Mechanics Transport Communications

ISSN 1312-3823 (print)
ISSN 2367-6620 (online)
volume 22, issue 3/3, 2024

*Academic journal* http://www.mtc-aj.com article № 2600

# CHARACTERISTICS OF RUBBER ELEMENTS IN SUSPENSION OF RAILWAY VEHICLES

**Dragan Petrović[1], Milan Bižić[1], Dobrinka Atmadzhova[2]**
petrovic.d@mfkv.kg.ac.rs, bizic.m@mfkv.kg.ac.rs, atmadzhova@abv.bg

*[1] – Faculty of Mechanical and Civil Engineering in Kraljevo, University of Kragujevac, Dositejeva 19, 36000 Kraljevo, SERBIA*
*[2] – University of Transport "Todor Kableshkov" Geo Milev 158, 1574 Sofia, BULGARIA*

**Key words:** *Railway, Rubber, Suspension*

**Abstract:** *The purpose of the suspension of railway vehicles is to prevent rigid contact between the running gear and the vehicle body, which significantly improves safety and riding comfort. The designer of railway vehicles has at his disposal a wide range of rubber and other (polymeric) materials, which can be used to soften the effect of forces on the wagon structure. Rubber elastic elements are most often used in railway vehicles for damping high-frequency oscillations. They are not suitable for carrying large concentrated forces, and for this reason they are combined with other elastic elements in the suspension system of railway vehicles. The characteristics of rubber elastic elements are quite different from, for example, the characteristics of metal elements. Therefore, in designing of rubber elastic elements, their characteristics must be known. First of all, these characteristics refer to the modulus of elasticity, Poisson's ratio, type of load, shape of the element, hardness, permissible shear angle, etc. In addition, the characteristics of rubber elements depend on atmospheric influences and aging of rubber over time.*

*This paper presents the basic characteristics of rubber elements that must be taken into account when designing the suspension of railway vehicles. In addition, an example of a concrete solution for the use of rubber elements in the suspension system of wagons for coal transport coal is given. Adhering to these recommendations, it is possible to apply rubber elements in a wide range of railway vehicles, as well as in other structures where it is necessary to achieve the required damping and elasticity.*

## 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 for example is 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 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).

**Fig. 1. The derailment caused by the failure of the suspension system**

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 economically and that allowing 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 [1–4].

By analyzing the suspension of railway vehicles it can be noticed that the leaf spring is supported on the axle-box bearing over the spring buckle (Figs. 2 and 3). The connection of the leaf springs with the underframe of the vehicle is realized over the suspension brackets and spring hangers.

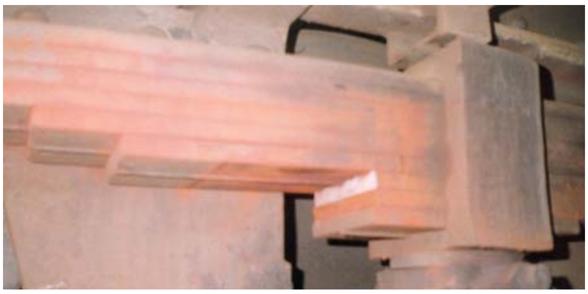

**Fig. 2. Leaf spring**

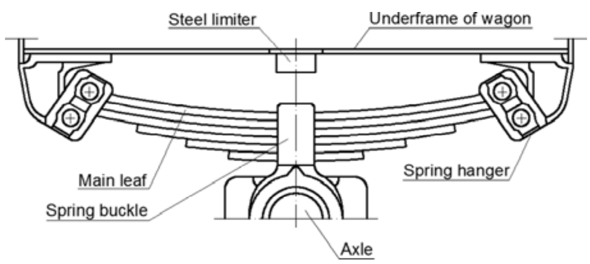


**Fig. 3. Connection of leaf spring and underframe**

The spring hangers can be single and double and over the pins and suspension brackets connecting the leaf springs with the underframe of railway vehicle.

In case of impacts which are unavoidable during the exploitation of railway vehicles, the stresses on the elements of suspension and whole structure have the change which is shown in Fig. 4. In order to reduce impacts during the operation of railway vehicles, a suspension system was designed that instead of a rigid stop (steel limiter) has rubber elastic element (Fig. 5).

