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Design and Harmonic Analysis of Locomotive Wheel Axle

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ABSTRACT

A Railway axle is a rolling stock subjected to continuous cyclic loading & repeated stress causes forced vibrations in the axle. These forced vibrations causes resonance leads to heavy stresses and deformations induced in axle. To minimise these factors, stepped bore axle is modelled in the place of solid wheel axle.

To study the response of mass participation factor, stresses and deflections induced in axle, modal and harmonic analysis are performed in ANSYS.

Results show that stepped axle is subjected to minimum stresses when axle is in vibration, which has no adverse effect on strength and stability of an axle. Also the effective mass participation factor is least in the stepped bore axle compared to solid axle which reduces the vibration.

In Ansys Static, modal and harmonic analysis is carried out for the two models. Comparison is made between these models to predict the safe design under dynamic loading conditions.

Keywords: Rolling stock, resonance, dynamic characteristics, Harmonic analysis.

I.INTRODUCTION

The axial loads of the railway vehicle are important for predicting the stress of the vehicle components. In addition to, it is possible to reduce the weight of the vehicle structure by giving affordable forces

A rail wheel is a sort of wheel exceptionally intended for use on railroad tracks. A moving segment is normally pressed on to a axle and mounted specifically on a wagon by implication on a truck Wheels are threw or manufactured and heat treated to have a particular hardness. All wheel profiles ought to be occasionally observed to ensure a right wheel guide interface. Inaccurately influenced wheels will improves rolling resistance, reduce energy efficiency and can make perilous operation.

A railway wheel is ordinarily made out of two principle parts the wheel and tire, which is around the wheel outside. Tire is generally made of steel, and is commonly warmed and pushed on the wheel, where it stays tight while being limited and cooled. Mono block wheels have no encompassing tires, while the flexible wheels of the aides have a versatile material [1], for example rubber between the tire and wheel.

Generally train wheels have a conical geometry in most of the cases, which is the main important reason behind this, keeping the train moving aligning to the track.

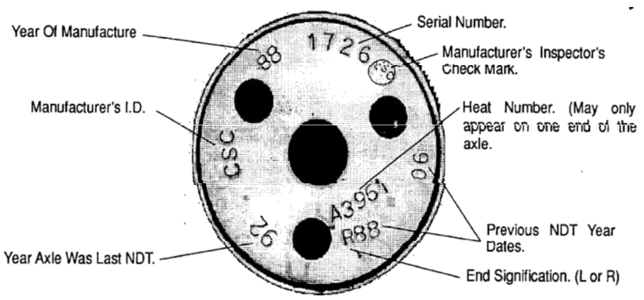

Figure 1.1: Typical stamping found on axle ends.

II.SYSTEM MODEL

The design of the wheel set depends on:

• Vehicle type (traction or drag) † Type of braking system used (brake shoe, brake disc on axle or brake disc on wheel)

• The construction of the wheel centre and the bearing position on the axle (internal or external)

• The desire to limit the forces of greater frequency using elastic elements between the centre of the wheel and the tire.

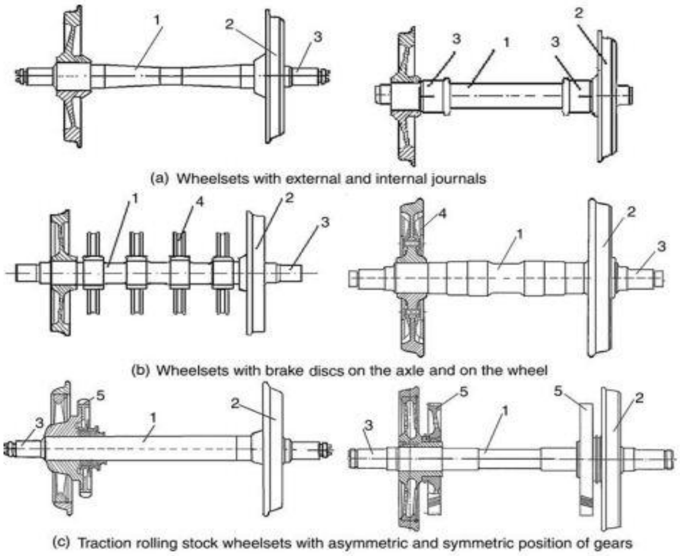

Fig. 2.1 Main types of wheel set design: (a) with external and internal journals; (b) with brake discs on the axle and on the wheel; (c) with asymmetric and symmetric position of gears (1, axle; 2, wheel; 3, journal; 4, brake disc; 5, tooth gear).

