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Analysis of Railway Wheel to study Thermal and Structural Behaviour

Pramod Murali Mohan

Abstract— Wheel-Rail systems are intensively subjected to damage caused by rolling contact and slip behaviour between the wheel and the rail. This is caused because of the brake block pushed against the wheel tread to create friction through which energy is dissipated. Friction also generates heat which results in distortion of the wheel as well as thermal stresses.In order to accurately predict this phenomena an accurate understanding of the thermal and structural loading on the wheel is required. In this paper this type of problem is being discussed. Two applications are presented. In the first the behaviour of wheel due to thermal and structural loading are dealt and in the second the combined loading is being discussed.

Index Terms— Failure, Fatigue, Fracture, Heat, Railway Wheel, Structural load, Thermal load, Wear

1 Introduction

Rail systems exploit friction to transmit power, therefore high cyclic loads, dynamic loads; heat generation and wear are inevitable. Premature rail replacement, re-profiling of wheels, increased noise, reduced performance and, in the worst case, failure are the consequences of this phenomenon.

The fracture occuring on the railway wheels, are caused by thermal load. Many research institutes such as Indian Institute of Mechanical and Electrical Engineering, Rail Research Institute (ERRI) are carrying out research aiming to define new design of wheel which is as little as possibly sensitive to thermal and structural combined loading.

Due to high thermal loads acting on the wheel due to long-term braking for maintaining constant train speed on lower side or in some cases the wheels are locked.

This paper is intended towards analysing a CJ36 Griffin Freight Car wheel subjected to thermal, structural and combined loading.

Analysis is carried out by finite element method (FEM). A detailed discussion is being carried out on how to analyse railway wheel. Further, on basis of results obtained, a method to carry out combined loading and the thermal loads effect on the wheel is discussed.

2 Assumptions and Calculation

2.1 Assumptions

Due to intensive braking, there will be an increase in train traction consumed energy and thermal load. This is done to maintain the train speed constant.

• *Pramod Murali Mohan, Bachelor of Enginering in mechanical engineering in BMSCE, VTU, India. E-mail: pramodmchintu@gmail.com*

Let us consider a typical case of a 4 wheel bogie that carries a load of 220KN. This bogie is travelling at 80KM/h is brought to rest through one brake shoe on each wheel in 30s.

Following are the assumptions considered during analysis:

- CJ36 Griffin freight car wheel as shown in Fig.1 has been used for modeling.[1]
- Heat generated is uniformly distributed around the periphery of the wheel.
- Apart from the thermal load generated due to braking, the wheel is also subjected to a vertical load and horizontal load of 320KN and 160KN.
- The bogie load is equally distributed to the four wheels of the freight car.

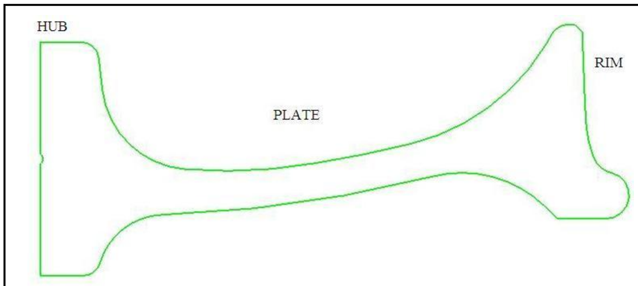

Fig.1. Cross section of CJ36 Griffin railway wheel

2.2 Calculation

Load acting on for wheels = 220KN = 22426.0958 Kg.
Load acting on one wheel (m) = 5606.5239 Kg.
Velocity of the bogie (v) = 80 KM/h = 22.222 m/s.
Time the bogie brought to rest = 30s.
Kinetic energy generated at wheel = $0.5*m*v^2$ = 1384326.8 J.
Power generated = Kinetic energy / time taken = 46144.226W.
Heat flux generated at the rim = Power generated / area.

The diameter of the wheel from the hub is 500mm. The width of the rim that is in contact with the rail is approximately 80mm for the selected wheel.

The surface area which is in contact with the rail is:
Area = π*diameter of wheel * width = 125714.285 mm^2.
Heat flux generated = 0.36720411 W/mm^2.

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3 Analysis

Griffin wheels are heat treated to improve the wear resistance, and imbibe the circumferential residual compressive stresses in the wheel's upper rim. These are meant to prevent fatigue cracks. This also induces axial tensile stress which could cause rapid fracture added with impact and thermal load.

