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Road and Rail Infrastructure III

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ADVANTAGES OF INSTALLATION OF RUBBER-METAL ELEMENTS IN SUSPENSION OF RAILWAY VEHICLES

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Abstract

During the exploitation of railway vehicles, failures of elements of the suspension are very often. The fractures on the components of suspension are especially characteristics for freight wagons operating in extreme loading conditions. This causes a decreasing of the efficiency of rail transport and very often can cause a derailments with huge material damage and human victims. The task of this paper is to explore the possibilities for improvement of suspension behaviour through subsequent installation of rubber-metal elements of simple design. The methodology is based on the identification of causes of failures through numerical and experimental analysis of suspension behaviour. These research is basis for design of simple solutions of rubber-metal elements which can be subsequently installed in suspension of wagons. In this paper the proposed methodology is applied on the freight wagons for coal transportation whose suspension is based on laminated springs. Subsequent installation of rubber-metal elements is resulted with prevention of very frequent failures on elements of suspension. Besides, this solution enables reducing of maintenance costs, increasing the efficiency of transportation, and enables many other advantages.

Keywords: rubber, suspension, railway vehicles, wagons, laminated spring

1 Introduction

One of the most important parameters which determine the reliability and running safety of railway vehicles is functionality of the suspension. The malfunction of suspension causes very serious consequences and in many cases may cause derailment. For this reason, the design and reliability of suspension of railway vehicles has previously been the subject of many papers, including those concerning the detection of faults and analysis of failures [1–4]. The aim of all these researches was to indicate the potential problems and to give the motivation for improvements in existing or newly-designed solutions of suspension. Many studies show that failures of elements of the suspension are particularly frequent when the wagons are used in extreme operating conditions. One such system is, for example, the system of railway transportation of coal from mining basin ''Kolubara'' to the thermal power plant ''Nikola Tesla'' Obrenovac, Serbia. The transportation is based on the Fbd wagons and this line is among the most busiest industry railway lines in Europe. Because of this and because of some specifics in the design of suspension which is based on the laminated springs, the very frequent fractures of spring leafs were caused derailments in many cases (one such case is shown in Fig. 1). The consequences of derailments were huge material damage and significant decreasing the efficiency of railway transportation. Such problems are very often on many loaded railway lines for the transport of cargo. In these lines the suspension of freight wagons is usually based on the laminated springs. In the case of such problems, the logical way is to explore the failure of laminated springs and to improve the suspension system. The main task of improving of suspension is to be economical and to allow quick implementation. The one of the main idea for solution the problem is subsequent installation the rubber-metal element in suspension. The motivation lie in the fact that rubber can significantly improve the behavior of suspension and dynamic characteristics of railway vehicles. This is confirmed by numerous studies [5–9].

Figure 1 The derailment caused by the failure of the suspension system

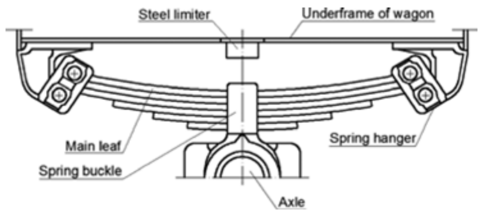

Figure 2 The scheme of suspension of Fbd wagon

2 Analysis of failure of suspension

The typical scheme of suspension of freight wagon that is based on the laminated springs is similar to those for Fbd wagon shown in Fig. 2. The steel limiter is fixed for the underframe of wagon and has the task to limit the stroke of laminated spring. In extreme operating conditions at maximum loads there are intense dynamic rigid impacts of spring buckle in the steel limiter which is very unfavorable for the suspension and the underframe of wagon.

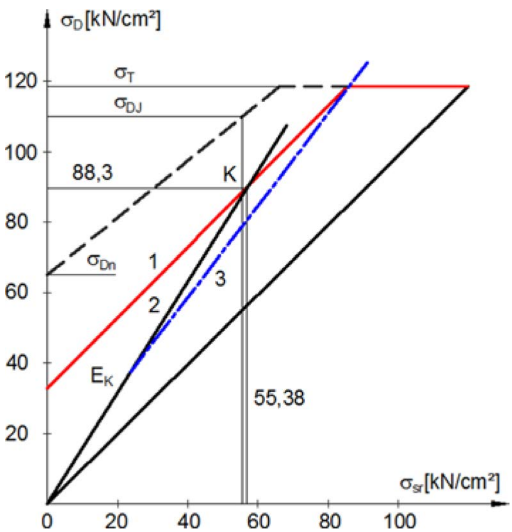

Figure 3 The Goodman-Smith diagram

In the case of Fbd wagons used in the thermal power plant ''Nikola Tesla'', statistical analysis has shown that at the annual level, per one wagon there are almost 3 fractures on the elements of the suspension system. In addition, it is found that the most dominant are the fractures of the laminated springs. The start of solving the problem should be experimental testings of laminated springs with the aim to analyzing and discovering the causes of failure of suspension.