The main types of wheel mounting are shown in Figure 2.1. Despite the variety of designs, all these sets of wheels have two usual features: the rigid connection between the wheels through the axle and the cross section of rolling surface of wheel, called the wheel profile. In curves, the outer rail will have a greater radius of the inner rail. This means that a cylindrical wheel must travel more on the outside rail than on the inside rail. Since wheels moving on internal and external rails must have the same number of rotations per unit of time, such movement cannot be achieved by pure rolling. So that the two-wheel distances are equal, one or both "slips", thus increasing the rolling resistance and causing wheel and rail wear.

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III. PROPOSED METHODOLOGY

According to RDSO specification ,hollow ,solid & Stepped bore axle is modeled in CATIA V5 R21.

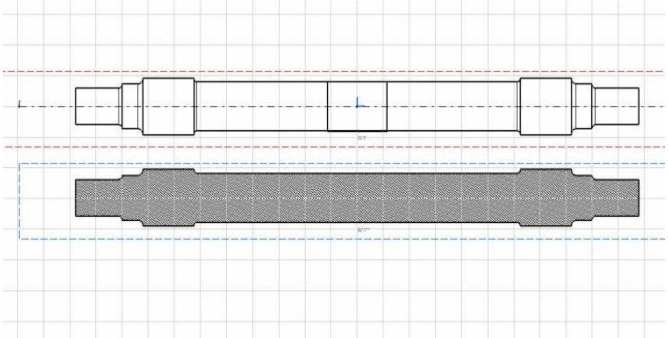

Figure 4.1 solid axle drafting

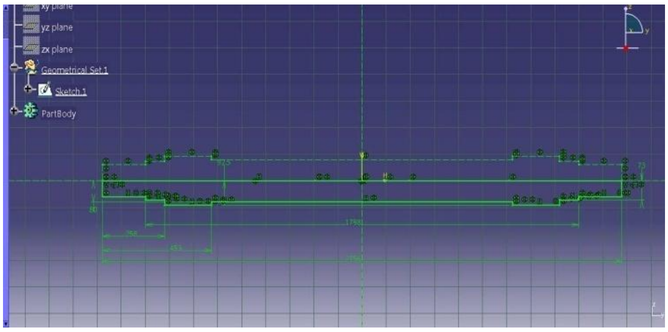

Figure 4.2 Drafting

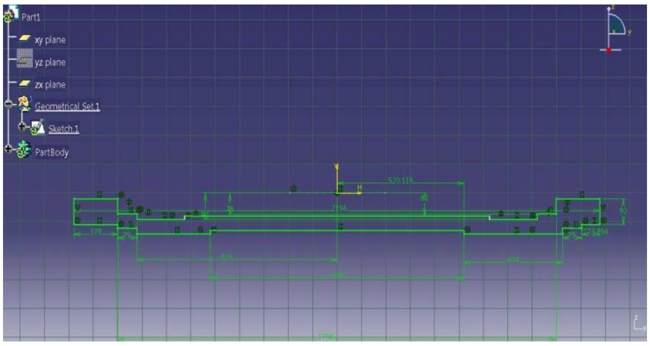

Figure 4.3 Stepped Drafting

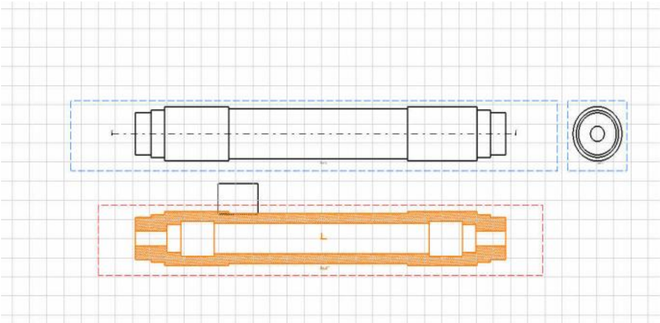

Figure 4.4 Stepped Axle Drafting

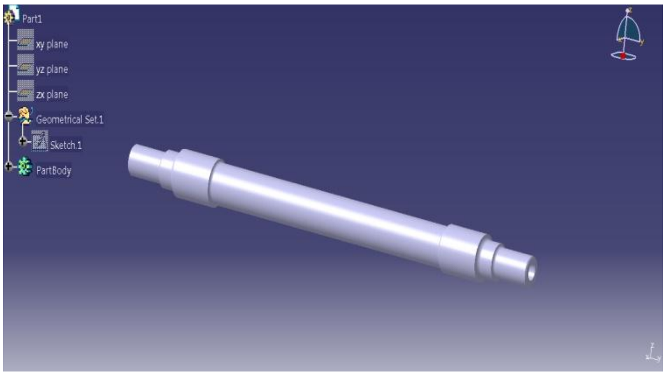

Figure 4.5 3D Modelling of Axle

IV. SIMULATION/EXPERIMENTAL RESULTS STATIC STRUCTURAL ANALYSIS :

A static analysis figures the impacts of consistent stacking conditions on a structure, while neglecting inertia and damping impacts, for example, those conveyed by time differing loads. A static examination is utilized to find the deformations, stresses, strains.

