

Mitigation of hanger pin failure in Pakistan railway carriage system by the application of COMSOL Multiphysics

*Ahmad Kamal Mustafa*¹, and *Mushtaq Khan*²

¹School of Mechanical and Manufacturing Engineering (SMME), National University of Sciences and Technology (NUST), Sector H-12, Islamabad 44000, Pakistan

²Mechanical Engineering Department, Prince Mohammad Bin Fahd University, Al Khobar, Saudi Arabia

Abstract. The frequency of failures in hanger pins of Pakistan Railway carriages has risen to an alarming level. Such as hanger pins have become the reason for the highest number of cases regarding failures of Carriage and Wagons in Pakistan. The pins have been failing after only 3 months while the intended life of these pins was supposed to be 6 months at least. Previously we have been using rectangular cross-section cotter pins in the hanger brackets. Studies have shown that instead a circular cross-section cotter pin can make a major contribution to the lower the value of these fatigue stresses. In this study, we compute and perform the stress and fatigue analysis on the hanger pin assembly using Findley criterion. Findley criterion was used as it most closely resembled in the properties needed to carry out our desired simulation. COMSOL model is used to compute the stresses as well as do the fatigue analysis on the said model. Fatigue usage factor has been used in the COMSOL. The first part contains the analysis on the already in-effect hanger pins of rectangular cross-sectional area. While the second half contains analysis done by changing the cross-section to modified circular shaped hanger cotter pins. The new proposed material proved to have decreased the stresses induced in the components thus increasing its life.

Keywords: fatigue and stress analysis, Findley Criterion, COMSOL Multiphysics

1. Introduction

Truss bar is a component of the under gear of a Conventional Bogie. It is an iron beam having two brake blocks, one on each end. It is linked with a pull rod by means of floating lever. The force which comes out from vacuum cylinder reaches to the truss bar which transmits it to the brake blocks. Truss bar hanger is a strong lever used to hang the truss bar assembly. It is fastened with frame from one end and holds the truss bar from the other end. Truss bar is an extremely vital component of a bogie as it transmits the braking power to the brake shoes and brake pads. The problem regarding the truss bar hanger pins have been in the system since long but in the past 1-2 years it has risen exponentially. There is a dire need to increase the life span of the truss bar hanger pins so that they may at least be able to survive till their life expectancy.

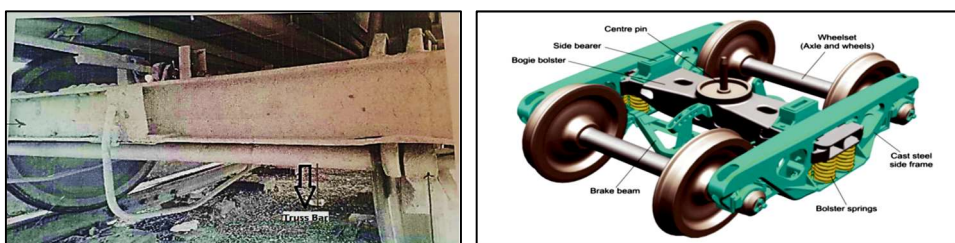


Figure 1: Truss bar and undergear of 4-wheeler bogie

In the hotter areas of Pakistan i.e. lower Punjab and Sindh belt, the temperatures are in the range of 45-50 °C which are also a big concern. The bogies were originally made for vacuum-based braking system with the maximum speed of up to 65 km/hr but were later modified to run in air-brake system with the maximum speed increased to 105 km/hr without any subsequent changes in the material of bogie. The track all around Pakistan is outdated and even though it has been changed in parts from time to time, due to no fencing around the track and people living beside the railway line, has led to weakening of the ballast underneath the track which in-turn has led to uneven tracks and more pressure and forces on the components. The hanger pins have to bear extra jerks and vibrations due to it as well. There are various probable causes that might be the reason of the reduced life of the hanger pins in Pakistan Railways Some of them are; uneven track, loose coupling, lack of supervision, lack of spare parts and humidity.

