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Structural and Thermal Analysis of Railay Locomotive Wheel

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ABSTRACT

Wheel is one of the most intensively loaded components of rolling stock. When the brakes are applied, friction is generated between the wheel tread and the brake block, through which energy is dissipated. This friction generates heat which results in thermal loads on the wheel in addition to static and dynamic loads during their service. Other sources of thermal loads are sliding action between wheel and rail. These thermal loads along with structural loads may cause failure of the wheels if they not designed properly. The project deals with the behavior of the wheel due to structural and thermal loads. For this purpose, stress analysis was carried out on rail loco wheel by using analysis software ANSYS, which was modeled as axisymmetric model usingPRO-E. Also study has been done on the effect of re-profiling of the wheel on deformations and stresses due to both thermal and mechanical loads.

INTRODUCTION:

The railroad wheel supports the locomotive as it rolls on its tread along the rail and guides the vehicle through curves and switches with its flange which projects outward from the tread. When brakes are applied, the brake shoes press against the wheel treads, and through their rubbing friction slow down, stop, or control train speed. Due to this thermal loads will develop and due to the weight of the train mechanical loads will develop and the combination of mechanical and thermal stresses often caused cracks in the wheels. Some of the cracks led to loss of wheel material and wheel failures.

Thermal damages:

Due to the continuous breaking friction will be generated between the break disc and tread surface and because of this friction heat will be generated and due to conduction and convection this heat will rapidly cooled. This rapid cooling cause tensile surface stresses and that result vertical cracks in typical “dry clay” pattern and martensitic (whiteetching layer) phase is formed

PROBLEM DEFINITION

The main objective of this project is studying the behavior of railway locomotive subjected to structural and thermal loads under static conditions.Thermal loads are applied on locomotive wheels frequently. The main sources of thermal stresses in locomotive wheels are due to braking and sliding between wheel and rail. The sliding action takes place due to braking process.Similarly wheels are also subjected to horizontal and vertical loads. At the interface between wheel and rail, loads are acting. Vertical load means reaction force. This is due to weight of the bogie. The weight is distributed uniformly among all wheels. At the interaction between rail and flange horizontal load is acting. Thus the wheel is subjected to structural loads.

OBJECTIVES:

To analyze the locomotive wheel under

- Thermal Loads
- Structural Loads
- And Re-Profiling The Wheel

- Modeling The Wheel In PRO-E/CATIA

- Analyzing The Wheel By Applying Thermal And Structural Loads In Ansys And Computing The Results
- Comparing The Results With Standard Results
- Re-Profiling And Introducing Fillet To The Wheel
- Analyzing And Computing The Results For The Modified Wheel In Ansys

MODELLING PROCEDURE

INTRODUCTION TO PRO-E

Pro-E Is The Industry Oriented Standard 3D Mechanical Design Suit. It Gives A Broad Range Of Integrated Solutions To Cover All Aspects Of Product Design, Assembling And Manufacturing. Much Its Success Can Be Attributed To Its Technology Which Spurs Its Customer's To More Quickly And Consistently Innovative New Robust, Parametric Feature Based Model. Because Of That Pro-E Is Unmatched In This Field, In All Process, In All Countries, In All Kind Of Companies Along The Supply Chains. Pro-E Is Also The Perfect Solution For The Manufacturing Enterprises, With Associative Applications, Robust Responsiveness And Web Technology That Make It The Ideal Flexible Engineering Solutions To Accelerate Innovations. Pro-E Provides Easy To Use Solution Tailored To The Small Medium Sized Enterprises As Well As Large Industrial Corporations In All Industries, Customer Goods, Fabrications And Assembly. Electrical And Electronic Goods, Automotive, Aerospace, Ship Building And Plan Design. It Is User Friendly Solid And Surface Modelling Can Be Done Easily.

MODULES OF PRO-E:

Pro-E is stands for Pro-Engineering. There are different modules in Pro-E using which different tasks can be performed.

The main modules are:

- Sketcher
- Part design
- Assembly
- Drafting
- Wireframe and surface design.