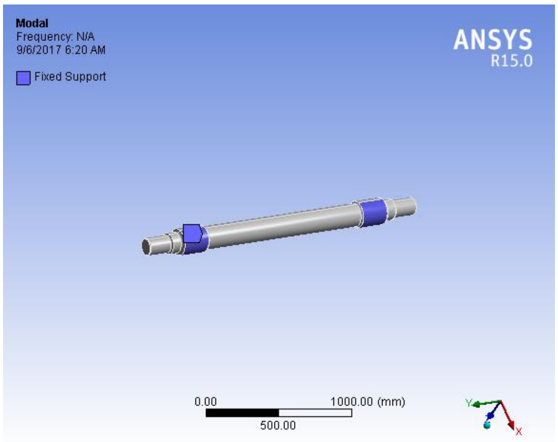

Figure 5.1 Fixed support of rail axle Solid Axle

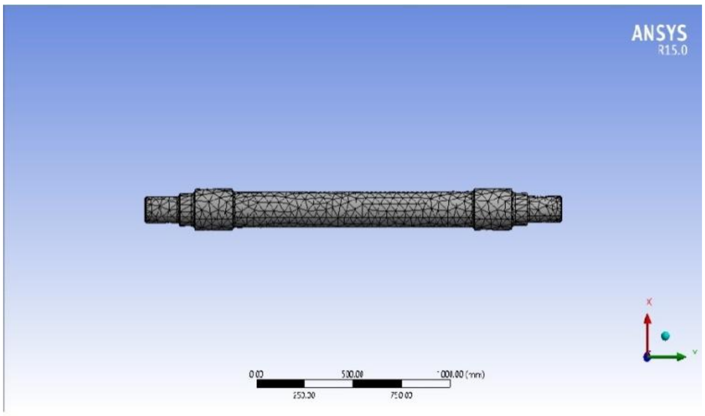

Figure 5.1 Meshing of rail axle

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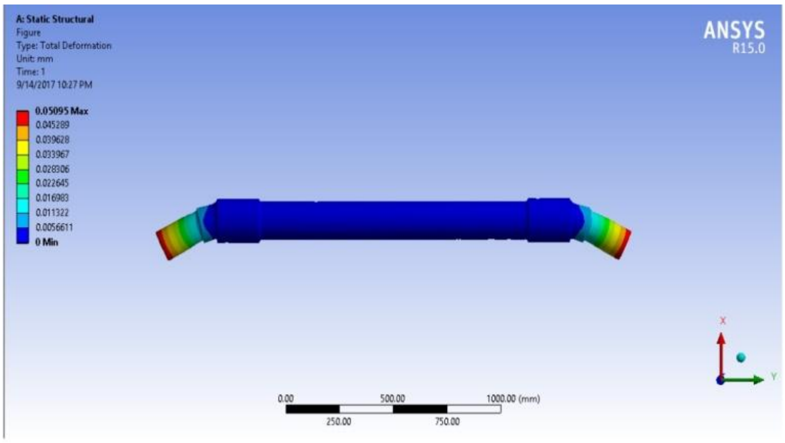
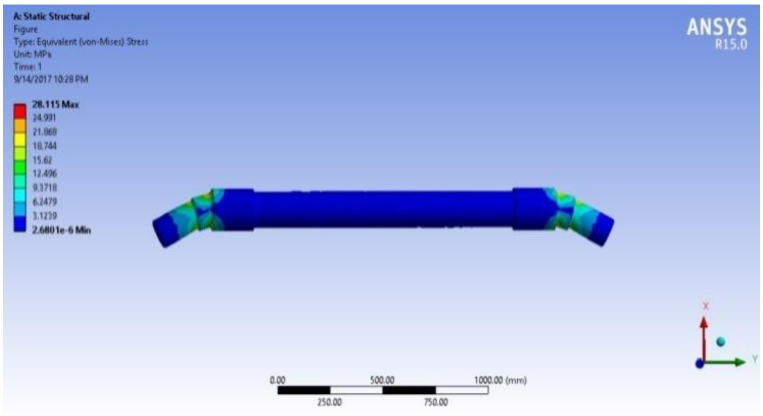