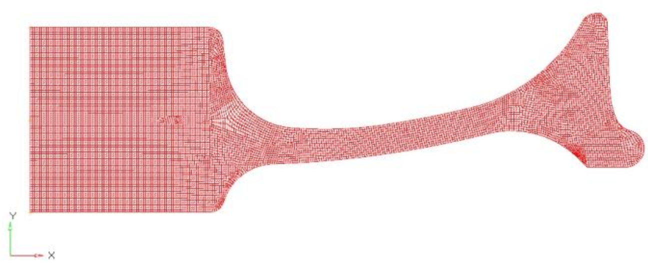

Fig.2. FEA Model of CJ36 Griffin railway wheel

Fig. 2 shows the mesh generation for cross section of the railway wheel. The mesh is generated using Hypermesh. 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 wil not be constant in the element, because of which Quad element is used. The element size 2 is optimized to maintain a aspect ratio within 3-4.

TABLE 1
Material Properties

Property	Imperial system	SI units
Thermal Conductivity	2.3993 BTU/ hr-in-F	49.83063e-3 W/mm-K
Specific Heat	0.10929 BTU/ lb-F	0.45757e3 J/kg-K
Density	0.283 lb/in^3	7833.4114e-9 Kg/mm^3
Young's Modulus	29.181e6 psi	2.012e5 N/mm^2
Poisson ratio	0.3	0.3
Coeff. of thermal expansion	9.44e-6 in/in-F	1.69971e-5 mm/mm-K
Film Coeff.	3.47e-2 BTU/hr-in^2-F	28.3768e-6 W/mm^2-K
Bulk temperature	70 F	291.11 K

The material selected for the analysis is AAR class U, Association of America Railroads AAR M 107/208, EN 1326, BS 5892 part 4. The Table 1, Depicts the material property used for analysis. [1]

A solid wheel is used for analysis which presents the dominate influence of thermal loads. Model is taken as axissymmetric because the convection and conduction process on wheel surface, during high wheel revolution is considered as uniform.

One of the major steps in analysis is determination of thermal balance, i.e. wheel areas where thermal energy exchange happens with the environment.

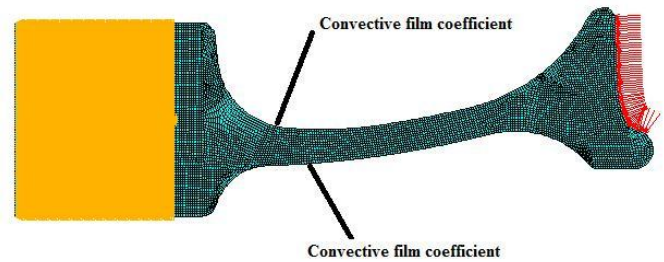

Fig.3. Thermal load and boundary condition applied on the wheel.

The plane 55 element has been chosed which suits axisymmetric with a two dimensional thermal conduction as well as applicable to steady state thermal analysis. The Fig. 3 shows the thermal load and boundary conditions applied on the wheel. The boundary conditions applied are hub of the wheel is considered to be maintained at ambient temperature, the edges of the plate are subjected to convective film coefficient as air is in contact with the outer surface and the rim edges which is in contact with the rail undergoes heat generation due to friction, this is applied as heat flux load to the wheel.

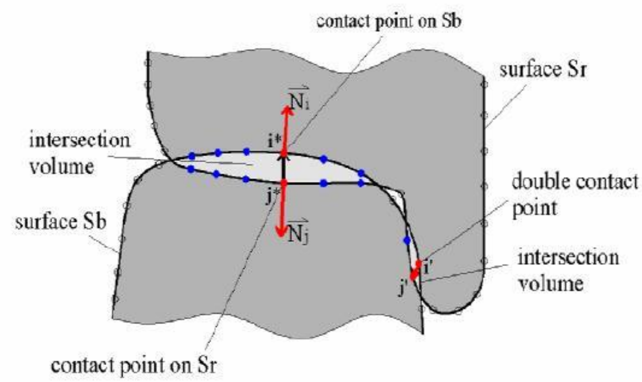

Fig.4. Structural loads acting between the rail and wheel.

Fig.4 shows the wheel and rail interactions where the horizontal and vertical loads are acting. The points in the figure represent the contact points where volume of each other is intersecting. Usually contact point problems are addressed by dynamic analysis to estimate attitude of axle and effect of normal forces on the contact surface. To carry out a detailed dynamic analysis, axle and rail is to be accounted. Here we assume only the horizontal and vertical loads acting on the wheel. [2]

Fig.5 shows the vertical and horizontal load applied on the wheel under consideration. The plane 182 element is used for structural analysis since the geometry is axisymmetric and thickness can be assigned for plane stress problem.

