XV SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS RAILCON '12

IMPROVEMENT OF SUSPENSION SYSTEM OF WAGONS WITH LAMINATED SPRINGS

Dragan PETROVIĆ [1]
Milan BIŽIĆ [2]

Abstract *– During the exploitation of freight wagons with laminated springs, a large number of fractures of elements of suspension have been noticed. These fractures decrease efficiency of transportation and very often cause the derailment with large economic losses and sometimes with human victims. This paper presents the failure analysis and improvement of suspension of wagons with laminated springs. The technique is based on specially designed rubber elastic elements which can be subsequently installed in suspension of wagons. This solution is result of many years research of Railway Vehicles Center of Faculty of Mechanical Engineering Kraljevo in this field. The rubber elastic element is very easy to install in all existing wagons, between the laminated spring buckle and underframe. The applied methodology is based on theoretical and experimental analysis of behavior of suspension with and without rubber elastic elements. Subsequent installation of rubber elastic elements can prevent very frequent fractures of laminated springs and cracks on the underframes. This provides enormously reduced costs of maintenance of wagons and increased the efficiency of railway transportation.*

Keywords - improvement, suspension, wagon, laminated springs

1. INTRODUCTION

One of the most important parameters which determine the reliability and running safety of railway vehicles is functionality of the suspension. In addition, it affects the quality of ride comfort of passengers or cargo. Inadequate functioning of suspension causes very serious consequences and in many cases may cause derailment. For this reason, the fault of suspension is very important topic that is the subject of many scientific papers such as [1–5]. The main aims of these researches was to indicate the potential problems and to give the motivation for improvements in existing or newly-designed solutions of suspension.

Failures of elements of the suspension system based on the laminated springs are particularly frequent when the wagons are used in extreme operating conditions. Very intense loadings in exploitation caused the increasing of stresses of these elements. As a consequence, there have been very frequent fractures of elements of suspension system and cracks on the underframe. Such fractures very often cause derailment, as is for example shown in Fig. 1. The consequences of such events were huge material damage and significant decreasing the efficiency of railway freight transportation.

Fig.1. The derailment of Fbd wagon for coal transportation in thermal power plant ''Nikola Tesla'' Obrenovac, Serbia

Such events caused the need to improving the suspension system based on the laminated spring. Obtained results of improvement through subsequently installation of rubber elastic element are presented in this paper.

2. TYPICAL SOLUTION OF SUSPENSION BASED ON LAMINATED SPRING

The principal scheme of typical solution of

---

[1] Dragan PETROVIĆ, University of Kragujevac, Faculty of Mechanical Engineering Kraljevo, Dositejeva 19, 36000 Kraljevo, Serbia, petrovic.d@mfkv.kg.ac.rs
[2] Milan BIŽIĆ, University of Kragujevac, Faculty of Mechanical Engineering Kraljevo, Dositejeva 19, 36000 Kraljevo, Serbia, bizic.m@mfkv.kg.ac.rs

suspension system based on the laminated spring is shown in Fig. 2.

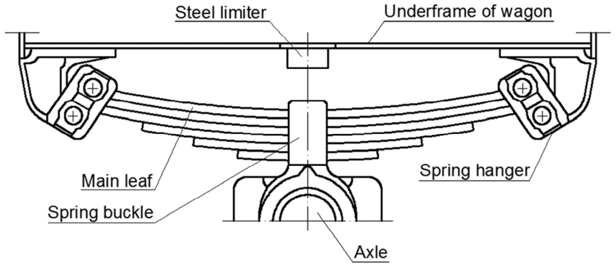

Fig.2. The scheme of typical solution of suspension system based on laminated spring

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 system and the underframe of wagon. As a result there are very often fractures on the underframe and elements of the suspension system.

For example, for Fbd wagon for coal transportation it is calculated that on average at the annual level, per one wagon there are almost 3 fractures on the elements of the suspension system [6]. In addition, it was noticed that the most dominant are the fractures of the laminated springs [6].

