Analyzing behaviour of a rail wheel assembly with alumino thermite weldment with modal analysis simulations in ANSYS

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Abstract. The Free vibration response of the Railway track is an important area in the design of the Rail and its joints to improve the ride comfort of the passengers. In this study, the rail weld considered is alumino thermite weldment used in majority of Indian Railways network. This paper aims at the study of the vibration response of rail wheel assembly having an AT weld on as a rail joint subjected to free vibration and to find the Natural frequencies of vibration and mode shapes. The geometric model of rail and weldment with wheel and axle components is modelled using Space-claim which is a part of ANSYS package and analysed using numerical simulation package ANSYS 2020 Workbench. In this work, free vibration analysis or modal analysis of the rail weld is carried out to extract the first few modes of vibration. The Natural frequencies obtained along with the corresponding mode shapes of the rail weldment show that they are within the permissible range specified by the standards of railway department also for better ride comfort of the passenger.

1. Introduction

Humans are frequently exposed to mechanical vibrations having adverse effect like causing discomfort or any negative impact on their health. Vibration study in the realm of transportation, particularly in railways industry, is an essential area for engineering people and academics to examine the cause, so it can be eliminated for the sake of passengers. The vibrations produced by a train travelling on a track are primarily caused by a combination of wheel vibrations and track imperfections. The track joint system in contact with the wheel during service causes vibration in the train coaches. It has been observed that if the rail joint at the weldment as well as the wheel surfaces at the contact surface if the train wheel isn't entirely smooth, it will rotate in a succession of rise and falls of track joints, producing train compartments to vibrate. If the contact is not smooth, a resultant force is created in the vertical direction, resulting in greater vibration forces. The rail vehicle and track vibrate at various resonance frequencies as result of the action of mechanical elements, which are transmitted to the passengers via bogies and coaches. The free vibration or modal analyses carried out in this study are on a UIC 60 rail track with an AT weld on it. In this modal study, the first six natural frequencies and mode shapes of the rail weldment of a UIC 60 rail are obtained.

The rail joint is an important part of the track system. Because the rail joints are less rigid and powerful than the rail centres, local settlement occurs. To damage the rail wheel and joint on rail ends can occur when a train travels through discontinuous gaps of where rail joints occurs, which can harm the rail and its joints, and other track elements like sleeper and ballast too. This phenomenon is harmful to the overall track body since
trains are easily exposed to impacts or vibrations, that minimizes commuter comfort and needs a substantial amount of labour and money for track and wheel maintenance [1]. Figure 1 shows a AT weld joint on a rail and a weld under contact of wheel during operation.

![AT Weld](image1)

(a) An AT weldment (b) Rail weld with wheel contact.

**Figure 1.**

1.1. **Literature survey**

Continuous welded rails are now considered standard for main lines. Continuous welded rails (CWRs) are made up of many long or short rails that are welded together in most modern railways. Fishplates around the rail joint are used to connect the web of the next rail with bolts in traditional CWRs, for eliminating the discontinuous dwell at rail joint and significantly lowering shocks and sounds during motion of the train. When a railway vehicle is subjected to dynamic loading and moves under track defects and variations in geometrical parameters, dynamic wheel–rail forces are generated. The excitation amplitude determines the dynamic properties of the rail weld. A deeper understanding and extensive analysis of the rail weld response is required to design a rail joint with improved ride comfort. FE model analysis saves money and time during the construction of railway cars, and complicated simulations can be run at any point of the design process [2]. To measure operating quality and anticipate fatigue life, random vibration calculations are conducted from any point on the vehicle system structure [3]. The displacement in the lateral direction is represented by modal frequencies up to 30 Hz, indicating the relevance of freight trains running under rolling movement [4]. Peak vertical responses are detected in the low-frequency band between 0 to 20 Hz is produced by track abnormalities with extended-wavelengths that produce discomfort [5].