Fig 3 Solid axle with total deformation



4 Solid axle with equivalent (von –mises) stress

Table 1: Static Structural Analysis Results of solid axle

Axle Model	Total Deformation(mm)		Equivalent (Von-mises) stress (MPa)		Equivalent strain	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Solid	0	0.05095	2.6801e-6	28.115	6.995e-11	0.00015698

Hollow Axle

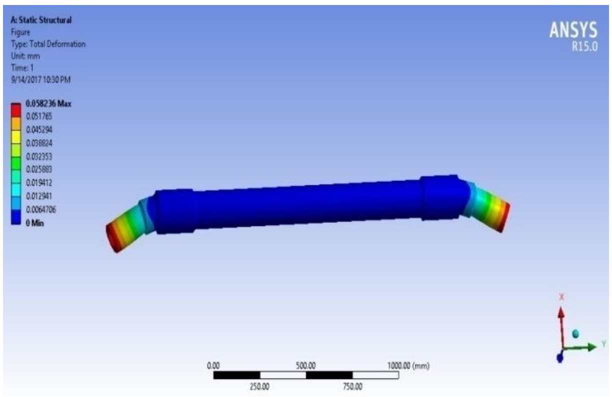


Fig 6 Hollow axle with total deformation

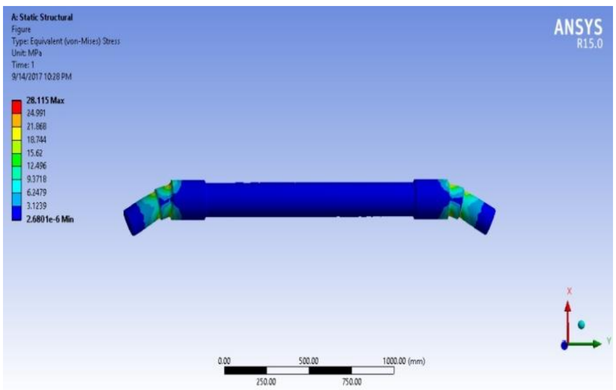


Fig 7 Hollow axle with von mises stress

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Table 2: Static Structural Analysis Results of hollow axle

Axle Model	Total Deformation(mm)		Equivalent (Von-mises) stress (MPa)		Equivalent strain	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Hollow	0	0.058236	9.2257e-6	28.238	1.7191e-10	0.0001571

Stepped Axle

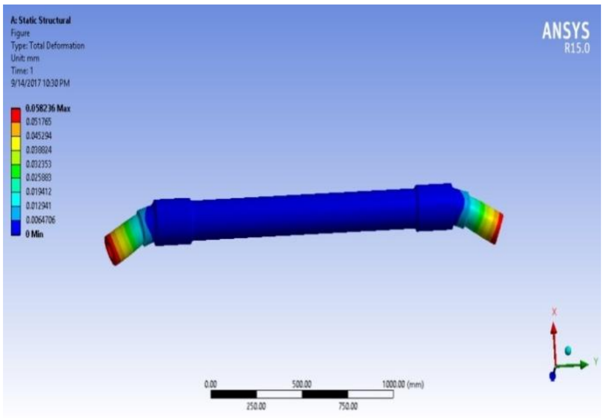

Fig 9 stepped axle with total deformation

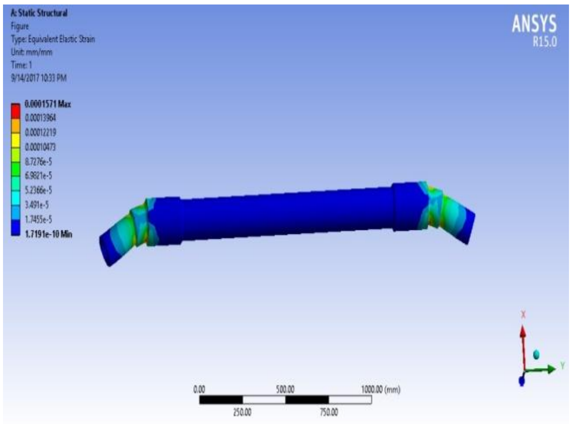

Fig 10 stepped axle with von mises stress

Table 3: Static Structural Analysis Results of stepped axle

Axle Model	Total Deformation(mm)		Equivalent (Von-mises) stress (MPa)		Equivalent strain	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Stepped	0	0.014884	1.9681e-5	8.8968	1.1827e-10	5.2982e-5