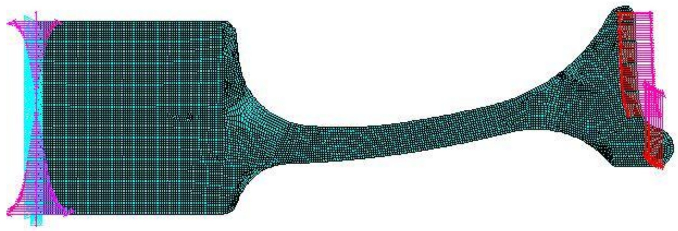

Fig.5. Structural load and boundary condition applied on the wheel.

The wheel hub is constrained so that the model restrains to rigid body motion. The rim which is in contact with rail is subjected to vertical and horizontal load of 320KN and 160KN.

4 Results of Computation

The steady state heat transfer through a rail road wheel is considered for analysis. The steady model includes heat transfer by conduction through the web of the wheel and convection heat transfer via the plates, i.e. the exposed surfaces of the wheel. The web is treated as an annular disc of uniform thickness, connected to the wheel tread and hub by contact conductance and transferring heat to the surroundings by convection.

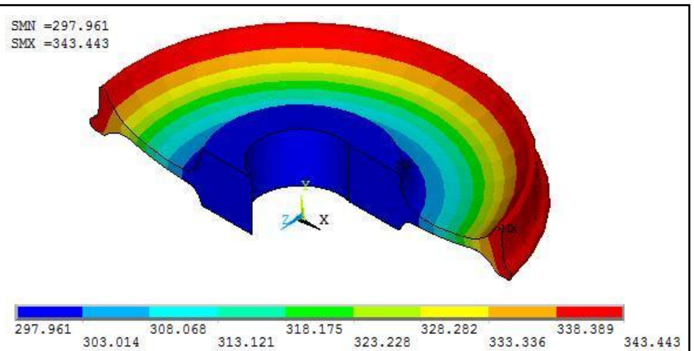

Fig.6. Temperature distribution of the wheel.

Fig.6 shows the steady temperature distribution in the uniform annular disc. Since the rim of the wheel is in contact with the rail, due to friction between rim and rail during brake applied heat generation is more. The maximum temperature attained is at the rim with a temperature of 343.44K. Due to convection around the plate of the wheel the temperature reduces even though it is conducted towards the hub. If effective cooling is not employed and due to excessive braking, residual thermal stress will get induced which will lead to wear and fatigue failure of the wheel. [3,4]

To reduce the complexity of structural analysis, the vertical and horizontal loads are acting on the rim. This results in the simplicity of point loads acting on the surface of the wheel.

Fig.7 shows the structural displacement and von mises stress distribution for the load acting on the wheel. It is observed that the maximum deflection of the wheelis 0.2196mm at the rim portion of the wheel. The material AAR M107 class U is ductile in nature and it is a high carbon steel with a carbon percentage of 0.6-0.79 percent. Due to this von mises stress is plotted. The maximum stress is observed at the bottom of the plate with a stress of 46.34 N/mm². This is due to the contact load acting on the major portion of the rim. The bottom portion of the plate's radius is less than upper portion of the plate. This along with the pre-stressed state of the plate has induced the maximum stress in this region.

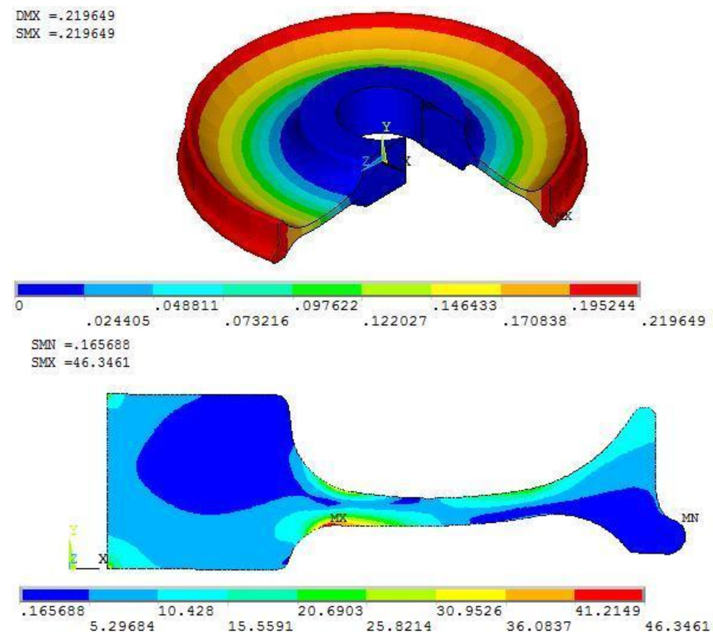

Fig.7. Structural displacement and von mises stress distribution due to structural loads.