During the experimental tests of laminated springs of the Fbd wagon the following measuring equipment was used: device for dynamic testing HBM MGC Plus, inductive transducers of displacement HBM W100, and PC. Also, the following software was used: software package for data acquisition and on-line data processing - “Catman” (production of HBM), and software package for processing and displaying data - "Origin" (production of MicroCal). Using the mentioned measuring equipment the behavior of laminated spring in the exploitation was recorded. During the tests, the vertical deflection (movement) of the spring buckle was measured. The collected data from exploitation were used to form a Goodman-Smith diagram and determine the lines of operating and the critical stresses of laminated spring.

During the exploitation, the suspension system of Fbd wagon is exposed to effect of forces $F=F_{sr}+F_a$. The mean load is $F_{sr}=92.8$ kN, while the investigation is established that the real values of the total force F range and up to 50% above average, due to the overload of wheel and dynamic effects during movement. Therefore, the effect of amplitude load F_a on the fracture of laminated spring is dominant.

The spectrum of force amplitude or stress of laminated spring corresponds to the hard working regime. Based on the characteristics of laminated spring material (51Si7 according to EN) the line of main dynamic strength was formed (dashed line on the Fig. 3), where are:

$\sigma_T=110\div125$ kN/cm^2 – the yield strength,

$\sigma_{Dn}=60\div70$ kN/cm^2 – the dynamic strength during the alternating variable load,

$\sigma_{Dj}=110$ kN/cm^2 – the dynamic strength during the DC variable load.

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.

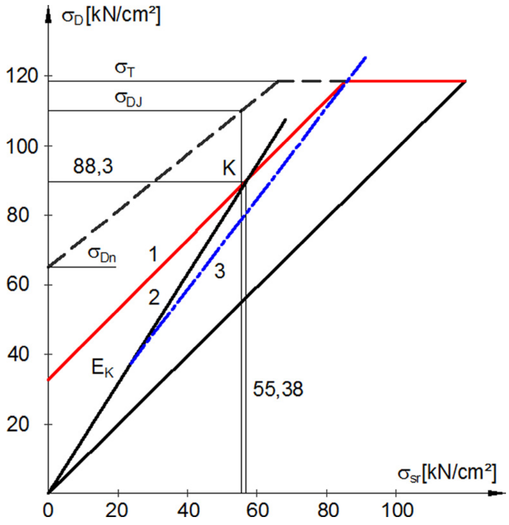

Fig.3. The Goodman-Smith diagram

The quality of the laminated spring production, the conditions of exploitation, and uniformity of loading are random variables, whose influence on the fracture was taken into account through the correction of main dynamic strength by the factor k_A. On that way, the line of critical stress of laminated spring was obtained (red line 1). On the other hand, the loads during the exploitation caused the stresses in the laminated spring of the following intensities:

$\sigma_{sr}=55.38$ kN/cm^2 – the medium dynamic stress in the laminated spring,

$\sigma_{max}=88.3$ kN/cm^2 – the maximal dynamic stress in the laminated spring.

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 this analysis it can be 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. In this case, increased loads arising not only due to overload of wagons by coal, but also because of their uneven loading that cannot be accurately controlled.

On of the solutions of this problem implies that, with the minimum processing and reconstruction, the existing suspension system to improve to the satisfactory level of reliability that will significantly improve the efficiency of railway transport

3. SUBSEQUENTLY INSTALLATION OF RUBBER ELASTIC ELEMENT

Respecting the existing design of the wagon, the special solution of the rubber elastic element, which can be subsequently installed in suspension system, can be designed. In concrete example of Fbd wagon this element is shown in Fig. 4. It is predicted that the life time of this element must be minimal 5 years. This enables that this element can be replaced in frame of regular servicing of wagons.

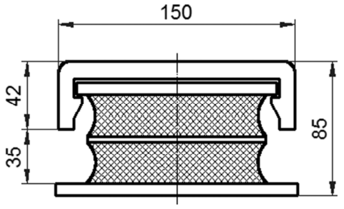

Fig.4. The rubber elastic element

The element is very easy to install in existing wagons, between the laminated spring buckle and underframe, instead a steel limiter, as shown in Fig. 5.