Dynamic forces on the tracks are influenced by geometrical track faults, vehicle unsprung and sprung masses, track stiffness, damping changes in track flexibility, wheel flats, and corrugations on wheels and rails [1,6]. Pombo and Ambrosio suggested a wheel–rail contact model for small-radius curved tracks [7], whereas Sugiyama et al. used track tests and simulations to compare the steady-state lateral force of small-radius curved tracks [8]. Wen et al. [9] investigated the impact of wheel–rail contact at the rail joint on axle load, the effect of train speed on dynamic vertical forces, and the distributions of railhead stress and strain using finite element analysis models. In a dynamic examination of wheel–rail contact, Sharma and Kumar discovered that the rolling distance had an effect on pressure distribution under various track curvatures [10].

In addition, numerical analysis was used to simulate the wheel–rail contact interaction of the insulated rail junction [11]. As a result, the majority of past research has focused on main line track behaviour or the service life of CWRs, which have less track impact during train operation. All trains must travel on lines that have not been converted to CWRs and have various rail connections, such as the vehicle base, station tracks, side tracks, and subsidiary main lines, in order to enter the tracks of the main line. Ultimately the significance of comprehending rail joint behaviour in particular cannot be emphasised. Various systems for monitoring the health of railroads have been developed over time. Due to the fact that all currently existing solutions don't totally satisfy the standards establish by organisations in charge of railway infrastructure, hence significant endeavours in research in this subject are still necessary. The development of dependable technologies for identifying rail flaws that could be dangerous before they progress into rail breakages represents a significant challenge. Indeed, the availability of train
diagnostics tools allows for the introduction of predictive maintenance processes rather than the current preventive maintenance plan. According to a literature review, researchers all around the world used diverse approaches to analyse the dynamic behaviour of rail tracks and weldments. In the literature, finite element analysis is frequently used to assess railway track and weldment, as well as to analyse their dynamic response. The benefits of using FE software to perform analysis under dynamic conditions and determine the natural frequency response of the railway assembly in static operational situations have been demonstrated. This will result in more dependable railway networks, as well as a significant boost in the efficiency and long-term economic viability of maintenance processes [12]. Few review articles on rail track monitoring have been published in the recent two decades [12–13]. Furthermore, in recent years, new technologies and methodologies have been developed in this field, attracting the interest of governments and enterprises. The numerical results are highly useful for designing tolerances for welded rail profile defects caused by hand-grinding following rail welding and track maintenance.

1.2. Scope of work and objectives
Main purpose this paper is to perform modal analysis or free vibration on a UIC 60 rail weld wheel assembly under dynamic load i.e. at varying rotational speeds. The first six natural frequencies in each rotational speed of the assembly and specifically for rail weld are obtained. This paper's outline can be found as introduction, literature review in Section 1 which covers about the dynamics of rail and its weldment. The process of developing and modelling a UIC 60 rail, wheel with an AT weld and FE parameters, are covered in Section 2. The assembly’s modal analysis results are discussed in Section 3, and the current analysis conclusions are discussed in Section 4.

2. Methodology for design of UIC 60 rail, weld and wheel assembly

2.1. Introduction to UIC60 rail, wheel with AT Welding
The European standard EN 13674-1 is followed in the production of the UIC60 rail type. It is utilised in the construction of railroads. This is a type T section rail, also known as flat bottom rails, with a mass per metre of 60.21 kg. For medium and high load traffic, the 60E1/UIC60 rail is utilised on a standard track.

The alumino thermite welding method is widely used to join the ends of rails all over the world. Alumino thermite welding is a method that involves fused metal with superheated molten metal produced by an alumino thermite reaction between a metal oxide and aluminium. It's significant that alumino thermite welding takes place on-site. Figure 2 shows the diagram with dimensional parameter used in Indian Railways and used in this work for model preparing.