Procedure for designing axi-symmetric view of locomotive wheel using Pro-E:

The model geometry is created in Pro-E software with standard dimensions. The tools like sketch and fillet are used to create axi- symmetric view of loco motive wheel. The designed part should be in xy-plane of first quadrant. So while designing the model proper plane should be selected. For this model we selected Front plane as a reference plane in Pro-E. After selecting the plane the model is created using options like line, splines, curve, arc, point etc. Thus the model was created with the dimensions given in the figure. In order to do the further analysis it should be saved with.igs (IGES) Initial Graphic Exchange Specification.

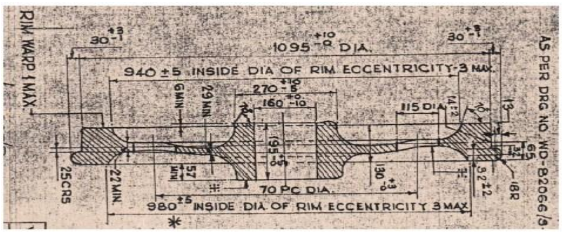

FIG: STANDARD DIMENSIONS FOR THE MODEL

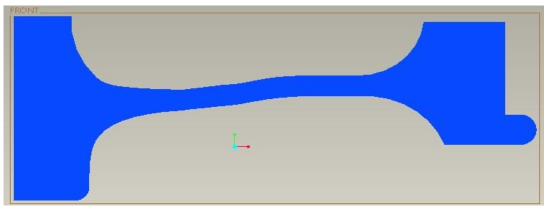

FIG:DESIGNED MODEL OF LOCOMOTIVE WHEEL CROSS SECTION

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LATER THE DESIGN IS MODIFIED BY INTRODUCING FILLET RADIUS BETWEEN FLANGE AND TREAD SURFACE, INCREASING PLATE THICKNESS AND RE-PROFILING THE TREAD SURFACE.

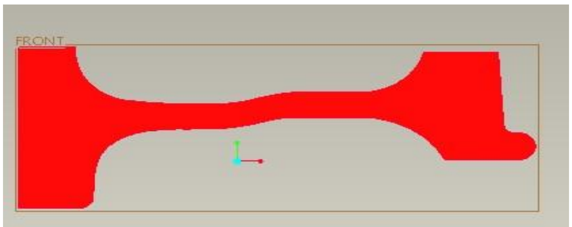


FIG: MODIFIED DESIGN OF THE LOCOMOTIVE WHEEL CROSS- SECTION

ANALYSIS OF THE MODEL USING ANSYS.

Model Geometry:

Here we can assign the material by clicking parts and the required material under Model.

Mesh:

Under mesh size is selected i.e. fine, medium or coarse and generate the mesh is generated.

Static Structural:

Supports and loads are given by selecting load on lines or surfaces (Here fixed support at one side and the load is vertically downward i.e. in negative Y direction).

Solution:

In solution the required output parameters are selected like stress, deformation etc.

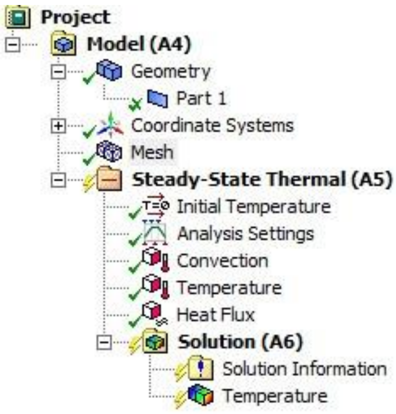


FIG: TREE FOR THE THERMAL ANALYSIS.

STEADY STATE THERMAL:

HEAT FLUX IS GIVEN ON THE LINES, CONVECTION COEFFICIENT IS GIVEN ON THE PLATE BOUNDARIES AND AMBIENT TEMPERATURE IS GIVEN ON THE HUB.

SOLUTION:

IN HE SOLUTION THE REQUIRED PARAMETER IS TEMPERATURE DISTRIBUTION.

MESH GENERATION:

Because of axi-symmetric nature of both the geometry and load, a two-dimensional axisymmetric model of the wheel cross section was constructed by using 8-node 2-D iso-parametric elements. The same finiteelement mesh was used for both the thermal and mechanical analyses. The parameters considered during mesh generation are element size is 2 and type of element is QUAD element. The triangular element is also called as constant strain triangle (CST) element which is commonly used for most of the analysis. This element is not being employed due to stress tensor being constant throughout. In practical situations, the stresses will not be constant in the element, because of which Quad element is used. The element size 2 is optimized to maintain an aspect ratio with 3-4.