The truss bar along with its hanger pin had a life span of 9 months. Currently, the number of cases to hanger pin failures have risen quite a bit in the past 2 years and are a cause of great concern for all administration. Apart from that there is no Research and Development Department in Pakistan Railways which has in-turn led to almost more research been done in the department and hence no proper solution is ever given out and instead a solution is presented without any analysis or proper experimentation.

The ultimate purpose of the study is to investigate the stresses involved in the truss bar hanger pin assembly and come with modification that might help in improving its durability. The first objective of the study is to make and simulate the truss bar hanger pin assembly in COMSOL Multiphysics software and second objective is to modify the structure and perform the analysis on the modification to improve it. The basic control unit for the study has been taken as 4-wheeler BG-64 Germany made Bogie. The distance has been taken from Lahore Railway station to Karachi Cantt Railways Station.

2. Methodology

The analysis presented in this study has taken an average value of forces. It does not involve variations due to friction and wasted energy due to heat loss from brake application.

The pressure inside the brake cylinders = 25 psi
Diameter of Brake cylinder = 7 in
Calculating the Cross-Sectional Area (A) = $\pi r^2 = \pi \times (7)^2 / 4 = 38.484 \text{ in}^2$
Force = Pressure x Area = (25) x (38.484) = 962.1 lbf

The forces are being calculated at an angle of 30 degrees as it the maximum angle that the rod makes w.r.t the horizontal plane.

Forces in different planes:

Force in the x-axis : $F_x = 0$
Force in the y-axis : $F_y = 962 \sin (30) = 481 \text{ lbf}$
Force in the z-axis : $F_z = - 962 \cos (30) = - 833 \text{ lbf}$

In this research work Findley Criterion is used because it is very closely resembled the model that we are analyzing.

$$f = \frac{1}{2}\sigma_{-1}(k + \sqrt{1 + k^2}) = \frac{1}{2}\sigma_0(2k + \sqrt{+(2k)^2}). \quad (1)$$

Using the values of stress as 962 lbf and 657 lbf in-order to compute the values of limit factor and the normal stress sensitivity coefficient factor.

$$\begin{aligned} 657k + \sqrt{431649k^2 + 431649} &= 2f \\ 962k + \sqrt{925444k^2 + 231361} &= 2f \end{aligned} \quad \text{for } f, k. \quad (2)$$

$$\begin{aligned} f &= \frac{21\sqrt{182060905}}{610} \approx 464.512931052252, \\ k &= \frac{100144\sqrt{182060905}}{3823279005} \approx 0.353425019689735 \end{aligned}$$

Hence the value of normal stress sensitivity coefficient factor is 464.512 and the value of limit factor of Findley is 0.353

The distance from where the data collected was taken from the Lahore Junction to Karachi Cantt Railway station as both of them are the major stations and most of the passenger trains either start or are terminated over there. The distance from Lahore Junction to the Karachi Cantt Railway station is of 1219 kms.

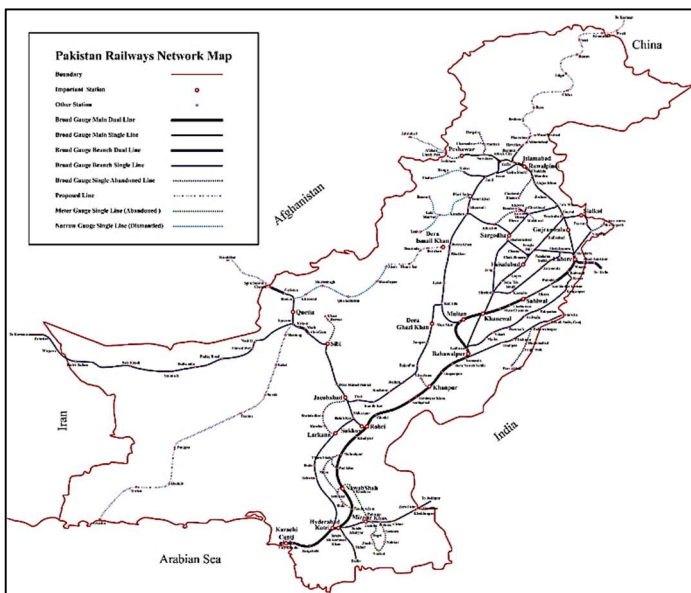


Figure 2: Pakistan Railway Track

The Sample was selected at random from one of the derailment sites on 12 November 2019.



