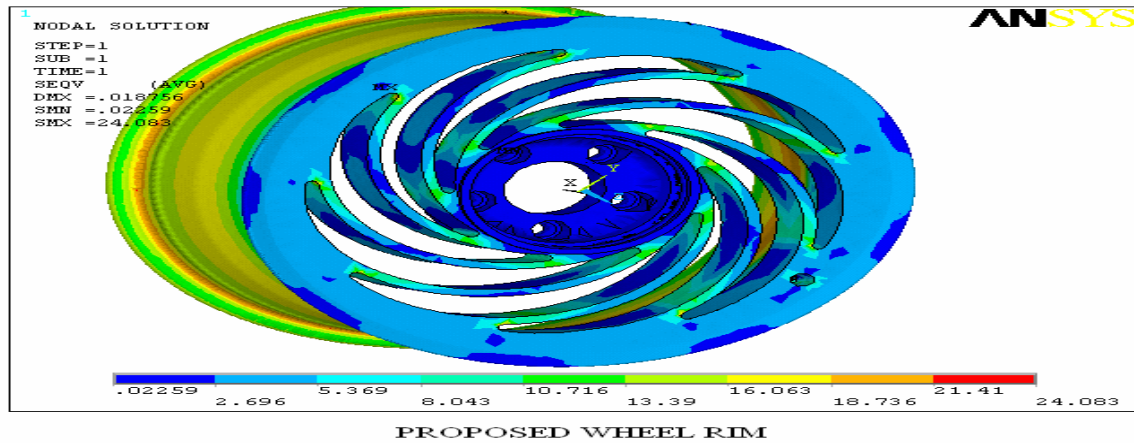
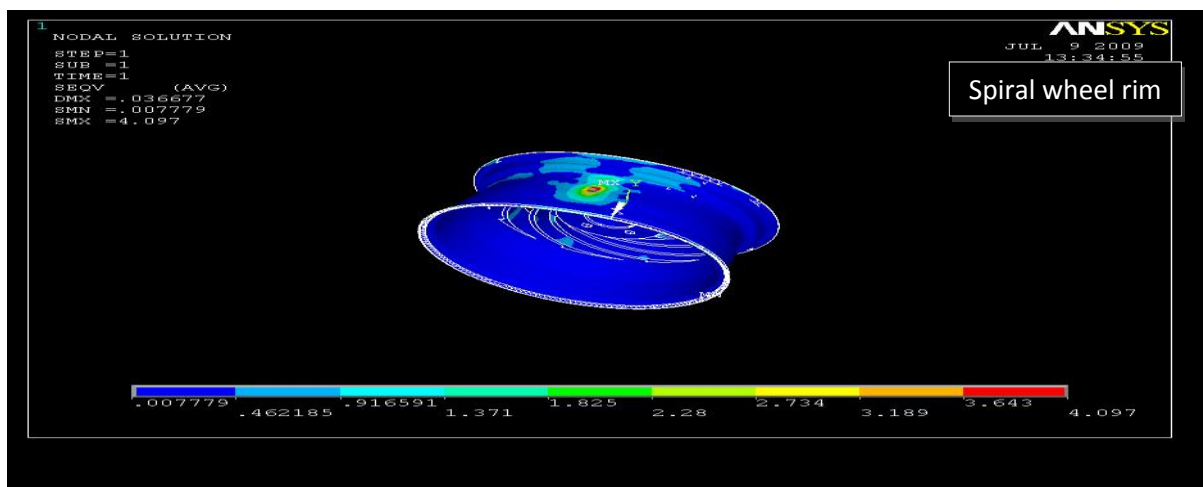**FIG 3. LOAD CASE PRESSURE VON-MISES STRESS DISTRIBUTION**

FIG 4. LOAD CASE VERTICAL VON-MISES STRESS DISTRIBUTION

VIII.   DISCUSSION OF RESULTS

The weight for the existing wheel rim is 11.8 kg and for the proposed wheel rim is 10.58 kg.
Save in material weight = Existing weight - Proposed weight
Existing weight = 11.8 – 10.58
                                = 0.1034
                                =10.34%
From the above calculation it is observed that there is a reduction in material in the case of spiral rim when compared to existing rim thus saving the material cost to a considerable amount.

8.1 Von Mises stress distribution

When a machine member is subjected to Bi-axial or tri-axial stress system, the determination of failure stress is more complicated. Hence some theories are found out for finding the failure properties of different materials. Among these theories, the von Mises theory or maximum distortion energy theory is calculated theoretically and verified with practical results.
Von Mises theory:
Vm² = σ1² + σ2² + σ3² - σ1 σ2 – σ2 σ3 - σ1 σ3

IX.   RESULT
9.1 Load case bending:
Von Mises stress distribution = 34.636 N/mm²
9.2 Load case pressure:
Von Mises stress distribution = 24.083 N/mm²
9.3 Load case centrifugal:
Von Mises stress distribution = 1.428N/mm²
9.4 Load case Vertical:
Von Mises stress distribution = 4.097 N/mm²
Tensile strength of material taken = 230 n/mm^2
= 230/34.636
=6.606
      i.e. >1.5(factor of safety limit)
     Hence the design is safe.
The stress is within the permissible limits. Thus the wheel is safe under the given loading conditions.

X.   CONCLUSION
The modeling and analysis for the wheel rim is carried out successfully and satisfactorily. The wheel is analyzed for the following two load conditions:
1.   Bending endurance test.

2.   Radial endurance test.

In radial endurance test three conditions are checked.
a. pressure loading

b. centrifugal loading

c. Vertical loading.

        The wheel is constrained appropriately and the loads are calculated based on the specifications and applied to appropriate nodes. The wheel is analyzed for the calculated loading condition and the stress plot is obtained. In the case of bending test normal stress along Y-axis shows compression on the top rib and tension on the bottom rib and compression on the bottom rib.
        In the case of pressure loading, normal stress along X-axis shows compression on the top rim and on the inside portion of the rim there is a gradual transition from compression to tension. Normal stress along Y-axis shows bending stress coming on to ribs because when the rim is getting compressed, it forces the rib to move outwards. In the case of vertical loading normal stress along Y-axis shows tension on the outer rib and compression on the outer side of the rib. When a section plot is taken it will show a gradual transition from tension to compression.
        The file, which is created in ANSYS, is equivalent with the provision for flexibility by which stress can be modified to suit any possible situation that may arise in future.
The linear static stress analysis is performed for the present wheel rim. The future work involves different types of analysis such as Impact testing, dynamic and vibration analysis etc

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