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Structural Assessment of Parabolic Leaf Springs for Freight Wagons based on the Dynamic Operating Conditions: The Initial Phase for Fatigue Analysis

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Abstract

Over the recent years, the Portuguese railway sector has suffered a significant shortage of resources, generating many issues associated with the limited maintenance of the rolling stock that has been revealing strong mechanical wear, affecting their operability. Fatigue problems have often occurred in suspension components from rolling stock, more properly in leaf springs. These occurrences have been generating derailments that in addition to economic losses, threaten human life. The leaves are subject to high and dynamic loads during their operational life and therefore a previous approach using procedures such as rainflow is necessary. Using the rainflow procedure, it was possible to identify the loading levels in terms of displacement and in terms of stress in the leaves. It was found that the distribution of the alternating component tends towards a Gaussian distribution.

Keywords: Railway, Leaf Springs, Instrumentation, Finite Element Method.

1 Introduction

Over the years, rail freight transport has shown its great impact on the world economy. Despite its strong socio-economic and environmental responsibility, the freight rail sector has been observed a great devaluation in Portugal. The disinvestment includes infrastructures, rolling stock, and services [1,2].

Regarding the rolling stock sector, the lack of investment has affected its operability, security, and evolution in terms of recent technology. Most of these constraints have occurred due to failure in suspensions of freight wagons, mainly in leaf springs. These occurrences have been generating derailments that in addition to economic losses, threaten human life [3,4].

In Europe, freight wagon suspensions have been standardized by the International Union of Railways. One of them is the link suspension bogie with leaf springs [5-7]. The link suspension system has been used over the years because is relatively less expensive, and lighter, allowing to carry higher loadings per wagon [7]. This suspension is a primary suspension (axle-box type), composed of single- or double-stage leaf springs that may be trapezoidal or parabolic. Nowadays, parabolic leaf springs have been widely more used than trapezoidal because they have shown better leaf spring characteristics, safer, and wagon motion quality.

Although the research in leaf springs has been quite made, in the railway sector, the research in the fatigue field does not appear to be very deep. That lack of knowledge may explain why failure in freight wagons is due to the failure of suspension members [8,9]. Therefore, exhaustive research in the fatigue characterization of leaf spring materials is required, to permit a greater safety of these members, enhancing an economic, social, and environmental impact in the railway sector.

This paper aims at presenting an experimental and numerical campaign for the evaluation of leaf springs' behavior. A set of experiments in real conditions have been performed to determine the loading applied on leaf springs. Examples of acquired data are accelerations, displacements, and strain distribution. This knowledge was used for numerical model validation which will be later used in the generation of big data. With the generated data it is still possible to perceive the predominant average and amplitude components during the wagon circulation, performing rainflow procedures. Furthermore, using rainflow we intend to determine a statistical distribution associated with the spring loading. With this knowledge, it is possible to predict the fatigue life, allowing a reduction of maintenance time and hence increasing the availability of wagons.

2 Methods

The methodology for the mechanical behaviour assessment of parabolic leaf springs in freight wagons consists in two parts: experimental, and computational.

In the experimental part is used accelerometers, inclinometers, and LVDTs for measuring components of acceleration, and displacement involved when the wagon is working. Regarding leaf springs, strain gauges are used which are placed on leaves surfaces to measure the strain on them. In addition, ultrasonic sensors (non-contact sensors) are installed to acquire the vertical displacement of the leaf spring. Figure 1 illustrates an example of how displacement transducers are installed with the suspension system.

For the computational component of the experiment, a three-dimensional finite element model is elaborated in order to produce big data after its validation. The validation procedure is based on data obtained from experiments in-situ. This process is necessary in order to create models which require less geometric and computational complexity.

Next, some of the results of the experiments are shown.

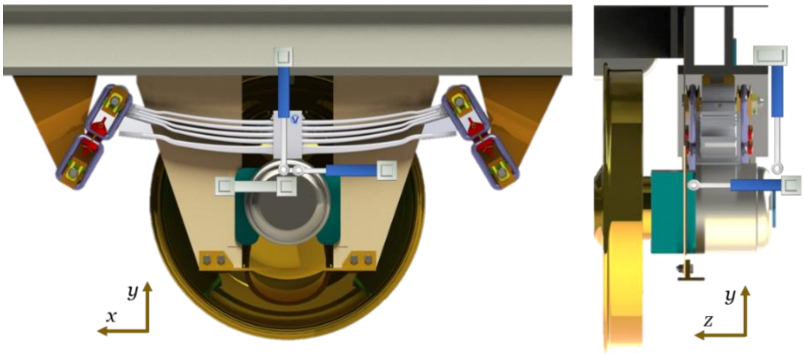

Figure 1 – Installation of LVDTs on the right side of the wheel-set to measure the vertical, longitudinal, and lateral displacements

3 Results

From experiments performed in real conditions of freight wagons, it is possible to evaluate the accelerations, displacements, and strains. The experiment was performed for a specific path, such that the data is acquired along that path.