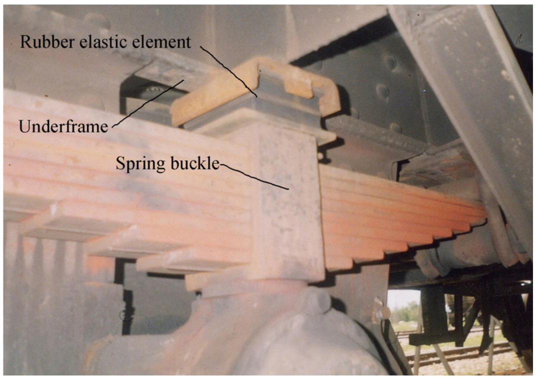

Fig.5. The rubber elastic element in suspension system

The constructive solution of rubber elastic element must be designed on the basis of free space to install in the suspension system. In order to determine the necessary characteristics of rubber incorporated in the elastic element, the main aim is to find compromise between the laminated spring relieving, the life-time of the rubber elastic 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). The diagram of stiffness of adopted rubber elastic element for Fbd wagon obtained by the experimental way is shown in Fig. 6.

In concrete example of Fbd wagon, the subsequent installation of rubber elastic element caused significant decrease of stress amplitude, and therefore a new line of operating stress of laminated spring in Goodman-Smith diagram (blue line 3 on Fig. 3).

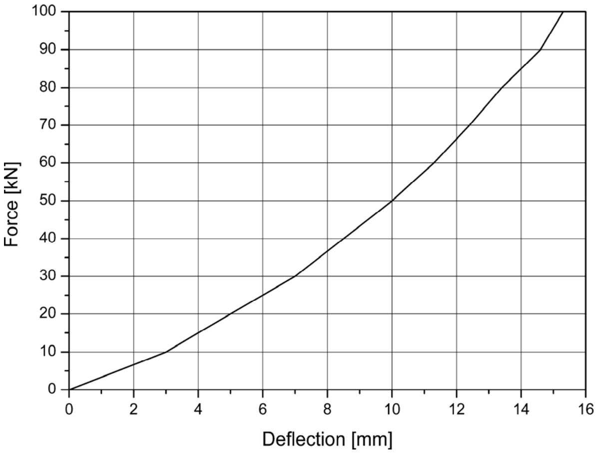

Fig.6. The diagram of stiffness of rubber element

This solution results in significantly lower stress amplitudes, and hence reduces the extent of fatigue loading. Therefore, the blue line 3 on the Goodman-Smith diagram on the Fig. 3 represents the compromise between the laminated spring relieving and load of rubber elastic element, which provide a permanent dynamic strength of the laminated spring.

4. RESULTS OF THE INTRODUCED IMPROVEMENT

The testing of suspension system with rubber elastic element in exploitation was performed with the same measuring equipment and on the same track as previously tests without it. The change of deflection of rubber elastic element z in function of time, for empty and laden wagon in exploitation conditions is shown in Fig. 7.

Based on the processing and analysis of recorded signals of behavior of suspension system elements, the quality of the projected improvement was assessed. Characteristic loads of laminated spring with and without the rubber elastic element, in the static and dynamic conditions for laden wagon are given in Table 1.

Table 1. The effect of the introduced improvement

Force on LS	Without REE [kN]	With REE [kN]	Relieving of LS [%]
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

LS – laminated spring
REE – rubber elastic element

From the previous table 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 elastic 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. The rubber elastic element has a parabolic curve of dependence of force and deflection and a percentage of relieving of the laminated spring in dynamic conditions is increased and ranged between 56.6 % and 57.3 %. During these tests, the maximal dynamic deflection of rubber elastic element for laden wagon is equal to $z_{max}=12.2$ *mm* (Fig. 7).

