Study of the lifecycle of rubber suspension elements for optimised maintenance and safe dynamic behaviour

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Abstract :

Transport industry and, more specifically, railway industry, is confronted with a permanent need of improvement of its products. The competitiveness of rolling stock does not come only from low-cost production, but also from wise-calculated lifecycle costs. Nowadays, many contracts for railway operators include not only rolling stock, but also its maintenance services throughout its lifetime, which may reach up to 30% of global costs. Hence, deep knowledge about the system's ageing is a strong asset to ensure a good performance, both on quality of service and financial costs.

Rubber parts are widely used in railway technology because of their mechanical properties, providing both stiffness and, to a certain extent, additional damping and vibration filtering. Unlike metallic parts, whose mechanical properties remain relatively stable, rubber's behaviour can change throughout a lifecycle, due to service loads and environmental influence. Such changes might have an impact on the system's overall behaviour and lead to undesirable scenarii. For a given bogie model, we seek to estimate the stiffness variation of some rubber parts, which are deemed critical for safe operation.

Key Words : Railway - Suspension - Ageing - Safety - Maintenance

1 Introduction

The works on our projects are carried out in a partnership with a rolling stock manufacturer. The contents of the article will describe the normative frame and the safety constraints which apply to rolling stock design and operation. The link between safety assessment and mechanical characteristics will be addressed, outlining the need of thorough knowledge on the evolution of the rubber's mechanical characteristics. Ageing mechanisms will be briefly described, as well as a strategy to study the impact of these changes on the parts' macroscopical characteristics. Finally, a review on maintenance objectives will be outlined.

1.1 Safety assessment on railway rolling stock

Railway industry has to comply with several safety norms to obtain the homologation certificate of its products, allowing the exploitation of rolling stock on one or more networks. Compliance is assessed according to local regulation, yet a common base is set up by the UIC (French acronym for "International Railway Union") and EN European norms.

Thus, we carry out several simulations according to safety norms UIC 518 and its european transposition EN 14363. The simulation cases include safety assessment against derailment, curving behaviour, gauge restrictions assessment (roll coefficient), and dynamic behaviour assessment for several train loads and track configurations. We use the MBS software SIMPACK to perform each of the simulated runs. According to the norms, each scenario has to respect some safety indexes, whose limits are fixed on the technical norms [4],[6]. Among these indexes, one can find:

- Nadal's ratio, Y/Q of lateral (Y) and vertical loads (Q), which has to be lower than 1.2;
- wheel lift, Δz [mm], which has to be lower than 5 millimetres;
- roll coefficient over the carbody, s_R, depending on the type of train and on operator's requirements (0.21 for our specific case);
- shift forces over the axle, ΣY [kN], limited by Prud'homme's rule, which is dependent of the axle load;
- acceleration levels [m/s^2] on the bogie frame over the axle boxes, $\ddot{y}^+$, whose limit depends on the bogie's mass, and over the carbody, $\ddot{y}^*$ and $\ddot{z}^*$, which have to remain under 3 m/s^2.

Apart from safety indexes, there are other parameters that might be worth taking into account once safety features are ensured. The comfort index of the rolling stock can also be taken into account within our study. Its calculation is described by the norm UIC 513, which is based on the norm ISO 2631. It requires the recording of acceleration signals on some precise points of the carbody (front, middle, rear, seats, etc.). These signals are filtered to extract the frequencies which have a higher impact according to human sensibility, and they are sampled following 5-second intervals. An RMS value of each sample is then calculated, and the 95-percentile of the measured samples is extracted for each space axis. The comfort index can then be calculated. There are several indexes, depending on the chosen method (complete or simplified) [5]. The simplified comfort index is given by:

$$N_{MV} = 6\sqrt{(a_{XP95}^{W_d})^2 + (a_{YP95}^{W_d})^2 + (a_{ZP95}^{W_d})^2}$$

1.2 Rubber suspension elements

The use of composed rubber parts on train suspension began in the 1960's and 1970's. The main interest on using these parts is that they can handle heavy loads nearly as well as a metallic component would do, with an additional advantage: an inherent damping/dissipative behaviour. These parts play a key role providing both structural strength to the system, as well as filtering vibrations. Their structure can be very different, depending on the desired role: early examples came as stacked layers of rubber and steel [1] (e.g. Figure 1, 2^{ary} suspension on SNCF's BB 22000 series), stack-layered chevrons or, more recently, concentrical-layered rubber-metal springs (e.g. Figure 2, 1^{ary} springs on Renfe's CIVIA series).