In figure 2 -left is presented a part of the acquired data by accelerometers. We can see that different accelerations and decelerations levels exist.

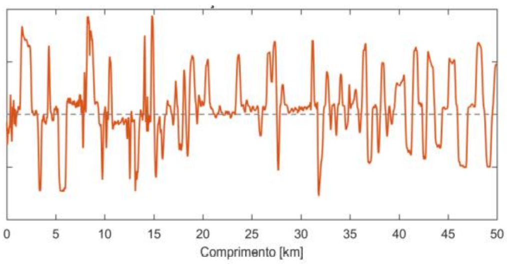

Figure 2 – Left – Vertical accelerations measured by accelerometers.

Other outputs from LVDTs are the displacements in vertical, horizontal, and lateral directions. Figure 3 illustrates the acquired signal.

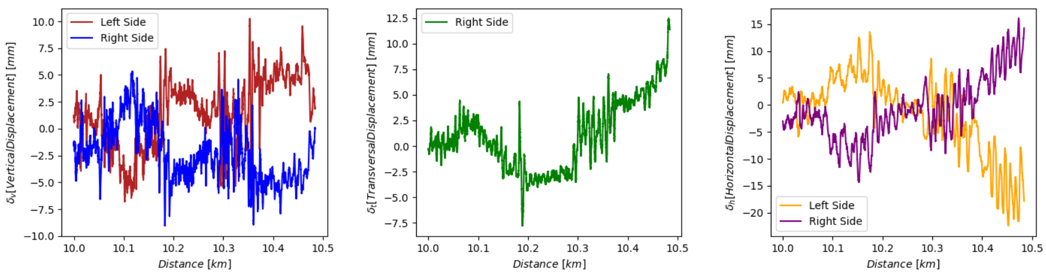

Figure 3 – Illustration of the axle-box's displacements in the three directions gathered from LVDTs.

A rainflow procedure can be performed in order to obtain the set of mean and amplitude of displacements. Figure 4 shows the results of rainflow process, showing a Gaussian distribution, approximately

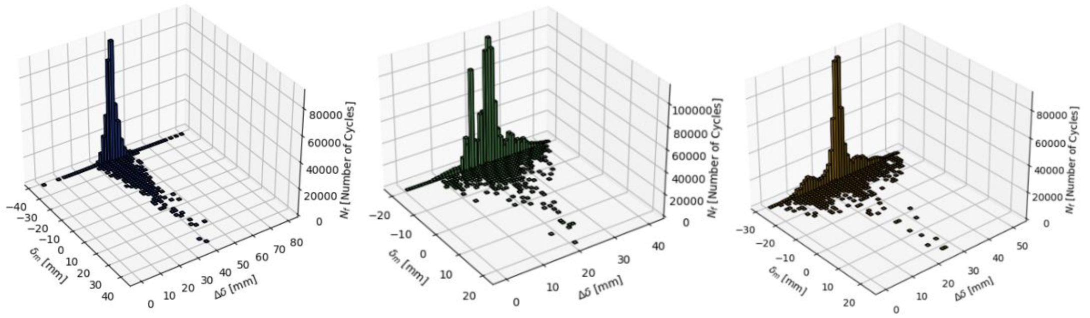

Figure 4 – Representation of rainflow matrices considering 20 km. Left – Vertical displacement; Middle – Lateral displacement, Right – Horizontal displacement.

Another output from experiments is the strain level on the surfaces of leaves. Figure 5 – left presents the acquired data from strain gauges glued on the top surfaces of the master leaf. Figure 5 – right presents the gathered data from the strain on the thickness of the master leaf. All strain data are converted to stress data by using Hooke's law.

