

Failure Analysis of Pivot Housing in Wag-09 Locomotive

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Abstract

Railway system in India plays a vital role in transportation. The demand of prolong service life and reliability of the various component are always considered as critical issue. The component of the study has been obtained from the Central Railway, Electric Loco Shed Ajani Nagpur M.S India. In the present study the failure of one of the components of traction link (Pivot Housing) is carefully investigated. This paper presents theoretical and finite element analysis (FEA) results for the pivot housing assembly which predicts the failure load and determines ultimate failure strength. A significant result of these studies includes increasing the bending strength of Pivot Housing. The measured stresses were in good agreement with theoretical results. To get the additional insight, finite element analysis results are presented and compared to both.

Keywords: FEA; Failure analysis; Pivot housing; WAG-9

Introduction

WAG-9 is the name of a type of electric locomotive used in India shown in Figure 1. This six axle loco is designed to give a starting tractive effort of 460 kN and maximum braking effort of 260 kN. Rated 6000 HP. Pivot Housing is an assembly used in Indian Railway's loco WAG-9/WAP-7 as a main power transmitting unit as shown in Figure 2 and 3. This assembly connects the superstructure (under frame) and bogies. The centre-pivot of the bogie is used to transmit the tractive and braking forces. It has also to bear the body weight. As this assembly is main power transmitting unit, numerous types of forces acts on the assembly which may be static or dynamic. Pivot assembly comprises of various components such as traction link, safety cables, chain, link rod, pivot housing, ring, retaining plates, and locking tab [1,2].

The loco was manufactured initially in Switzerland. In 1998 the technology is adapted by Indian government and then the manufacturing was started in India. This assembly is used to connect the central assembly of the transformer and two loco bogies. Failure of pivot housing of this assembly is discussed in detail in this investigation.

In this assembly the pivot housing is situated at each end of the link rod.

Methodology

Data collection and visual inspection

As per the maintenance record [2] of Loco Shed that there is early



Figure 1: WAG-9 Locomotive.

premature failure of Pivot Housing. Following are the observations on failed pivot housing:

1. The pivot housing usually fails during running condition after certain period.
2. 100% crack at the neck region of flange plate.
3. The initiation of crack begins near the corner of neck region which progresses and breaks the flange plate.

Specification of pivot housing

Dimensional details of pivot housing are as follows in Table 1 which is mentioned in the input data [3].

This Pivot Housing material is made up of cast steel (DIN 17182 GS 20Mn 5) [2]. In this proposed study the stress analysis of the crack



Figure 2: Pivot Housing Assembly.

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Particulars	Pivot Housing
Outside diameter (Do) (mm)	320
Inside diameter (Di) (mm)	250
Weight (W) (kg)	31

Table 1: Dimensional details of pivot housing.



Figure 3: Pivot Housing.



Figure 4: Failure Component.

formed at curvature of the flange region (Figure 4) of the Pivot Housing is discussed in details.

Results and Discussion

Theoretical analysis of forces acting on pivot housing

Schematic diagram of load distribution on Pivot Housing is shown in Figure 5

Pivot Housing is subjected to action of force, which can be conveniently resolved into three components:-

- Tangential (F_z) (centrifugal load)
- Radial (F_x) (pulling load)
- Axial (F_y) (cyclic load) [4].

CASE-I: Load Analysis for Loco Moving on Straight Path

The overall load of about 123 tonne of loco is acted over the Pivot Housing assembly. The schematic diagram of Figure 5 shows the load

distribution over the pivot Housing. Using various load acted upon the pivot Housing assembly when loco is moving on straight path are as given below.

1. Total weight of loco=123 T
2. Speed V_{max} =100 km/hr
3. Speed V_{min} =50 km/hr
4. Radius of curvature=292 m
5. Under weight (bogie weight)=20 ton
6. Cross sectional area of Flange=7800 mm²
7. Maximum Pulling force=24 Tonne
8. Minimum pulling force=6 Tonne [2]

CAST STEEL DIN 17182 GS20Mn5, following properties are considered [5,6].

- Ultimate Tensile strength=550 MPa
- Yield strength=300 MPa
- Endurance limit for cast steel:-

$$F_e = 0.4f_u$$

$$= 0.4 \times 550 = 220 \text{ mpa}$$

- Endurance Strength (F_e)=220 Mpa

Where F_e -endurance stress

F_u -Ultimate tensile stress

The load 24 Tonne is acting on a single pivot Housing. As there are two Housings, net load is 48 Tonne. This load is distributed over entire pivot Housing assembly. Following assumptions were made for simplification [7].

- The rails are smooth and there are no geometrical irregularities.
- The loading is static.
- Impact load during operation are neglected.
- All other kind of load than mentioned in calculations is neglected.