Table 4: Static Structural Analysis Results of Axle Models

Axle Model	Total Deformation(mm)		Equivalent (Von-mises) stress (MPa)		Equivalent strain	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Solid	0	0.05095	2.6801e-6	28.115	6.995e-11	0.00015698
Hollow	0	0.058236	9.2257e-6	28.238	1.7191e-10	0.0001571
Stepped	0	0.014884	1.9681e-5	8.8968	1.1827e-10	5.2982e-5

From the above table it is observed that Von-mises stresses for solid axle is 28.115MPa, hollow axle is 28.238, and stepped bore axle is 8.8968. Among all the three model axles stepped axle induces less stress (8.8968MPa) for given boundary conditions. So stepped model is best suitable for design of axle.

Modal Ananlysis

Modal analysis [3] is utilized to decide the vibration qualities (common frequencies and mode shapes) of a structure or a machine part while it is being outlined.

Solid Axle

Solid Axle & Stepped Axle

The mode shapes for the above frequencies are plotted below:

- **Results –Model 1 @ 354Hz**

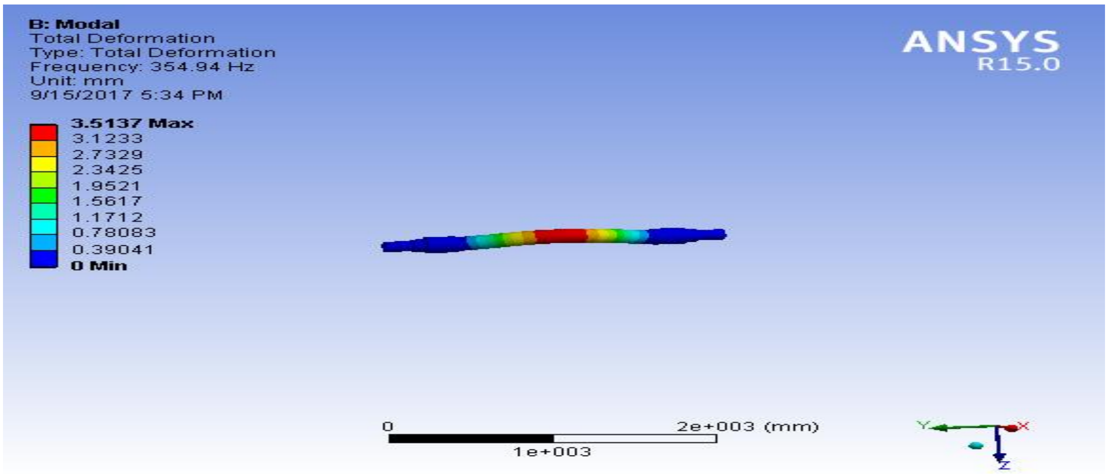

Fig. 6.8 Shows Mode shape 1 @ 354.94 Hz for Stepped locomotive axle

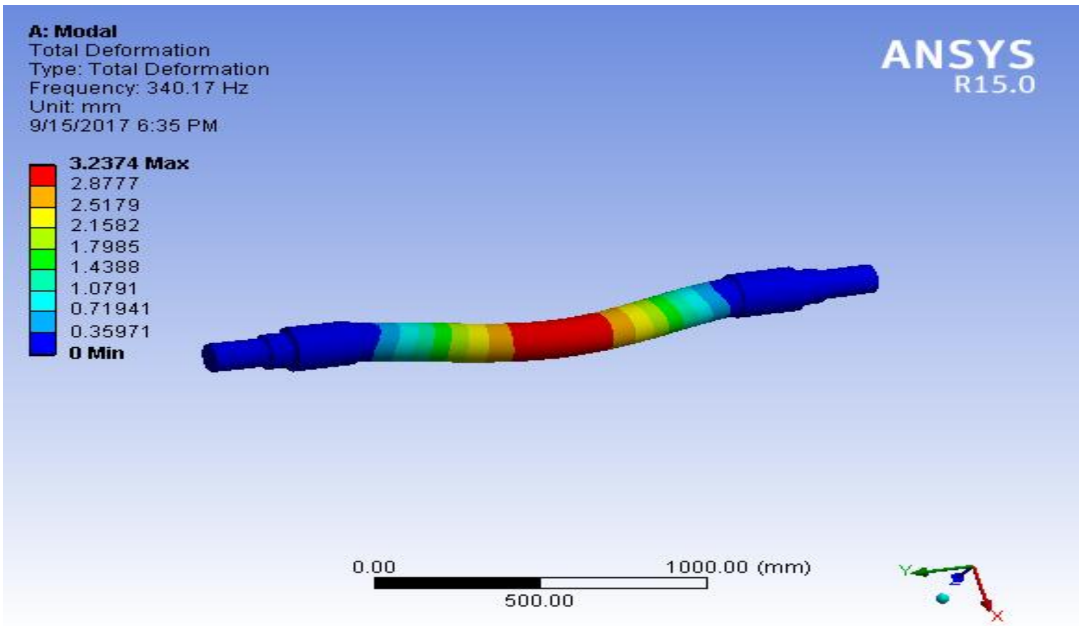

Fig. 6.7 Shows Mode shape 1@340.17 Hz for Solid Rail wheel axle

Mode	Frequency	PARTC FACTOR			EFFECTIVE MASS		
		X	Y	Z	X	Y	Z
1	354.936	0.3233	-0.13932E-04	-0.17726	0.104544	0.194094E-09	0.314198E-01
2	369.777	0.17740	0.23080E-04	0.32367	0.314718E-01	0.532677E-09	0.104759