THE NUMBER OF NODES USED ARE 31830 AND ELEMENTS ARE 10237. ELEMENT SIZE IS USED AS

2MM. AND FURTHER THE ANALYSIS IS CARRIED OUT BY DECREASING NUMBER OF NODES.

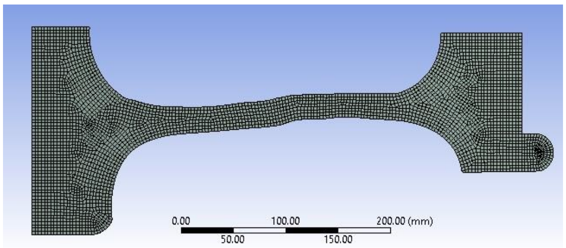


FIG: MESH GENERATION

MATERIAL PROPERTIES:

THE MATERIAL SELECTED FOR ANALYSIS IS AAR M 107 CLASS U, AND IT IS DUCTILBE IN NATURE AND IT IS A HIGH CARBON STEEL WITH A CARBON PERCENTAGE OF 0.6 - 0.79. The thermal and mechanical material properties are listed. The values of specific heat, thermal conductivity, modulus of elasticity, yield stress are mentioned below.

TABLE1: MATERIAL PROPERTIES OF AAR M 107:

Property	SI units
Thermal conductivity	49.83063e-3W/mm-k
Specific heat	0.45757e3 J/ Kg-K
Density	7833.4114e-9 Kg/mm^3
Young's modulus	2.012e5 N/mm^2
Poisson ratio	0.3
Coefficient of thermal expansion	1.69971e-5 m /mm-K
Film coefficient	28.3768e-6 W/mm^2-K
Bulk temperature	291.11K

Loads and Boundary Conditions:

Wheels are heat treated to improve the wear resistance, and imbibe the circumferential residual compressive stress in the wheel's upper rim. These are meant to prevent fatigue cracks. This also includes axial tensile stress which could

Cause rapid fracture added with impact and thermal load.

Case 1: Structural Analysis

In the static position the hub is fixed to the axle and total load is acting on the wheel rim. So the hub was constrained so that there is no deflection in the hub and restrains to rigid body motion. And the total load acting on rim is applied as vertical load of 320KN and a horizontal load of 160KN. Fig.3shows the vertical and horizontal load applied on the wheel under consideration.

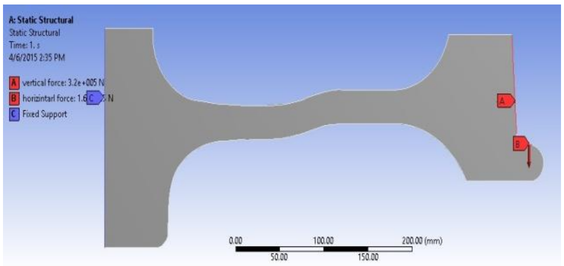


FIG: STRUCTURAL ANALYSIS- BOUNDARY CONDITIONS

Case 2: Thermal analysis

The boundary conditions applied are hub of the wheel isconsidered to be maintained at ambient temperature, the edges of the plate are subjected to heat transfer as air is in contact with the outer surface and the rim edges which are in contact with the rail undergoes heat generation due to friction. This heat flux is calculated as, the diameter of the wheel from the hub is 467.5mm.The width of the rim that is in contact with the rail is approximately 98.04mm for the selected wheel.

Calculations:

Load acting on wheels = 220KN = 22426.0958Kg.
Load acting on one wheel (m) = 5606.5239Kg
Velocity of the bogie (v) = 80KM/h = 22.22m/s.
Time the bogie brought to rest = 30s.
Kinetic energy generated at wheel = 0.5*m*v2 = 138432608 J.
Power generated = kinetic energy / time taken = 46144.226 W.

Area = π*diameter of wheel*width = 143990.815mm2.