Figure 1: Stack-layered rubber-steel 2^{ary} suspension blocks on SNCF's BB 22000 series [own work].

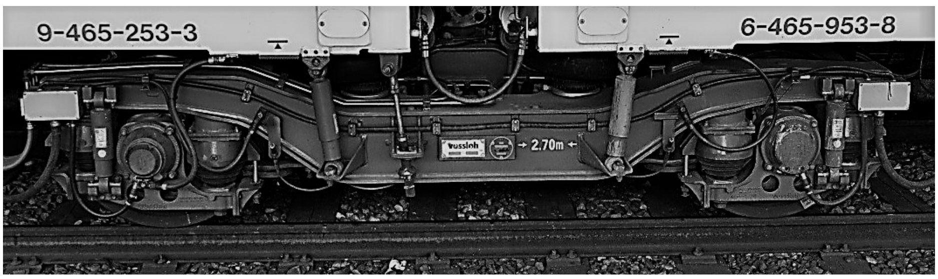

Figure 2: Concentrical-layered rubber-metal 1^{ary} springs on Renfe's CIVIA series [7]

2 Simulations on the train behaviour

The bogie which will be the basis of our study has several rubber-based suspension components. We have undertaken a preliminary analysis to select the elements which are deemed to be the most relevant for the bogie's performance. We are mainly interested in two components which, according to our industrial partner, have an influence on safety performances: a primary suspension element and an auxiliary spring on the secondary suspension, which provides additional stiffness when the secondary suspension is deflated.

According to our partner, these rubber-to-metal components might increase their stiffness up to 30% by the end of their lifecycle. Thus, we have performed a large simulation campaign, varying the characteristics of these suspension elements within a controlled range. First simulations consisted in six steps of +5% stiffness from 0 to 30% of variation, and showed a quasi-linear dependence of derailment test results with the increase of stiffness (see Figure 3 (left) for and example with Y/Q coefficient). An increase of stiffness yields higher Y/Q values, which under certain circumstances can lead to a higher derailment risk.

We have also performed a variability test over the same models. This time, the stiffnesses and dampings of each element were generated with a random uniform distribution. The distribution generated values around the chosen step, with a slight deviation of $\pm$ 5% (for example, +30% random shots were fed random values from 28.5% to 31.5%). This tests aimed to understanding if the linear behaviour seen before was reproduced over a wider spectre of stiffnesses. Results have shown that Y/Q and Δz behave almost linearly, as shown on Figure 3 (right).

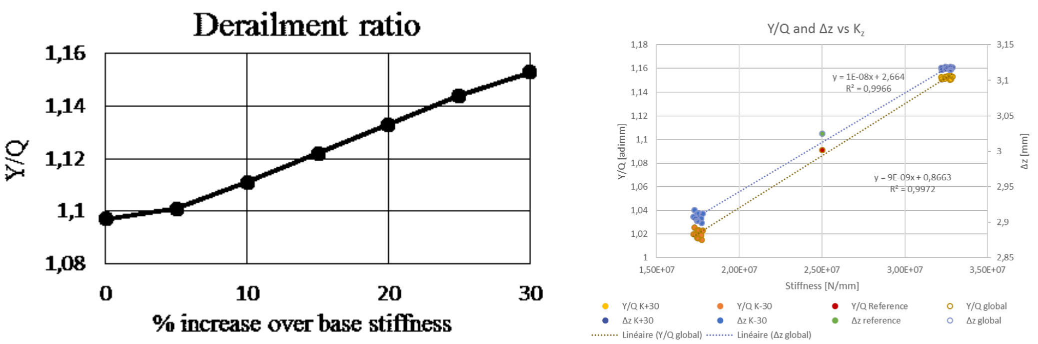

Figure 3: Evolution of Y/Q coefficient versus the increase of stiffness on the suspension elements.