![Figure 2](image-url)

**Figure 2.** Indian Railways geometry used for (a) UIC60 rail (b) Wheel.
2.2. Geometric modeling of Rail Wheel Weld assembly
All additional levels of analysis begin with the geometric model. It can be built with ANSYS or similar mechanical drawing application. Space-claim, an integrated part of CAD modelling interface is used to model the cad parts and assemble them for this paper. Its shape and dimensions have been chosen according to mentioned in paragraph 2.1. The length of rail is taken 800mm and wheel is 1150 mm of diameter where an AT weld is made of 35 mm having a realistic look as bulging surface about 2 mm and considered as grinded on the running surface. Figure 3 shows the assembly.

![Rail wheel weld CAD model](image)

Figure 3. Rail wheel weld CAD model

The dynamic behaviour of an assembly with an AT rail weldment is the subject of this research. The following are the assumptions used to create the rail wheel weld assembly geometric model.

- Modelling of UIC60 rail, weldment, axle and wheel, is completed, and the remaining components are ignored.
- Abruptness of rail weld at the joint take is ignored.

The characteristics of the rail, wheel and weld material should be determined in this stage. This can be also done by choosing the material from ANSYS library. Because steel is used in majority of the track, so steel material properties are taken into account for all parts in existing geometry. The assembly having the mechanical properties for rail track, weldment and wheel axle assembly are taken from the papers [10,13] Tables 1 and 2 show the values for the analysis purpose.

| Table 1. Parameters of elastic plastic weld model |
|-----------------------------------------------|
| Mechanical property | Value |
| Poisons Ratio       | 0.3   |
| Young’s Modulus (GPa) | 207 GPa |
| Ultimate tensile strength (MPa) | 996.7 MPa |
| Yield strength (MPa) | 675.7 MPa |
| Percentage reduction of area | 4.22 |
| Percentage Elongation | 3.09 |

| Table 2. CAD parts material properties |
|----------------------------------------|
| Part name | Modulus of elasticity(GPa) | Modulus of plasticity (GPa) | Yield stress (MPa) | Poisson’s ratio |
|------------|---------------------------|-----------------------------|-------------------|-----------------|
| Rail       | 206.9                     | 22.7                        | 483               | 0.295           |
| Wheel      | 205                       | 22.7                        | 640               | 0.3             |
| Axle       | 205                       | -                           | -                 | 0.3             |
2.3. Finite element setup in ANSYS mechanical and boundary conditions

The rail weld and wheel axle assembly model is used for finite element analysis to get results. We may develop a pre-stressed modal analysis at the solution level, in the project schematic, by linking a static structural system to a modal system, as shown in Figure 4. The static structural analysis has been done which is not discussed here and then the modal analysis with same geometric model and material properties of this assembly is transferred to Workbench Modal analysis window. The finite element assembly model obtained after meshing with tetrahedral mesh is shown in Figure 5. The Finite Elements Method is used in structural analysis tools to simulate model behaviour (FEM). The whole structure will be divided into small pieces, usually has the shape of pyramid, within a process called the meshing. For our model we got 43212 nodes and 19929 elements.

Following setups are made for FE modal analysis.

- Weld is considered as bonded joint on each side of the main rail track component which are joined together.
- Fixed support at both end of the rail, and four different rotations of 27.751, 33.406, 41.678, 55.501 rad/s have been set as input in tabulated form.
- Maximum number of the modes as six is set for the modal analysis to visualize. These and other boundary conditions are described in [16], [17], [18].

3. Results and discussion of the modal analysis

Primary goal of vibrational mode study of a mechanical system is to determine how the model behaves when it is motivated to vibrate. In following Figures 6 and 7 we present the 6 mode forms and natural frequency of UIC 60 rail wheel assembly with an AT weld, extracted from the modal simulation performed in ANSYS. The figures show the deformations which occur in each mode. The deformations which appear in the figures are exaggerated to illustrate how the rail wheel weld assembly is affected in each mode.