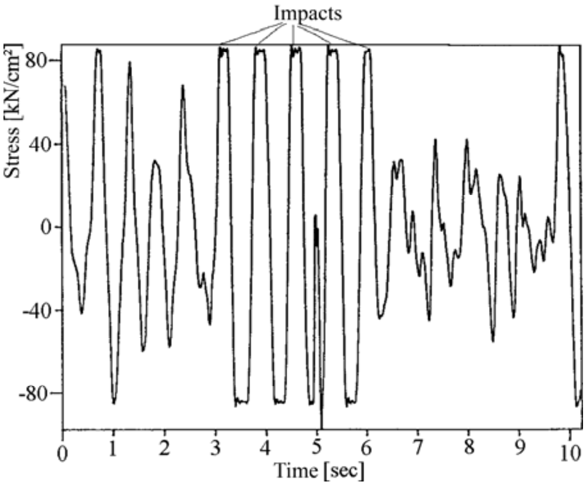


**Fig. 4. Diagrams of change of stress on the elements of suspension during the time**

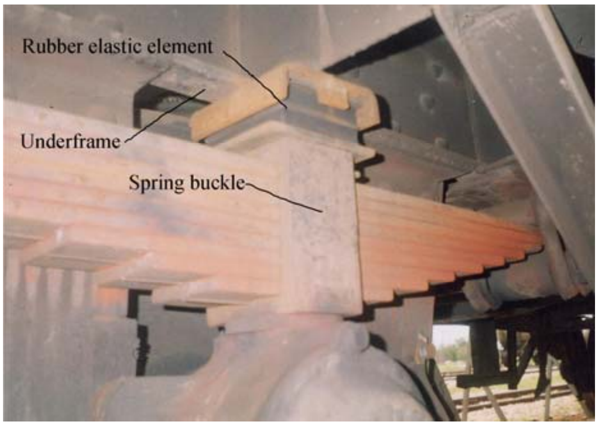


**Fig. 5. Combined suspension with leaf spring and reinforced rubber elastic element**

In order to more quality design of suspension of the vehicle it is necessary to well know the behavior of all its components.

## 2. CHARACTERISTICS OF RUBBER ELASTIC ELEMENTS

The reinforced rubber elastic elements are designed to receive load of pressure, shearing or both on the same time. They are not suitable for acceptance of the torsion, but in combination with the metal they can be used for that purpose. In the design of rubber elastic elements, allowed change of angle of shear should be in range $\theta_{\max} = 20 \div 25^{\circ}$, and maximal relative deformation at the pressure is $\Delta\delta_{max}/\delta = 0,2 \div 0,25$ [1]. In addition to the characteristics of the material, modulus of elasticity of rubber depends on the shape of the element and the type of load [3]. If $E_{ist}$ is modulus of elasticity of rubber at tension and $E_{pr}$ is modulus of elasticity of rubber at pressure, ration of these two modulus of elasticity is:

$$E_{pr} = k \cdot E_{ist} \quad \left[\text{kN/cm}^2\right] \tag{1}$$

Where:

$k = f(k_f)$ - coefficient of enlargement

$k_f = \dfrac{A_o}{A_b}$ - coefficient of shape of rubber element

The coefficient of shape represents the ratio of area of support $A_o$ and lateral area $A_b$ of the rubber element (Fig. 8). Medium dependence of coefficient of shape $k_f$ and coefficient of enlargement $k$ is given in the Fig. 6.

At the dynamic loads of rubber elastic elements, modulus of elasticity $E_{din}$ is larger than modulus of elasticity at the static load $E_{st}$:

$$E_{din} = k_{tv} \cdot E_{st} \quad \left[\text{kN/cm}^2\right] \tag{2}$$

The dynamic coefficient $k_{tv}$ depends on the hardness of the rubber $H_g$ and it is determined from the diagram which is shown in Fig. 7.