Figure 3: Damaged hanger and new hanger along with pins and their samples

The sample's profile was fit was our analysis. A new hanger bar pin was put beside a damaged one for the purple of size and shape comparisons.

2.1 COMSOL Modelling

The software used in the analysis was the COMSOL Multiphysics 5.5. It has very versatile features and also user friendly. COMSOL uses java as a language. One can easily select boundaries and surfaces for the simulations. The module of fatigue usage factor is also very significant. COMSOL has multiple modules to select from. Some of them are; Optimization Module, Microfluids, CFD, Structural Mechanics, Fatigue, Non-linear Structural Material, MEMS Heat Transfer etc. The Material used in the calculations was Steel AISI 4340. Which was also confirmed from the Elemental Analysis done from the USPCAS-E Centre, NUST.

The characteristics of the material were taken as:

Name	Value	Unit
Density	7870[kg/m ³]	kg/m ³
Young's modulus	205e9[Pa]	Pa
Poisson's ratio	0.29	1
Normal stress sensitivity coefficient	0.353	1
Limit factor	464.513[MPa]	Pa

2.2 Solid Mechanics Module

As the values taken were of forces and we had to find the stresses applied as well as the fatigue analysis the Solid Mechanics module was the most preferred one.



Figure 4(a) and (b): All Domain Selected and mesh setting

2.3 Boundary Conditions

The model was fixed from two points in the model. The points where it is attached to the truss bar of a BG-64 Bogie are shown in Fig 4.4 (a). The boundary Load was applied to the longitudinal rod that connects the brake cylinders with the truss bar as shown in Fig 4.4 (b). It makes an angle of 30 degrees. And the horizontal and vertical components of the forces have been calculated as 418 MPa and 833 MPa.

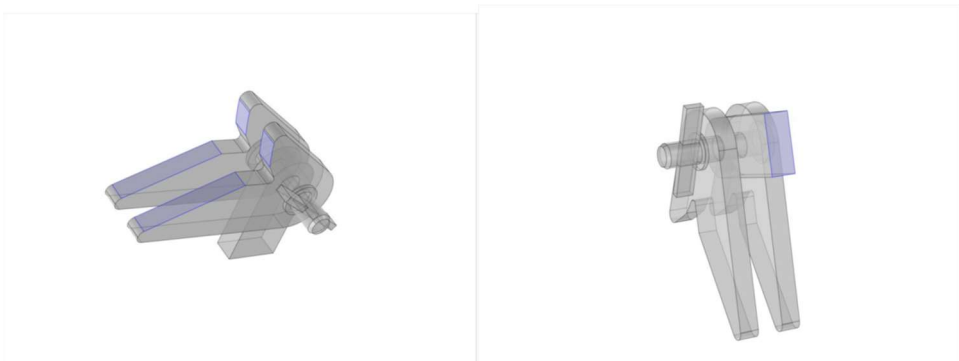


Figure 5(a) and (b): Fixed constraints and Surface boundary load

2.4 Findley's Criterion

For the purpose of calculations Findley's Criterion was used as it best served our purpose. For the Findley Criterion the orientation of the critical plane normally coincides with the plane where the maximum value of the linear combination occurs. For the Mataka Criterion the critical plane would coincide with the maximum shear stress amplitude. The value of normal stress sensitivity coefficient factor is 464.512 and the value of limit factor of Findley is 0.353.

2.5 Modified Design

There were a couple of changes that were implemented, and a new model was made and analysis was done on it.

2.5.1 The Cotter pin

The cotter pin was in rectangular shape in the original model as well as in the real railway bogies as well.