In the case of Fbd wagon, during the experimental tests, the behavior of laminated spring in the exploitation was recorded. The recorded data of vertical deflection of the spring buckle from exploitation were used to form a Goodman-Smith diagram and determine the lines of operating and the critical stresses of laminated spring (Fig. 3). The methodology with more details is shown in paper [10].

The spectrum of force amplitude or stress of laminated spring corresponds to the hard working regime. Based on the characteristics of laminated spring material the line of main dynamic strength was formed (dashed line), where the characteristic values are given in Table 1.

Table 1 The characteristic values of Goodman-Smith diagram

Yield strength	$\sigma_T = 110 \div 125$ kN/cm^2
Dynamic strength during the alternating variable load	$\sigma_{Dn} = 60 \div 70$ kN/cm^2
Dynamic strength during the DC variable load	$\sigma_{Dj} = 110$ kN/cm^2

The extreme values of these data (σ_T, σ_{Dn}) have low probability of occurrence, so in the further analysis the mean value of given areas are used. The critical stress of laminated spring (red line) was obtained by correction of main dynamic strength by the factor k_A. This factor takes into account the quality of the laminated spring production, the conditions of exploitation, and uniformity of loading are random variables. On the other hand, loads during the exploitation of laminated spring caused the stresses shown in Table 2 [11].

Table 2 The characteristic values of Goodman-Smith diagram

Medium dynamic stress in the laminated spring	$\sigma_{sr} = 55.38$ kN/cm^2
Maximal dynamic stress in the laminated spring	$\sigma_{max} = 88.3$ kN/cm^2

Change of the operating stress of the laminated spring is linear and in the Goodman-Smith diagram it is represented by the line 2 which passes through the origin and the point K which has coordinates (σ_{sr}, σ_{max}). In this case the line of operating stress of laminated spring cuts the line of critical stress.

From analysis of diagram it is concluded that in the existing state of laminated spring the occurrence of fracture is very likely. It is also concluded that occurrence of maximal stresses mostly affected the fractures of main leafs of laminated springs.

Therefore, the main reasons for the formation of fractures were primarily increased stresses and loads, and unreliable quality of laminated spring production. Increased loads arising not only due to overload of wagons, but also because of their uneven loading that cannot be accurately controlled.

3 Improvement of suspension

Based on previous considerations and with respecting the existing design of the wagon, the special rubber-metal element for subsequent instalation in the suspension can be designed. The design of rubber-metal element for Fbd wagon is shown in Fig. 4.

In this case, it is predicted that the life time of rubber-element must be minimal 5 years. This should enable the element to be replaced in frame of regular servicing of Fbd wagons. The element is very easy to install in existing wagons, between the laminated spring buckle and underframe, as shown in Fig. 5.

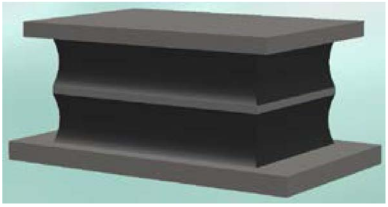

Figure 4 The rubber-metal elastic element

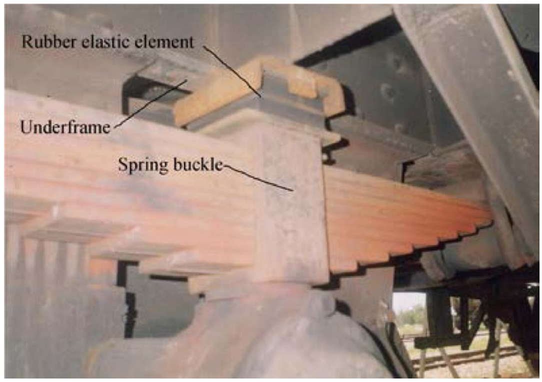

Figure 5 The rubber-metal elastic element instaled in suspension

In order to determine the optimal characteristics of rubber, several samples of different manufacturers and stiffness are tested in exploitation conditions. The main aim was to find compromise between the laminated spring relieving, the life-time of rubber-metal element, and dynamic characteristics of the whole wagon (number of occurrences and the values of the stress amplitudes – deflection as a function of the path traveled).
For the purpose of registering the mentioned dynamic sizes a special measuring system was designed. This measuring system is placed in the wagon and is based on the counter with the task to register the appearances and values of the amplitude of the laminated spring in a longer period of time during the exploitation of wagon. Analysis of results is shown that best solution is with rubber stiffness of 42 Shore. The diagram of optimal zone of stiffness formed on the basis of available space and deflection limitations is shown in Fig. 6. The diagram of stiffness of finaly adopted rubber-metal element obtained by laboratory experimental tests is shown in Fig. 7.