3 Evolution on rubber's mechanical characteristics

3.1 Mechanical and environmental ageing

It is well-known that rubber is subject to several phenomena which can affect its properties throughout time. In the specific case of railway applications, we can expect either an increase or a decrease of the stiffness, which may come from faulty manufacturing (un-bonding from the metallic frames/layers, bad vulcanisation...) or from changes from the rubber itself. Inherent changes might come from two sources: degradation due to mechanical loadings and chemical degradation due to environmental aspects (UV radiation, heat/cold cycles, humidity, grease, etc.).

On our train suspension elements, environmental degradation and mechanical loading occur simultaneously. It has been proved that the effects of these two phenomena can be counter-effective (see Figure 4, left). Indeed, mechanical loading can cause a progressive loss of stiffness, tending to soften the material, while chemical ageing has an influence on the reticulation rate within the rubber's chemical structure. Such changes usually lead to a loss of elastic properties and a stiffening of the rubber itself. The stiffening depends on several parametres, such as temperature or time of exposure. Thus, the main challenge is to assess which is the contribution of each mechanism on the ageing of the selected suspension elements.

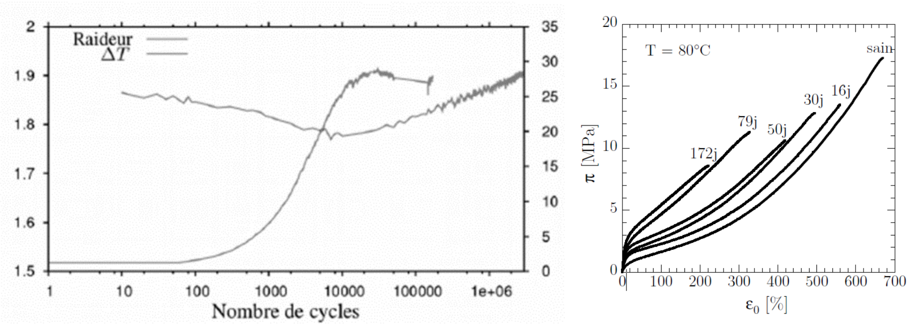

Figure 4: Left, stiffness evolution through cyclical loading [2]; right,stiffening of a rubber reference after different ageing periods for a same temperature [3].

3.2 An inverse approach to determine stiffness evolution during a lifecycle

Rolling stock manufacturers do not always have an access to their products once the warranty period is over. Furthermore, since the element's lifecycle extends for up to ten years, feedback on suspension performances can also be scarce. Hence, gathering information about worn out components becomes soon a major challenge. However, obtaining samples of the material from the suppliers is much easier and can be used as a starting base.

As the exploitation limits of some suspension organs lay far from the design stage, we aim to provide a basic tool that can perform predictive guesses on the evolution of certain elements' behaviour. This tool would be based on FE analysis and a study on the material's mechanical properties, coupled with current expertise from our partners.

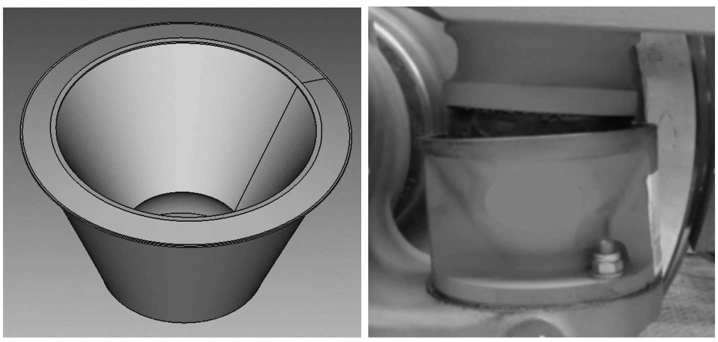

Figure 5: Rubber part of the 1^{ary} suspension element (left). Detail view of the element on the bogie.

4 Conclusion

Maintenance optimisation depends, among others, on the suspension element?s lifecycle. As it has been explained, it is possible to provide tools with a certain accuracy, which can provide some predictive assessment to complete the empirical expertise on lifecycle behaviour of rubber parts. Coupling the expected stiffness evolution of rubber parts with the operation boundaries of the system may show that overhaul delays can be extended further from the empirical limits while still remaining compliant with safety norms.

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