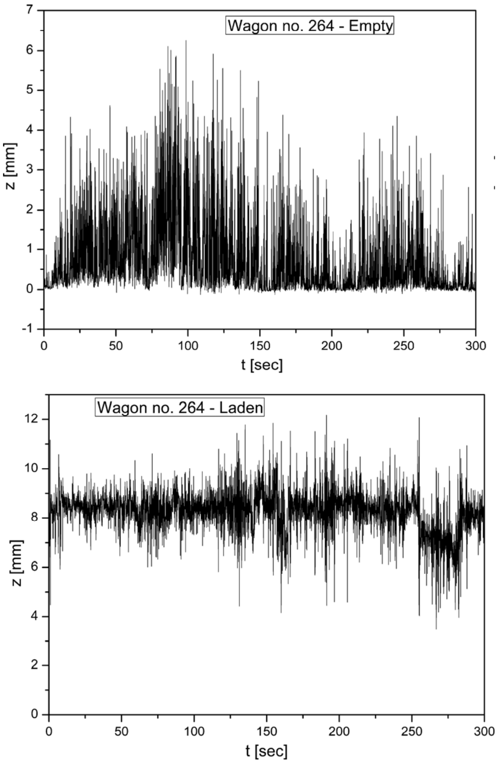

Fig. 7. The deflection of rubber elastic element

Based on those obtained results, the rubber elastic elements were installed on the over 400 wagons for coal transportation to the thermal power plant "Nikola Tesla" Obrenovac. The number of fractures was reduced by more than 90 %.

5. CONCLUSION

The paper presents the failure analysis and methodology for improvement of suspension system of wagons with laminated springs. The technique is based on specially designed rubber elastic element which can be subsequently installed in suspension of wagons. The element is very easy to install in existing wagons, between the laminated spring buckle and underframe. The methodology of identifying the causes of unwanted fractures is focused on theoretical and experimental analysis of behaviour of suspension system with and without rubber elastic elements.

In concrete example of Fbd wagon for coal transportation, the results of introduced improvement are: the static load of laminated spring of laden wagon is reduced by about 50 %; the dynamic load of laminated spring of laden wagon is reduced by over 60 %; in the eventual fracture of the main leaf of laminated spring, axle bearing do not remains unencumbered, which reducing the probability of derailment of empty wagon; the number of fractures was reduced by more than 90 %, (it should be noted that the rubber elastic elements are installed in the existing suspension systems); the reliability of transportation of coal is increased, and thus the overall reliability of the thermal power plant system.

In addition, designed rubber elastic element satisfies the following requirements: allows the behavior of suspension system which provides a permanent dynamic strength of the laminated spring; provides the required dynamic characteristics of wagon; prevents the occurrence of cracks and fractures on the underframe of wagon.

Therefore, subsequent installation of rubber elastic elements can prevent the very frequent fractures of laminated springs and cracks on the underframes on wagons with laminated springs. This can provides enormously reduced costs of maintenance of wagons and increased the efficiency of railway transportation.

ACKNOWLEDGEMENTS

The authors wish to express their gratitude to Serbian Ministry of Science and Technology for supporting this paper through project TR35038.

REFERENCES

[1] Huichuan Fan, Xiukun Wei, Limin Jia, Yong Qin, Fault detection of railway vehicle suspension systems, Computer Science and Education (ICCSE), 5th International Conference on Computer Science and Education, (2010) 1264-1269.

[2] X. J. Ding, T. X. Mei, Fault Detection for Vehicle Suspensions Based on System Dynamic Interactions, Proceedings of the UKACC International Conference on Control, (2008).

[3] Xiukun Wei, Hai Lui, Yong Qin, Fault isolation of rail vehicle suspension systems by using similarity measure, 2011 IEEE International Conference on Service Operations and Logistics and Informatics (SOLI), (2011) 391-396.

[4] Hayashi Yusuke, Tsunashima Hitoshi, Marumo Yoshitaka, Fault Detection of Railway Vehicle Suspension Systems Using Multiple-Model Approach, Journal of Mechanical Systems for Transportation and Logistics Volume 1, Issue 1, (2008) 88-99.

[5] M. A. Kumbhalkar, Y. L. Yenarkar, A. K. Grover, Failure Analysis of Inner Suspension Spring of Railway Engine: A Case Study, Proc. of Int. Conf. on Advances in Robotic, Mechanical Engineering and Design 2011, (2011) 12-16.

[6] Dragan Z. Petrović, Milan B. Bižić, Improvement of suspension system of Fbd wagons for coal transportation, Engineering Failure Analysis, 25 (2012) 89–96, doi.10.1016/j.engfailanal.2012.05.001