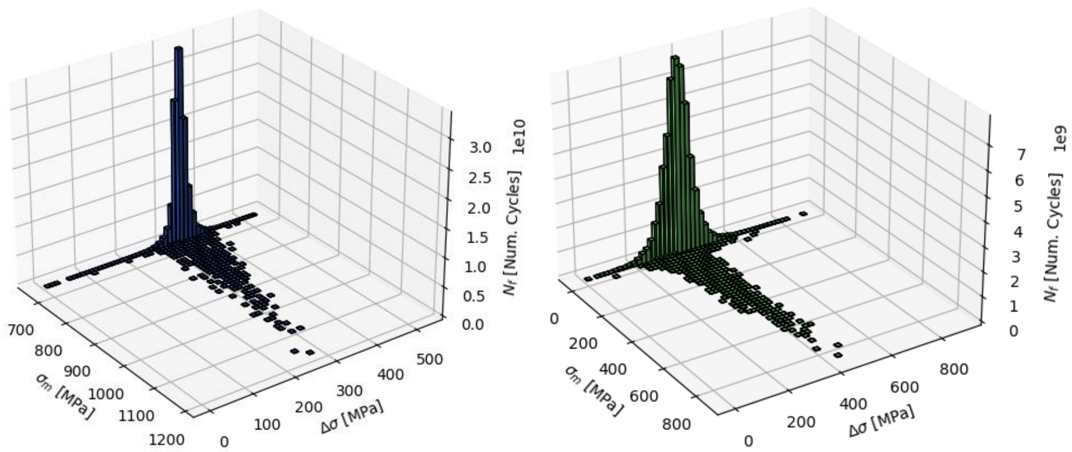

Figure 5 – Left – Longitudinal stresses and; Right transversal stresses measured by strain gauges.

Regarding the numerical approach, figure 6 presents the deformed shape of leaf springs. For low loading, the leaf spring remains in stage I, and consequently, only the main leaf spring contributes to the global stiffness (see figure 6 – Left). Additionally, under higher loadings, the auxiliary leaf spring starts to work, increasing the global stiffness (see figure 6 – middle). Moreover, we can evaluate the effect of lateral loads, which cause lateral bending and twisting of the leaves (see figure 6 – right).

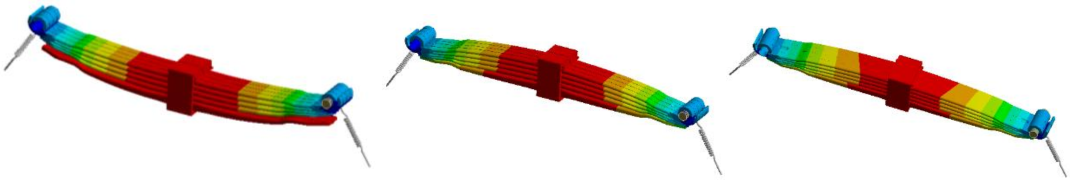

Figure 6 – Leaf spring's deformed shape due to loading: Left – Stage 1 (vertical); Middle – Stage 2 (vertical); Right – Stage 2 (vertical and lateral).

Equally, stress levels must be evaluated to identify where the probability of failure will be higher. Figure 7 presents the longitudinal component of the bending stress for stage I (left) and stage II (right). Also, figure 7 shows that for both high and low loading levels, the highest stress occurs in the middle of leaf springs when the vertical displacement is applied.

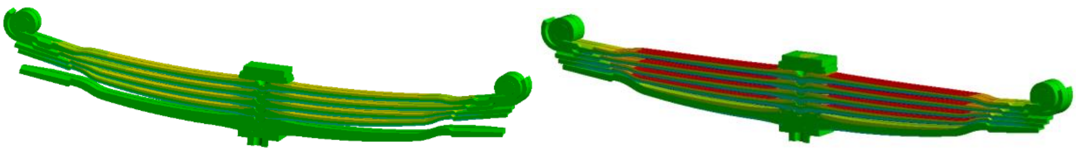

Figure 7 – Bending Stresses in leaf springs: Left – Stage I, Right – Stage II.

4 Conclusions and Contributions

The need for correct structural characterization of leaf spring is mandatory in order to have a correct prediction of failures. It is perceptible that models based on quasi-static conditions, the obtained results will not be so trustworthy compared to dynamic models in which oscillation frequency has quite an importance.

The need for correct structural characterization of leaf spring is mandatory in order to have a correct prediction of failures. It is perceptible that in models based on quasi-static conditions, the obtained results will not be so trustworthy compared to dynamic models in which oscillation frequency has quite important.

This research work shows that there are variations in acceleration levels along the railway. Also, it was shown that the stress levels are within a values range, however, higher bending stress can appear. However, the distribution of loading amplitude appears to be gaussian, while the mean component remains constant in most part of the track.

From the stress analysis in the numerical model, we can see that the major stress levels occur along the middle of the master leaf. This situation remains for a large range of its total resistance. In order to predict the fatigue resistance, the treated data by rainflow procedures requires posteriorly a fatigue analysis based on accumulated damage methods

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