Heat flux generated = power generated / area

=0.320466454W/mm2

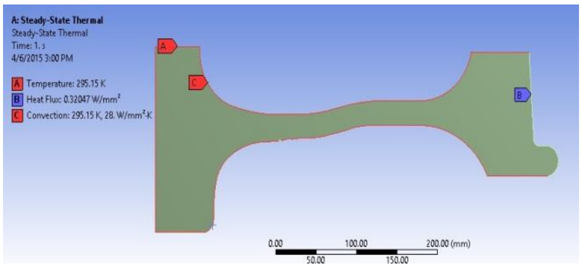


Fig Thermal analysis- boundary conditions

RESULTS AND DISCUSSIONS

Structural analysis was carried out by applying loads under given boundary conditions in static condition. Stress and deformation was observed.

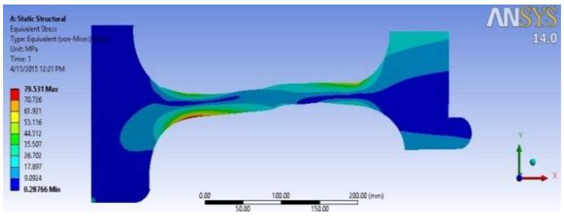


Fig: Stress distribution after applying loads

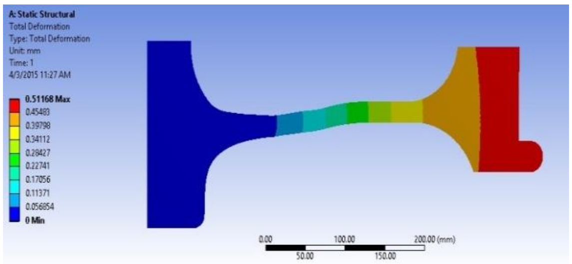
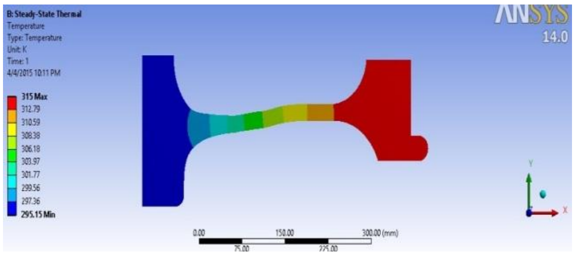


Fig: Deformation under structural loads

Table: stress and deformation variation by changing element size

Element size (mm)	No. of nodes	Max. stress (mpa)	Deformation (mm)
3	11901	79.391	0.51126
2.5	16739	79.484	0.51127
2	26050	79.531	0.51127
1.5	45742	79.56	0.51128
1	100785	79.57	0.51128

Similarly thermal loads were also applied on tread surface as heat flux. The boundary conditions were given as mentioned in above chapters. Heat flux was calculated as heat generated per unit area.

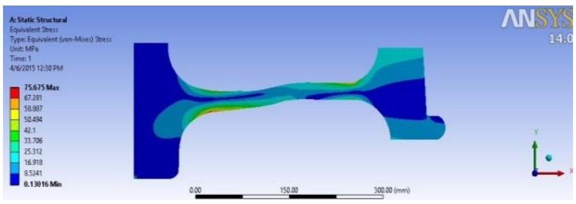


Temperature distribution under thermal load

Ansys workbench solves the model when it is discretized into finite volumes, then fluent applies governing differential equations at all finite control volumes converting them to algebraic equations and finally solves the algebraic equations for unknown dependent variables at different nodes.The results were analyzed after getting those. After that the design was modified introducing fillet radius and increasing thickness. The same analyses, both thermal and structural analyses, were carried out by gradually increasing the thickness and fillet radius. Stresses developed, deformation produced, temperature distributed were decreased. The decrease in stresses, deformation and temperature were noted down for respective increase in thickness. At the same time fillet radius between locomotive wheel flange and rail was also increased. The below figures shows us the distribution of stresses, change in deformation and temperature distribution.