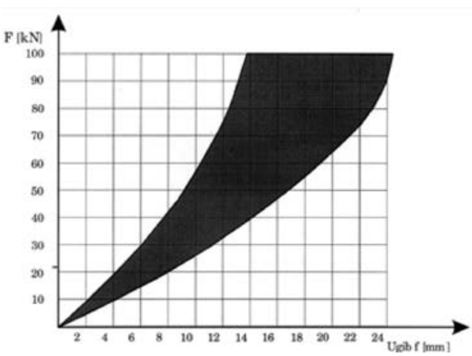

Figure 6 The zone of optimal stiffness

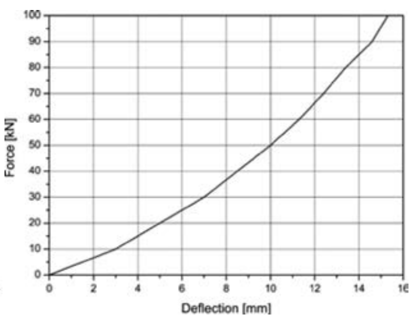

Figure 7 The diagram of stiffness of finaly adopted rubber-metal element

Subsequent installation of designed rubber-metal element in the suspension should cause significant decrease of the stress amplitude, and therefore a new line of operating stress of laminated spring in Goodman-Smith diagram (blue line 3). This should result in significantly lower stress amplitudes, and hence sholuld reduces the extent of fatigue loading. Therefore, the blue line 3 on the Goodman-Smith diagram represents the compromise between the laminated spring relieving and load of rubber-metal element, which provide a permanent dynamic strength of the laminated spring.

The designed rubber-metal elements are installed into the suspension of one Fbd wagon on which the experimental tests in exploitation were performed. The results of these tests are shown in the next chapter.

3.1 FEM analysis of rubber-metal element

The method of finite element (FEM) has been used to analyze the stress distributions and deflection of the rubber-metal element. The nominal loading range used is 100 kN. The calculated deflection of rubber-metal element is shown in Fig. 8. The obtained results have shown that rubber-metal element satisfy the stress limitations. Also, the obtained deflections is matching with those obtained by the laboratory experimental tests (Fig. 7). The results of FEM analysis confirm that adopted design and dimensions of element and rubber stiffness are satisfactory from the point of allowed stress and projected deflection.

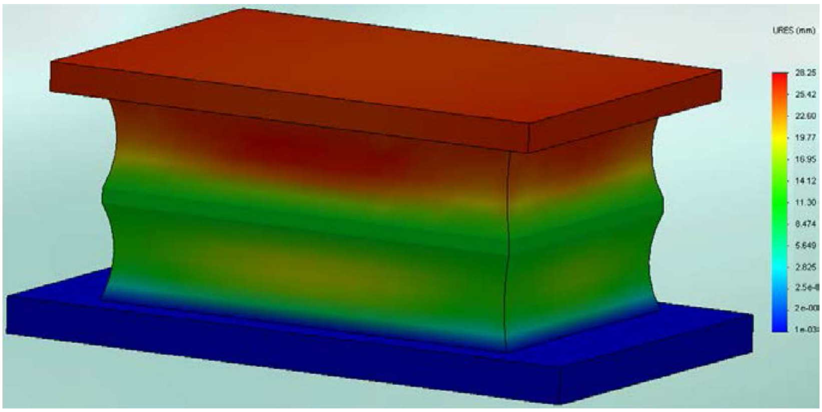

Figure 8 The deflection of rubber-metal elastic element

4 Exploitation tests

The exploitation tests of suspension with rubber-metal element was performed with the same measuring equipment and on the same track as previous test without it (Fig. 9). The change of measured deflection of rubber-metal element, as time function, for empty and laden wagon is shown in Fig. 10.