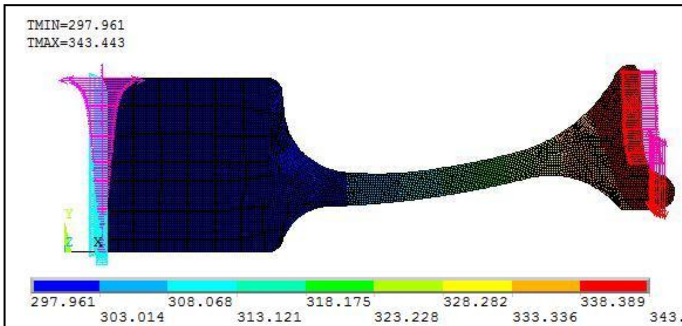

Fig.8. Combined loading acting on the wheel.

Fig.8 shows the combined loading acting on the wheel. The element plane 182 is retained for combined loading because the temperature distribution over the cross section of the wheel is applied as body loads. In this type of element the volumetric strains at the gauss integration points are replaced by the average volumetric elements to achieve reduced integration method. This helps to prevent volumetric mesh locking in nearly incompressible cases.

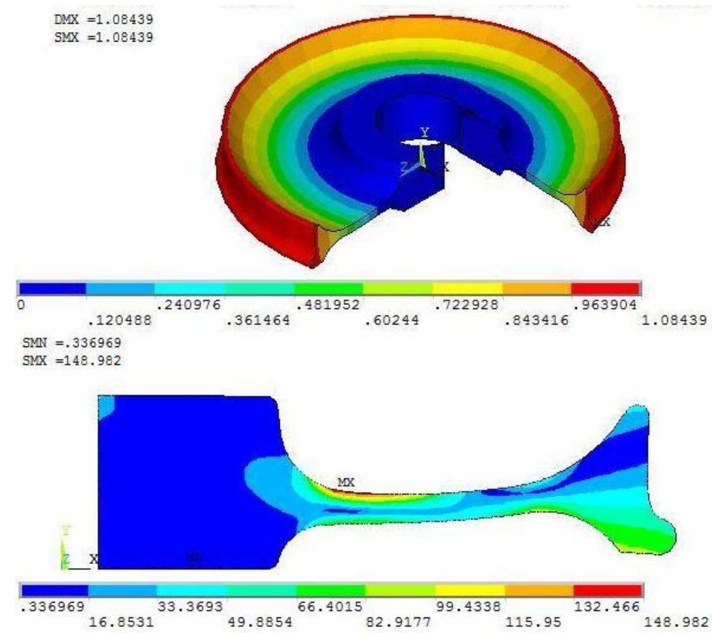

Fig.9. Displacement and von mises stress distribution due to combined loading.

Fig.9 shows the displacement and von mises stress distribution due to combined loading. Since temperature is applied as body load, thermal stresses are developed in the wheel. This along with the vertical and horizontal load has led to 1.084mm of deflection of the wheel as compared to 0.2196mm of deflection due to structural loading. If the excessive braking of the wheel is excercised continuously over a period of time, plastic deformation occurs on the surface of the wheel causing ratcheting across the periphery of contact surface of the wheel.[7,8]

This also leads to pressure driven vertical cracks in the wheel. As the temperature of rim increases, there will be a built up of the residual stress. This eventually leads to increase in deflection of the wheel, causing the wheel damage called "Wheel flat" formed by a locked wheel sliding on a rail.

The maximum stress attained is 148.982N/mm² as compared to 46.34 N/mm² during structural loading. Large amount of stress is induced due to the thermal load. During selection of material for wheel design, the factor of safety for yield stress should be considered greater than 2 to avoid damage that may occur due to combined loading.

Due to these damages it causes high impact load resulting in cracking, wear, noise and discomfort.

5 Conclusion

The paper is intended to outline a simple first stage analysis of railway wheel. The analysis result depicts the behavior of wheel for varying loading conditions. It is observed that excessive braking of wheel leads to thermal overloading which results in fatigue, crack propagation leading to fracture and wear.

In order to prevent damages, measures are to be taken for consistent wheel monitoring process and examination of residual stresses in order to prevent fracture.

Following process can be carried out to monitor:

- Determination of paint burns and therefore to choose the paint sensitive to high temperatures.
- Determination of increase in the distance of the internal side surfaces of the wheel.

Owing to these damages, wheel reprofiling has to be carried out. In order to prevent wheel fractures caused due to thermal loads best method is to test the residual stress of wheel rim of different material to determine the allowable level.[5] This along with intensive research by carrying out vibration analysis, transient analysis along with rail and axle would help to prevent the wheel damage at the initial stage.

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