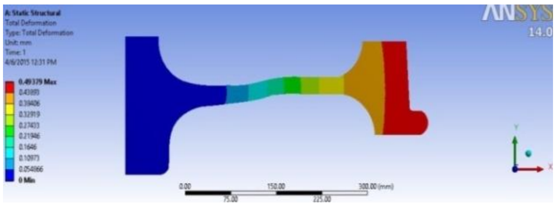
Structural analyses- Results:

For 24 mm thickness, 4 mm radius



Max Stress: 75.675 Mpa

Fig: Stress distribution for 24 mm thickness of plate



Max deformation: .49379 mm

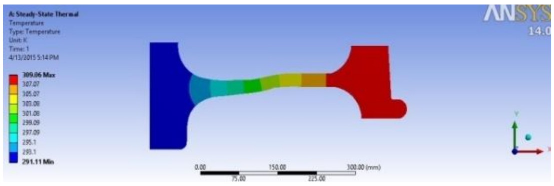
Fig: Deformation for 24 mm thickness of plate

Table. Structural analysis:

s.no.	Thickness of plate (mm)	Max. Stress (mpa)	Deformation (mm)
1	22	79.5	
2	24	75.675	0.49379
3	26	71.74	0.43381
4	28	67.798	0.40911
5	30	61.995	0.38027

Thermal analyses- Results:

For 24 mm thickness, 4 mm radius



Max Temperature: 309.06 k

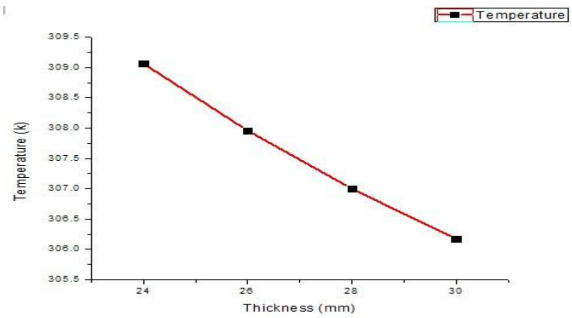
Fig : Temperature distribution for 24 mm thickness of plate.

Table: Thermal analysis

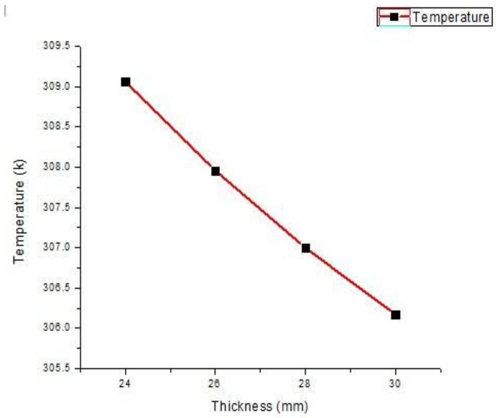
s.no.	Thickness of plate (mm)	Max temperature (k)
1	22	315
2	24	311
3	26	308

Graphs:

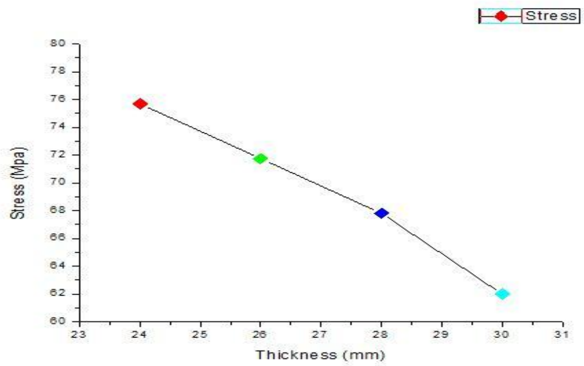
Thickness vs deformation



Thickness vs stress



Thickness vs temperature



CONCLUSION:

In this project we analyzed the effect of loads in locomotive wheel. Firstly we designed the two dimensional axi symmetric view of the locomotive wheel in Pro-E. The file was saved in **.igs** format for easy import to the ANSYS workbench software.

By using ANSYS we analyzed both structural and thermal load of the wheel separately. We observed the results. After that we modified the design of the axi symmetric view of the locomotive wheel by introducing fillet radius, increasing thickness of the plate, and re-profiling the tread surface, for minimizing the stress and deformation.

FUTURE SCOPE:

- The results are applicable for AAR M 107 material only. There may be different results for other materials.
- Results may be different if we add fins at the tread profile of the wheel.
- The results may be different with variations in heat flux and ambient temperature.
- From the results it is clear that thermal and structural loads will affect the temperature distribution, stresses and deformation. Further there may be chance to develop a device which helps in uniform temperature distribution and minimum stresses and deformation.

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