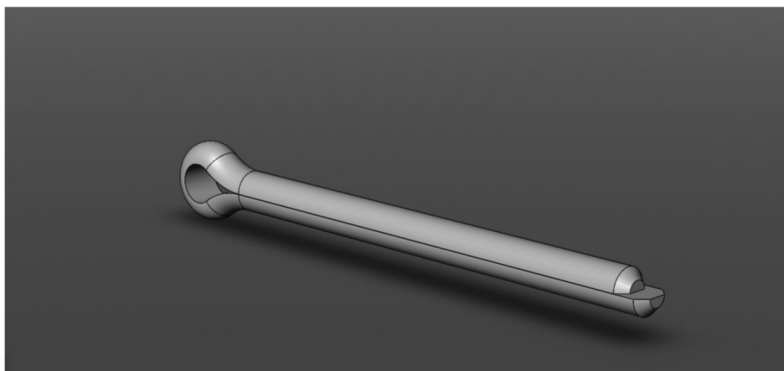


Figure 6: New Circular Cotter Pin

The modified cotter pin has a circular cross section with reduces the stresses induced in it due to the absence of corners.

2.5.2 Change of Material

The Material used in the calculations was Structural Steel. The characteristics of the material were taken as:

Name	Value	Unit
Density	7850[kg/m ³]	kg/m ³
Young's modulus	200e9[Pa]	Pa
Poisson's ratio	0.30	1
Normal stress sensitivity coefficient	0.353	1
Limit factor	464.513[MPa]	Pa

3. Results

The Solutions are analyzed first with the pre-existing conditions and values and then with the new conditions and values. Both models were taken as a linear elastic material with common properties. In a new model, couple of changes were implemented such cotter pin and changed material and then analysis was done on it as shown in figure (5.1).

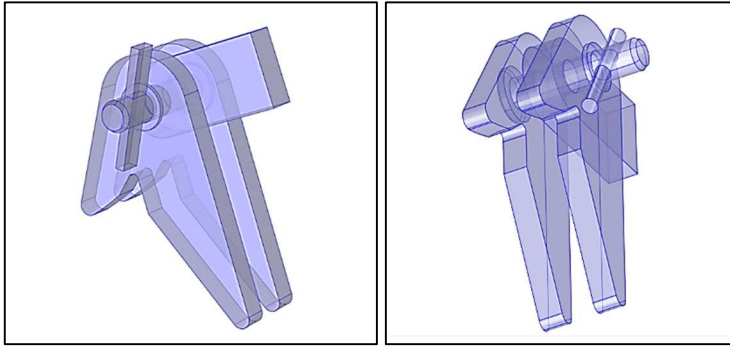


Figure 7(a) and (b): Original and Modified Model

In original model the maximum value of the Vons mises stress is $1.83 \times 10^8 \text{ N/m}^2$. The Yield Strength of the material is $2.65 \times 10^8 \text{ N/m}^2$ which is within its range. Which means that it is not breaking because of constant abnormal stress. Whereas in modified model the maximum value of the Vons mises stress is $4.25 \times 10^7 \text{ N/m}^2$. The Yield Strength of the material is $2.65 \times 10^8 \text{ N/m}^2$ which is within its range. Which means that it is not breaking because of constant abnormal stress but its value has decreased significantly as shown in figure (5.2).

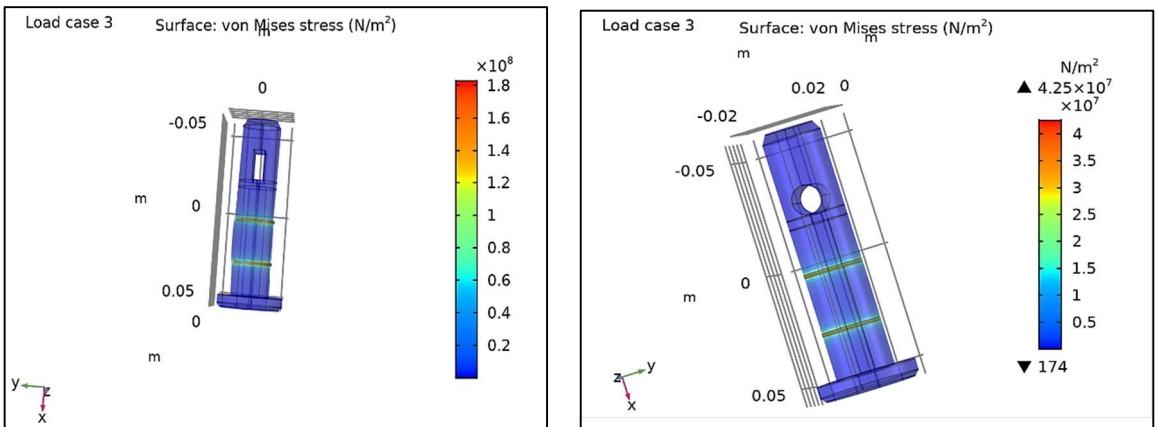


Figure 8(a) and (b): Von Mises Stress Solution of original Model and modified model