By applying the Soderberg Method for the combination of stresses, using surface finish factor and stress concentration factor, yield stresses

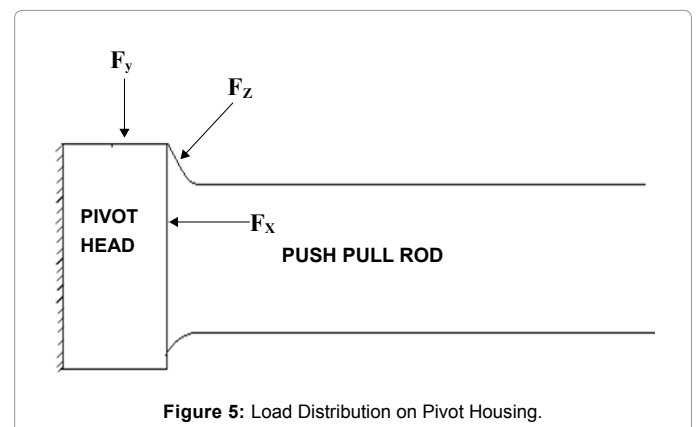


Figure 5: Load Distribution on Pivot Housing.

Particulars	Unit	Pivot Housing
Fatigue stress concentration factor (k)	-	1.35
Factor of safety	-	2
Surface finish factor (ksur)	-	0.85
Size factor (k _{sz})	-	0.84
Load (w)	N	235440
Yield stress (f_y)	N/mm²	164.72

Table 2: Analytical results of pivot Housing for the loco at straight path.

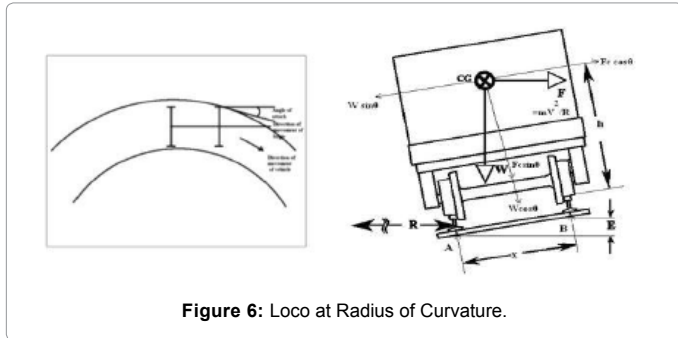


Figure 6: Loco at Radius of Curvature.

and other design parameters were calculated for the case of loading on straight path and are shown in Table 2.

Soderberg Equation- (for ductile material) [6]

$$\frac{1}{f_s} = \frac{f_m}{f_y} + \frac{f_v \times K}{f_u \times k_{sur} \times k_{sz}}$$

Where,

f_e =Endurance Limit

F_u =Ultimate stress (tensile or compressive)

f_s =Factor of safety

f_m =Mean stress (tensile or compressive)

f_y =Yield stress

f_v =Variable stress

k =Fatigue stress concentration factor

k_{sur} =Surface finish factor

k_{sz} =Size factor

CASE-II: Load analysis for loco moving on the curved path

While moving on the curved path the loco is subjected to additional load because of centrifugal force. The Figure 6 shows the load when the loco is moving on curved path. Following are the details for calculation of the load.

1. The loco speed is 100 km/hr.
2. The radius of curvature is 292 m, which is the minimum recommended radius.

The resultant stress calculated analytically is found to be (164.72+83.48)=248N/mm². From Table 2 and 3, it is clear that the stress is exceeding the endurance stress 220 N/mm² which is exceeding the endurance stress 220 N/mm².

Finite Element Analysis By Ansys-12: Using the technical specification of pivot housing the Finite Element analysis was carried

out in Ansys 12.0. A higher order 3-D, 10-node element having three degrees of freedom at each node: translations in the nodal x, y, and z directions SOLID92 was used [8]. Theoretical analysis of pivot housing carried out in earlier section and results obtained for maximum yield stress (F_y) are compared by using Finite elemental analysis.

The Figure 7 depicts the loading and boundary condition.

A 3D FE mesh was developed to study this problem and obtain the stress distribution in the part. Figure 8 shows 3D FE meshes of the node [9].

As clearly seen from Figure 9, the maximum stress value is obtained in the flange region and minimum stress value is obtained in the fixed pivot region. Table 4 shows the comparison of theoretical analysis & FE analysis.

The entire result and discussion thus can be compiled as follows.