The first 6 natural frequencies when four different rotations of 27.751, 33.406, 41.678, 55.501 rad/s are applied at wheel axle contact are shown in Table 3, listing the data extracted and tabulated. As illustrated in the bar chart, the frequency of each estimated mode on each rotation is indicated in Figure 6. The assembly's bounce mode is detected in the fourth mode. Similarly, the assembly's pitch mode is shown in the 5th mode, while Mode 6 represents the Twist mode, which is mostly seen on the wheel, and the combination of bend with twist mode is seen in the 3rd mode shape.
Figure 6. Each calculated mode's natural frequency.

We notice that the deformations increase when the frequencies are increased [17], [21], [22]. When the system is aroused at any natural frequency, the mode forms represent the unique way in which the system vibrates. The exaggerated views of the deformations occurred in the assembly for each mode (mode shapes) are presented in Figure 7. More details about these stages are presented in [10], [17] and [18].

Figure 7. Mode Shapes for model assembly obtained in ANSYS.
4. Conclusions
Drawing a high-detailed geometric model will make the results closer to reality, but it will complicate the simulation and will increase the simulation time and costs. Using a computer with a high performance will increase the simulation costs, but these costs are small and neglected, if they are compared to the costs of the experiment. Errors however, may be there with reality because of the following:

- The simplification of the geometric model in comparison with the real one;
- The limited abilities of the used computer;
- The ideal conditions and mathematical model used by ANSYS to obtain the results.

However, boundary conditions widely affect the simulation results and they should be carefully chosen. Figure 8 is a typical Campbell diagram plot, which depicts the vibration frequencies of a system at various working RPMs. On an operating system, the Campbell diagram depicts an overall or bird's-eye perspective of regional vibration excitation that can occur.

The natural frequencies at different solve points is illustrated in Table 3 for used assembly model, these are the frequencies at which the structure will naturally vibrate under given load. The findings of the modal analysis demonstrate that several modes, influenced by bounce, pitch, and twist due to dynamic behaviour of the model assembly in both free and induced vibration. The assembly's bounce mode is

![Figure 8. Campbell diagram for the modal analysis of Rail wheel weld assembly model.](image)

**Table 3.** Models Mode and its natural frequencies(Hz) for different solve points.

| Set | Solve Point | Mode | Frequency (Hz) | Mode | Frequency (Hz) |
|-----|-------------|------|----------------|------|----------------|
| 1   | 1           | 1    | 17.797         | 13  | 1              | 17.296         |
| 2   | 1           | 2    | 45.114         | 14  | 3              | 45.294         |
| 3   | 1           | 3    | 61.63          | 15  | 3              | 63.139         |
| 4   | 1           | 4    | 164.73         | 16  | 3              | 164.55         |
| 5   | 1           | 5    | 185.83         | 17  | 3              | 186.06         |
| 6   | 1           | 6    | 258.27         | 18  | 3              | 258.35         |
| 7   | 2           | 1    | 17.612         | 19  | 4              | 16.671         |
| 8   | 2           | 2    | 45.183         | 20  | 4              | 45.486         |
| 9   | 2           | 3    | 62.173         | 21  | 4              | 65.187         |
| 10  | 2           | 4    | 164.66         | 22  | 4              | 164.31         |
| 11  | 2           | 5    | 185.91         | 23  | 4              | 186.36         |
| 12  | 2           | 6    | 258.3          | 24  | 4              | 258.46         |
revealed to be around 164 Hz in 4th mode, with very little changes for different rotations which is observed in 4th mode different solver points of respective rotations. Pitch mode in 5th mode is counted to vary from 185 to 186 Hz for different rotations, while twist mode in 6th mode is found to be at 258 Hz with small variations for different rotations. It may also be stated that natural frequencies received after simulation of model assembly are more practical and consistent with other works than the model's theoretical results under specific load conditions. The results of the analysis yield the frequency values compatible with the values prescribed by Indian railways, implying that no Resonant situation exists.

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