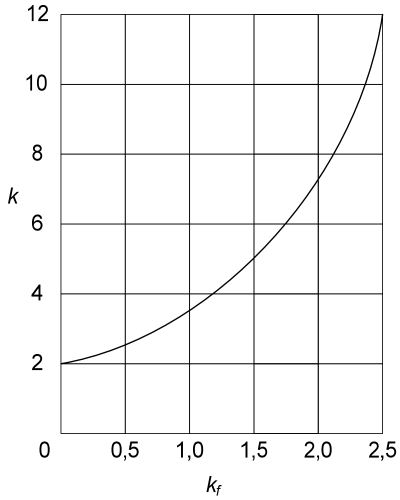


**Fig. 6. The dependence of coefficient of shape $k_f$ and coefficient of enlargement $k$**

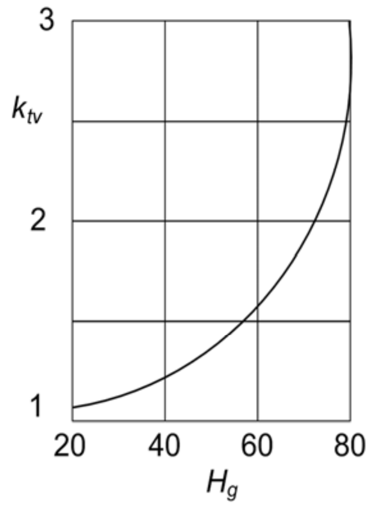


**Fig. 7. The dependence of dynamic coefficient $k_{tv}$ on the hardness of the rubber $H_g$**

If the hardness of the rubber $H_g$ is expressed in Shore, shear modulus of the rubber $G$ can be calculated from the empirical equation:

$$G = \frac{H_g^2}{38000} \quad \left[\frac{\text{kN}}{\text{cm}^2}\right] \tag{3}$$

The shear modulus $G$ can be calculated from its relationships with the modulus of elasticity at the pressure $E_{pr}$:

$$G = \frac{E_{pr}}{2 \cdot (1+\mu)} \tag{4}$$

The Poisson's ratio m represents the relationship of deformation in two, mutually perpendicular, directions and for rubber is approximately $\mu \approx 0.5$, so it is:

$$G \approx \frac{E_{pr}}{3} \tag{5}$$

In the design of rubber elastic elements, a smooth transition from the surface to the surface and the ability of free bulge of the rubber at the pressure should be provided.

### 2.1. The pressure load of rubber element

A rubber elastic element is loaded with pressure force $F_p$, as shown in Fig. 9. The initial height of the rubber element δ is reduced due to the load for value $f$.

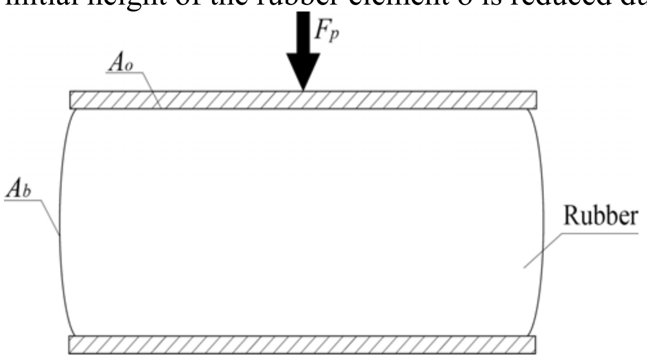


**Fig. 8. The reinforced rubber elastic element**

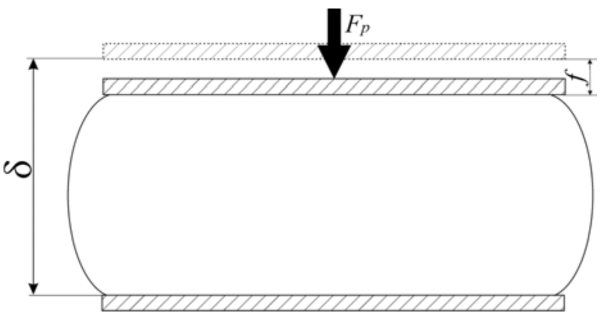


**Fig. 9. The rubber elastic element loaded on the pressure**

From the expression for stress $\sigma = E_{pr} \cdot \varepsilon$ and knowing that $\sigma = F_p / A_o$ and $E_{pr} = k \cdot E_{ist}$ the following relation is obtained:

$$F_p = k \cdot E_{ist} \cdot A_o \cdot \frac{f}{\delta} \tag{6}$$

where:

$A_o$ – area of cross-section of the rubber.

The pressure force $F_p$ is equal to the product of stiffness of the rubber at pressure load $c_p$ and deflection of the rubber $f$:

$$F_p = c_p \cdot f \tag{7}$$

By the equalization of the expressions (6) and (7), the stiffness of rubber element at pressure load is obtained:

$$c_p = \frac{k \cdot E_{ist} \cdot A_o}{\delta} \tag{8}$$

### 2.2. The shear load of rubber element

In this case, the reinforced rubber elastic element is loaded on the shear with force $F_s$, as shown in Fig. 10.