1. Theoretical equivalent stress value (F_y) is almost similar to that of the value calculated using Finite element analysis software. Hence it can be said that theoretical equivalent stress value (F_y) is validated using smart design tool of finite element analysis.
2. Allowable stress value is 220 N/mm² [6]. As per design

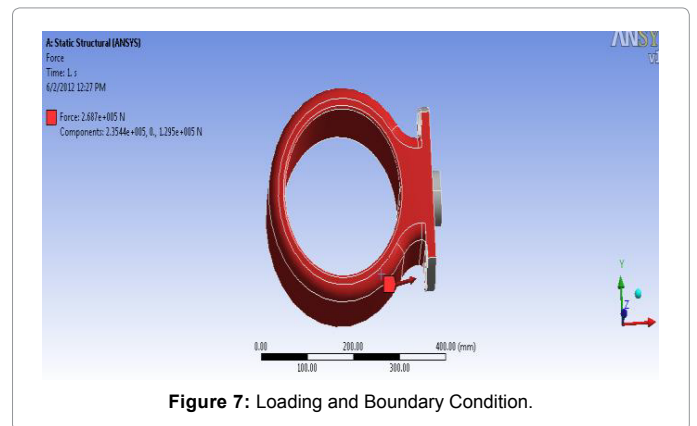


Figure 7: Loading and Boundary Condition.

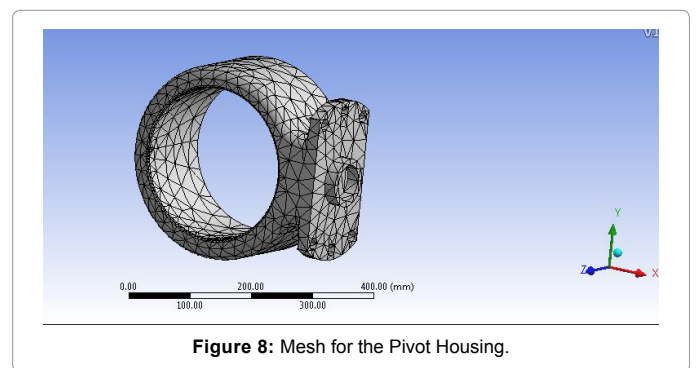


Figure 8: Mesh for the Pivot Housing.

Particulars	Unit	Pivot Housing
Load (w) (F _z)	N	129500
Yield Stress (F _y)	N/mm ²	83.48

Table 3: Analytical results of pivot Housing for loco at curved path.

Parameters	Analytical	ANSYS
Equivalent stress (N/mm ²) (F _y)	248	244.6

Table 4: Comparison of Analytical and ANSYS calculation.

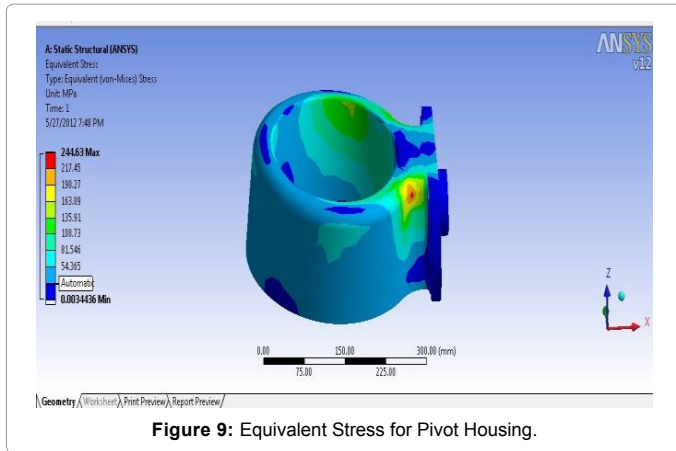


Figure 9: Equivalent Stress for Pivot Housing.

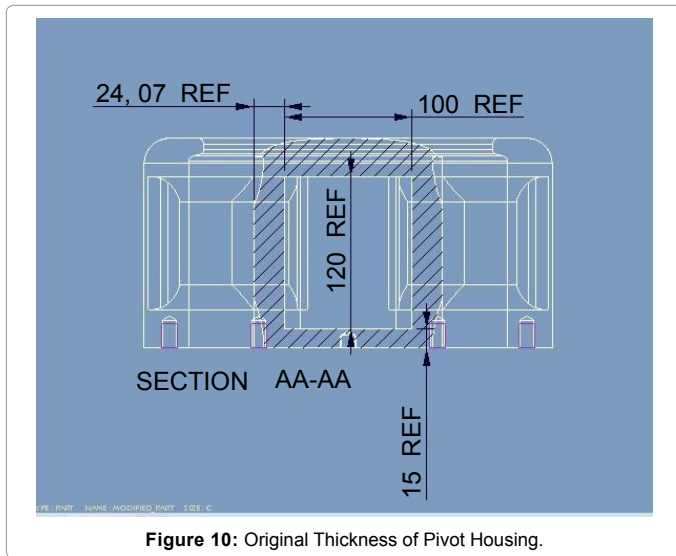


Figure 10: Original Thickness of Pivot Housing.