From the modal analysis of solid axle,

- At a frequency of 340Hz,It is watched that the most mass participation of mass is 0.123T in X-direction.
- At a frequency of 340Hz,It is watched that the most mass participation of mass is 0.71E-10 T in Y-direction.
- At a frequency of 340Hz,It is watched that the most mass participation of mass is 0.35E-019 T in Z-direction.

Mode	Frequency	PARTICIPATION FACTOR			EFFECTIVE MASS		
		X	Y	Z	X	Y	Z
1	340.17	0.35154	0.33372E-04	0.35	0.1235	0.714045E-10	0.375186E-01
2	352.739	0.19393	0.33372E-04	0.35	0.375E-01	0.111367E-08	0.123892

From the modal analysis of stepped axle,

- At a frequency of 354 Hz,It is watched that the most mass participation of mass is 0.104T in X-direction.
- At a frequency of 354 Hz,It is watched that the most mass participation of mass is 0.715E-10 T in Y-direction.
- At a frequency of 354 Hz,It is watched that the most mass participation of mass is 0.351E-01 T in Z-direction.

V. HARMONIC ANALYSIS OF RAIL WHEEL AXLE

Harmonic analysis was carried out on the axke to determine the deflections and stress of a structure in the frequency range of 340 -350 Hz. The total number of sub steps defined for the analysis is 5.

VI. MAX. DEFLECTION AND STRESS OF SOLID RAIL WHEEL AXLE

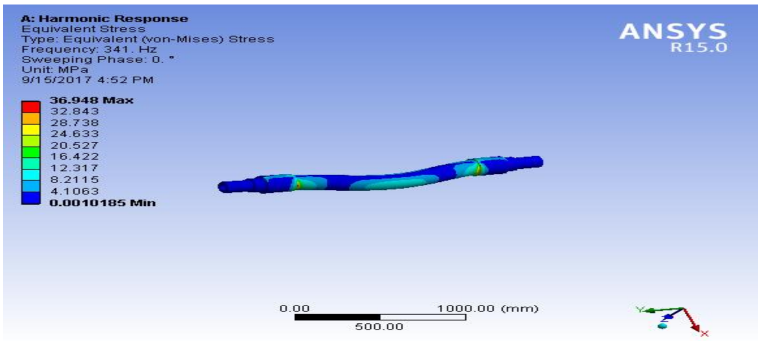

Fig 6.11 von mises stress for solid axle @ 341Hz

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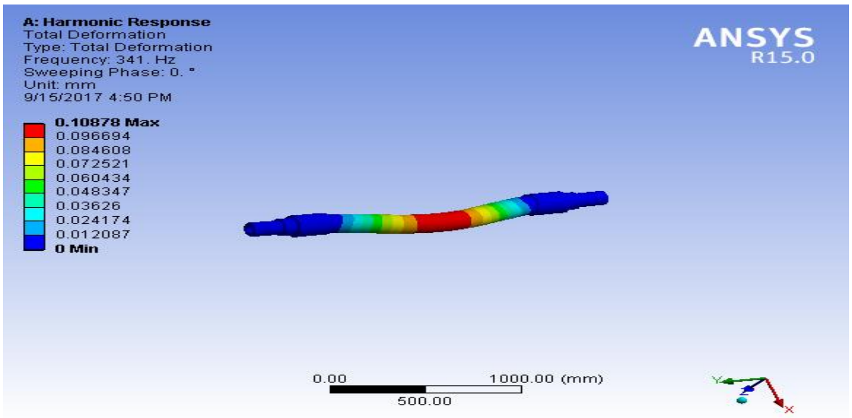