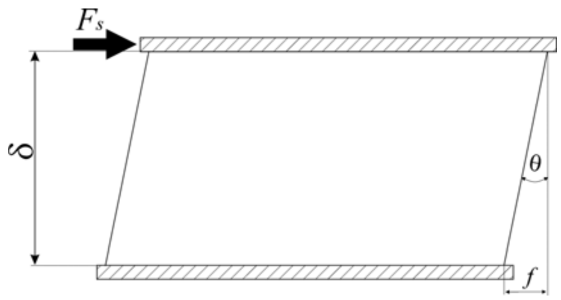


**Fig. 10. The reinforced rubber elastic element loaded on the shear**

From the expression for the stress $\tau = G \cdot \theta$ and $\tau = F_s / A_o$, shear force is:

$$F_s = A_o \cdot G \cdot \theta \tag{9}$$

where: $\theta$ – angle of shear

For small angles of shear, the following relation is satisfied:

$$tg\theta \approx \theta = \frac{f}{\delta} \tag{10}$$

The shear force $F_s$ is equal to the product of stiffness of the rubber at shear $c_s$ and deflection of the rubber $f$:

$$F_s = c_s \cdot f \tag{11}$$

Expression (5) gives:

$$G \approx \frac{E_{pr}}{3} = \frac{k \cdot E_{ist}}{3} \tag{12}$$

By the equalization of the expressions (9) and (11), the stiffness of rubber element at shear load is obtained:

$$c_s = \frac{k \cdot E_{ist} \cdot A_o}{3 \cdot \delta} \tag{13}$$

From the expressions (8) and (13) can be noticed that rubber elements have three times bigger stiffness at the pressure in relation to the shear.

## 3. CONCLUSION

The dynamic loads are very undesirable and have very harmful impacts on the passengers and cargo, whereby the durability of the vehicle and track is decreased. Consequently, in the suspension systems are increasingly used the reinforced rubber elements and elements made of polymer materials that, in addition to the elastic, have very good damping characteristics. It is very important to emphasize that during time, due to aging, there is change of elastic characteristics of rubber. Also, rubber is sensitive to the temperature influences. Nevertheless, advantages in characteristics of elasticity and damping are caused that rubber and polymer materials are widely used in suspension systems, not only the railway vehicles, but also other vehicles and machines. The proposed solutions given in this paper enable that existing suspension can be improved to a satisfactory level of reliability with minimal reconstructions. The most important conclusion of this paper is that installation of rubber metal elements in the suspension of railway vehicles has many advantages such as decreasing of loads of vital elements, increasing of ride comfort and running stability, increasing of efficiency of transport, etc. These conclusions should be taken into account, not only in the design of new, but also in the modifications and improvements of existing railway vehicles.

## ACKNOWLEDGEMENTS

The authors are grateful to the Ministry of Science, Technological Development and Innovation of the Republic of Serbia for support (contract no. 451-03-65/2024-03/200108).

## REFERENCES:

[1] Dragan Petrović, Milan Bižić, Improvement of suspension system of Fbd wagons for coal transportation, Engineering Failure Analysis, Volume 25, (2012), 89–96, ISSN 1350-6307, doi:10.1016/j.engfailanal.2012.05.001.

[2] Dragan Petrović, Dobrinka Atmadzhova, Milan Bižić, Advantages of installation of rubber-metal elements in suspension of railway vehicles, Proceedings of the Third International Conference on Road and Rail Infrastructure – "CETRA 2014", pp. 491-497, Split, Croatia, (2014), ISSN 1848-9842.

[3] Dragan Petrović, Milan Bižić, Repairing of broken laminated springs of freight wagons by welding, Proceedings of the XVI International Scientific-Expert Conference on Railways – "RAILCON 2014", pp. 145-148, Niš, Serbia, (2014), ISBN 978-86-6055-060-8.

[4] Dragan Petrović, Milan Bižić, Improvement of the suspension system of the wagons with laminated springs, FACTA UNIVERSITATIS, Series: Mechanical Engineering, Vol. 10, No 1, pp. 55-62, (2012), University of Nis, ISSN 0354–2025.