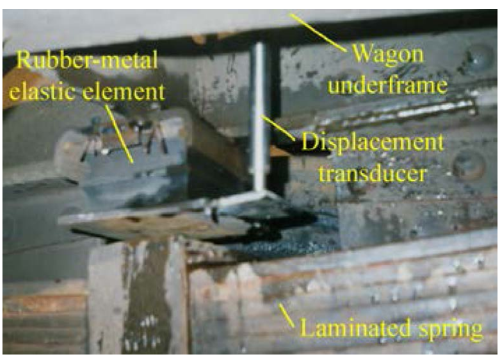

Figure 9 The exploitation tests of deflection of rubber-metal element

Based on the analysis of recorded signals of behavior of suspension, the quality of the introduced improvement was assessed. Characteristic loads of laminated spring with and without the rubber-metal element, in the static and dynamic conditions for laden wagon are given in Table 3.
From the Table 3 it is evident that the total static force on the one laminated spring F_u^{st} of fully laden wagon is lower for 48.4%. This means that part of the load is taken from the rubber-metal element, and in this way, even in the static conditions, the laminated spring is relieved for almost 50%. As expected, this was even more pronounced in wagon running at dynamic loadings.

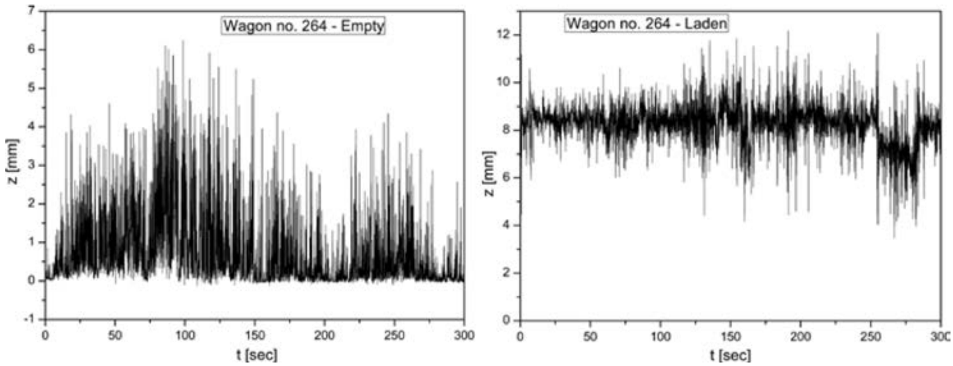

Figure 10 The measured deflection of rubber-metal element in exploitation

Table 3 The effect of the introduced improvement

Force on the laminated spring	Without rubber-metal element [kN]		With rubber-metal element [kN]	Relieving of laminated spring [%]
Static	F_u^{st}	119	61.42	48.4
Maximal dynamic	F_{max}^{d}	157	68.06	56.6
Minimal dynamic	F_{min}^{d}	125	53.45	57.3

The percentage of relieving of the laminated spring in dynamic conditions is increased and ranged between 56.6% and 57.3%. During the tests, the maximal dynamic deflection of rubber-metal element for laden wagon is equal to z_{max}=12.2 mm (Fig. 10).
Based on those obtained results, the rubber-metal elements were installed on over 400 wagons for coal transportation to the thermal power plant “Nikola Tesla” Obrenovac. During the later years of operation of these wagons there were no frequent fractures of laminated springs or other elements of suspension system. The number of fractures was reduced by more than 90%, where it should be noted that the rubber-metal elements are installed in the existing suspension systems. In mentioned period of 5 years there were no cases of debonding of rubber or any other defect of rubber-metal element. Of course, after this period, each element is replaced by new ones.

5 Conclusion

The fractures on the components of suspension are especially characteristic for freight wagons operating in extreme loading conditions. This causes a decreasing of the efficiency of rail transport and very often can cause a derailments with huge material damage and human victims. This this paper explore the possibilities for improvement of suspension behaviour through subsequent installation of rubber-metal elements of simple design. The methodology is based on the identification of causes of failures through numerical and experimental analysis of behaviour of suspension. Respecting the existing design of the wagon, the special solution of the rubber-metal element which can be subsequently installed in suspension can be designed. In this paper, the proposed methodology is applied on the freight wagons Fbd for coal transportation. The results show that static load of laminated spring of laden wagon is reduced by about 50%, while the dynamic load is reduced by over 60%. The number of fractures was reduced by more than 90%, and reliability of transportation is significantly increased. These results show that advantages of subsequent installation of rubber-metal elements in suspension of railway vehicles are very large. The proposed methodology can be applied even on the wagons whose suspension is not based on the laminated springs, but is based on coil springs or other elastic elements. The proposed solution implies that with the minimum processing and reconstruction, the existing suspension can be improved to the satisfactory level of reliability. The most important advantages of subsequent installation of rubber-metal elements in suspension is reducing of maintenance costs, increasing the efficiency of transportation, improving the ride comfort and running stability, etc.

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