Fig 6.9 total deformation of solid axle @ 341 Hz

VII. MAX. DEFLECTION AND STRESS OF STEPPED RAIL WHEEL AXLE

FREQUENCY @360Hz

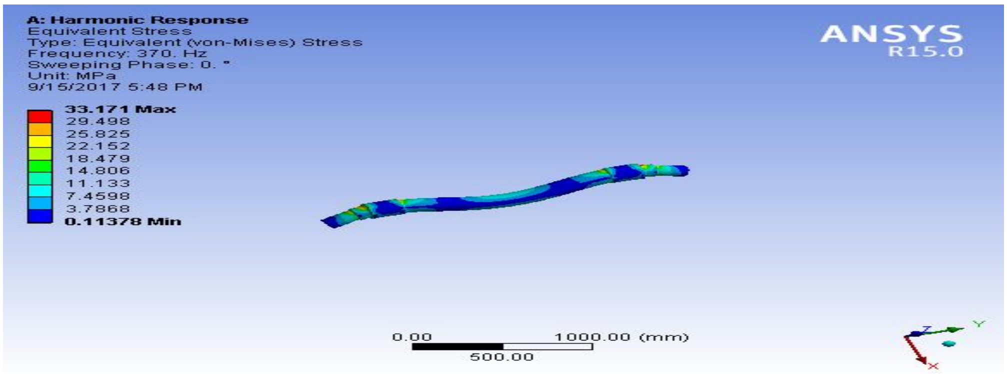

fig 6.12 max deflection of stepped axle @ 360Hz

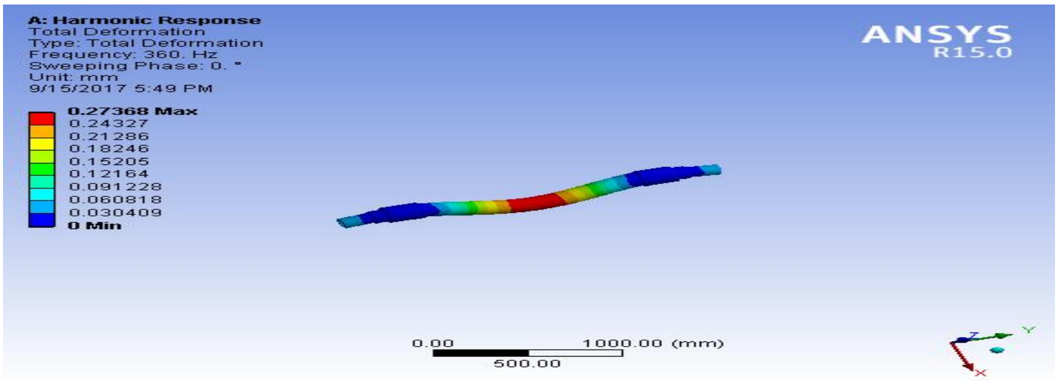

fig 6.13 maximum stress of stepped axle @ 370Hz

Solid Axle

Table 6.3 Deflections and von-mises stress for critical frequencies

S.No	FREQUENCY (Hz)	DEFLECTIONS (mm)	VON MISES STRESS(MPa)
1	341	0.108	36.9
2	343	0.127	43.45

Stepped Axle

Table 6.4 Deflections and von-mises stress for critical frequencies

S.No	FREQUENCY (Hz)	DEFLECTIONS (mm)	VON MISES STRESS(MPa)
1	360	0.278	33.17
2	370	0.092	90.85

From the above results it is observed that the critical frequencies 360Hz and 370Hz are having stress 33.17MPa and 90.85MPa respectively. The yield strength of the material (30nicr alloy) used for axle is 490MPa.

As per the Von-Mises Stress Theory, the Von-Mises stress of axle at frequencies 360Hz and 370Hz having stresses not as much as the yield quality of the material. Consequently the design of locomotive axle is safe for the above conditions.