Results	Design Changes	Thickness	Area	Endurance Limit (Mpa)	Max Stress (Mpa)
Iteration No. 1	Original 120×100	15×24	7800	220	248
Iteration No. 2	100×90	25×29	10800	220	179.3
Iteration No. 3	80×80	35×34	13400	220	145.5
Iteration No. 4	60×70	45×39	15600	220	150.3
Iteration No. 5	40 X 60	55 X 45	17400	220	111.22

Table 5: Suggested Solution By Changing Thickness of Pivot Housing.

calculations this limit is exceeding to 248 N/mm². Therefore the need of redesign is justified.

Suggested redesigned model: On the basis of the above conclusions, redesigning is carried out and related details are as follows

Cross section at neck region: Figure 10 shows sectional view indicating original thickness of forged pivot housing.

- In existing model, outer rectangular dimension is 132×150 mm and inner rectangular dimension is 120×100 mm which shows the thickness of 15×24 mm.
- Cross-sectional area of existing model = [(132×150)-(120×100)] = 7800 mm²

Table 5 indicates various iterations carried out for redesigning

purpose. The different combinations of length and thickness of pivot are considered in these iterations.

Figure 11 and 12 shows sectional view of the original pivot housing and Suggested Redesigned pivot housing. Amongst the different iterations, Iteration No 3 has shown optimized results. Hence further analysis of this redesigned model was carried out.

Analysis for suggested redesigned model: The suggested model contains same material properties, loading condition. The boundary condition is kept same as used in the existing model that is flange of pivot is kept fixed.

Equivalent von- mises stress: The maximum stress value is found in the flange region. The stress value calculated analytically is 145.5 Mpa and using ansys is 161.41 Mpa and minimum stress value is 0.4768 Mpa which is obtained in the fixed pivot region. The computed stress value 161.41 Mpa is highly acceptable because it is less than the maximum required stress limits 220 Mpa.

Conclusions and Further Suggestions

The loco has to travel on the rails which have the joints and local irregularities which bring the impact loads. Requirement of the design for moving the loco on the curved path is also very critical. The same was validated using FE Analysis. The FE analysis suggests the maximum yield stress of about 248 N/mm² while moving on the critical curvatures. This is more as that of allowable stress of 220 N/mm². The bending stresses may initiate a failure which is further enhance and

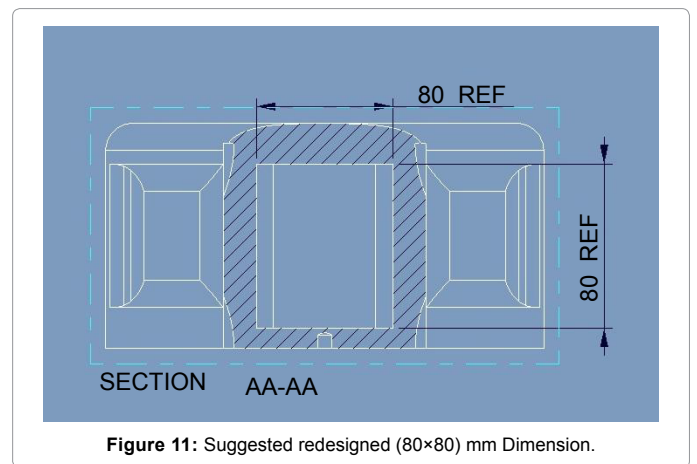


Figure 11: Suggested redesigned (80×80) mm Dimension.

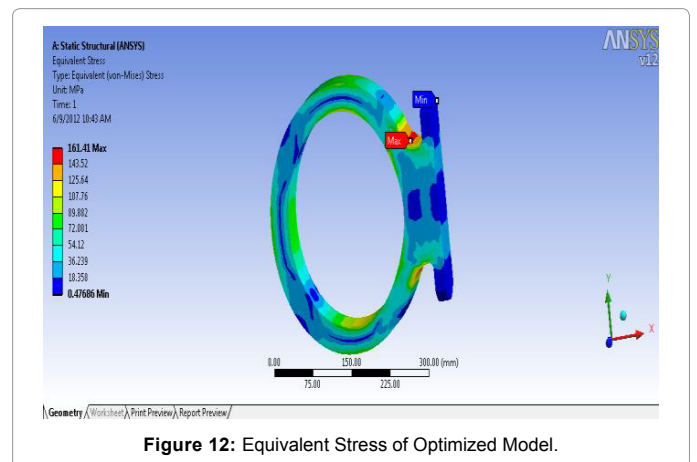


Figure 12: Equivalent Stress of Optimized Model.

aggregated because of stress concentration at the failure region and nature of loading.

Redesigning of Pivot Housing was carried out in this work.

Following conclusion were drawn on the basis of modeling (PRO-E) and Analysis (ANSYS) SOFTWARE. Thickness of the neck region was redesigned (Table 5).

- On the basis of five iterations, thickness was optimized.
- It is concluded that the following dimensions allowed the maximum possible stress with minimum weight of Pivot Housing.

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