Fatigue Usage Factor may be defined as the ratio of number of cycles that the part is expected to endure to the allowable cycles. This term is only used in the cases of stress-based evaluations. By another definition it is also called as a prediction in the stress-based Fatigue models where it is the fraction between the applied stress and stress limit. Here the

resulting factor is 0.13. The value of number of cycles in the Fatigue usage factor is taken as one million cycles.

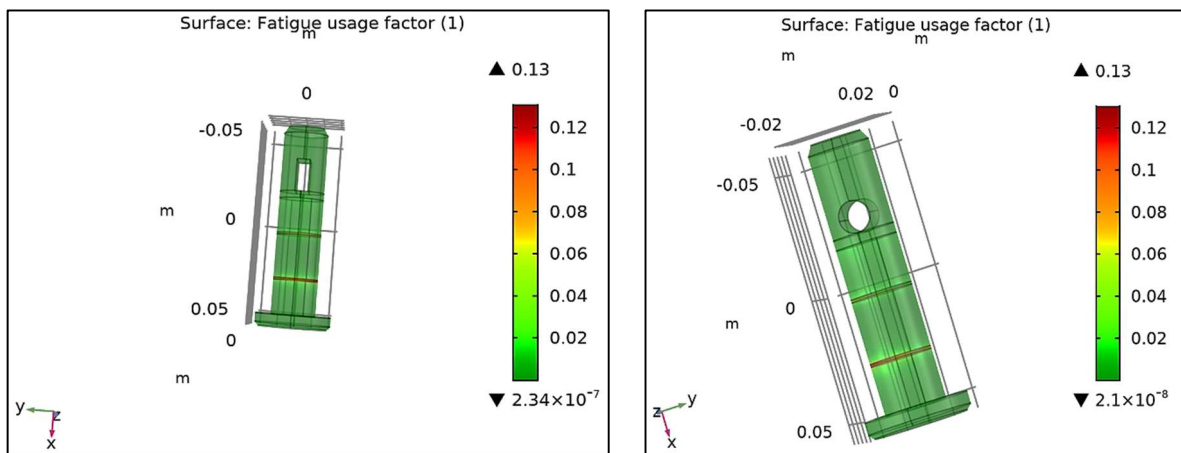


Figure 9(a) and (b): Fatigue Usage Factor Solution of original Model and modified model

The Life that these pins were made to last was 9 months and as we can see they are not even utilizing half of their life and are failing rather quickly. However, the amount of stress is quite different in both the simulations and hence this new modified design would be certainly an improvement in the original design as shown in figure (5.3).

4. Conclusion

The number of failures of hanger pins in the truss bar assembly can be significantly reduced if the new modified model is used. The new proposed material proved to have decreased the stresses induced in the components thus increasing its life. COMSOL Multiphysics proved to be a great software for the simulations. However, to implement the model in real life is really important and request for permission to implement has already been forwarded to the people concerned.

5. Recommendation

It is recommended to have a bigger set of materials that should be tested in-order to get an even better solution. It is also recommended to include experimentation in future as it was not possible to do so due to the shortage of time.

6. Future areas of research

Due to the absence of a Research and Development in Pakistan Railways there is a lot of scope for research in the organization. As far as future research in my proposed topic is concerned it can be further improved by following:

1. The simulations can be tested experimentally in the Pakistan Railways.
2. A larger set of data can be taken by taking proper permission from the Chief Mechanical Engineer.

3. More Materials can be tested for better results.
4. Proper measurements of force and pressure can be obtained using proper measuring instruments instead of using approximate values.

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