GRAPHS: Amplitude $v_{/S}$ Forcing Frequency:

Solid Axle:

1. Harmonicesponse

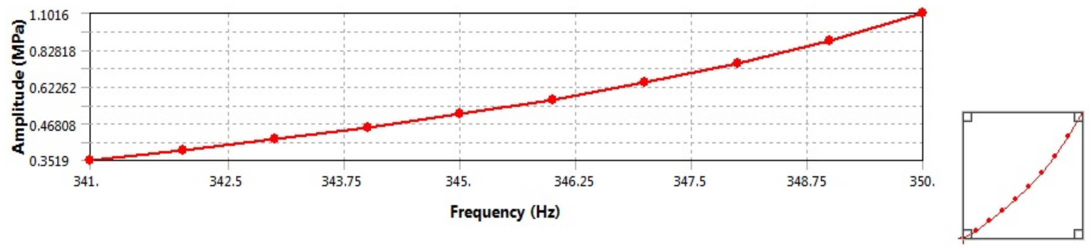

Fig. 6.5 harmonic response of Solid Rail wheel axle

Following amplitudes are obtained from the above results:

- At a frequency of 341Hz**.** , Amplitude 0.3519mm is obtained on the 1st fixed end of Rail wheel axle
- At a frequency of 342Hz ,Amplitude 0.412mm is obtained on the 2nd fixed end of Rail wheel axle
- At a frequency of 343Hz, Amplitude 0.462 mm is obtained on the mid location of Rail wheel axle

❖ **Stepped Axle:**

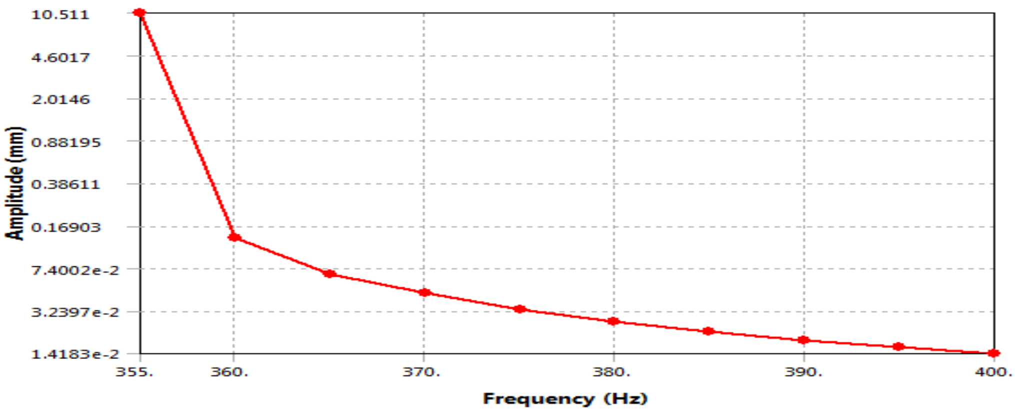

Fig. 6.5 harmonic response of Stepped Rail wheel axle

From the above graphs, the following amplitudes are observed:

- ❖ At a frequency of 355Hz**,**Amplitude 10.5mm is obtained on the 1st fixed end of Rail wheel axle
- ❖ At a frequency of 360Hz**,** Amplitude 0.169mm is obtained on the 2nd fixed end of Rail wheel axle.
- ❖ At a frequency of 370Hz, Amplitude of 0.007 mm is obtained on the mid location of Rail wheel axle.

VIII. CONCLUSION

3D model of an axle is modelled in CATIAV5R21 and its igs file is solved in ANSYS. An axial load of 73575 N is added along the wheel axle and is applied by given boundary conditions.

Following conclusions are obtained after performing the analysis with above said boundary conditions to stepped axle apart from the solid axle

- ➢ Deflections at the critical frequencies 360Hz & 370 Hz are also minimum i.e. 0.278 mm & 0.092 mm
- ➢ Since the Von-Mises stress of stepped bore axle is less than Von-Mises stress of solid axle for given boundary and load conditions, stepped bore axle design is best suitable.
- ➢ The mass participation factor is also least in all directions for stepped axle i.e 0.3E-3T & 0.207T.
- Since the compelling mass participation factor is minimum ,the components taking part in vibration additionally less. Along these lines diminishes overwhelming vibrations in the axle prompts safe operation of the axle
- From the above outcomes it is watched that the basic frequencies 360Hz and 370Hz are having stress 33MPa and 90MPa individually. The yield quality of the material (30nicr alloy) utilized for axle is 490MPa.
- The Von-Mises stress and deflections at frequencies 360Hz and 370Hz having stresses not as much as the yield quality of the material. Thus the outline of Rail wheel stepped axle is safe for the above conditions.

IX. FUTURE SCOPES

In the above proposed work

- This analysis can be extended to transient analysis also.
- If it is conceivable, damping ought to be added to the framework. Since, obviously in the damping case, sudden power rise can be kept away from and furthermore, dynamic powers for different rates can be diminished.

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