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APPLICATION OF RUBBER ELASTIC ELEMENTS IN SUSPENSION OF RAILWAY VEHICLES

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Key words: *Rubber, Suspension, Elasticity, Railway vehicles.*

Abstract: *The intensity of the dynamic load of railway vehicles, in addition to the quality of the track, depends on the elastic and damping characteristics of the suspension system. For existing track conditions can be stated that quality of dynamic behavior and safety of railway vehicles are primarily dependent on the characteristics of the suspension system. Suspension reduces the dynamic load, and thus reduces stresses in wheelsets, axle-bearings, bogies, car body, track, etc. Dynamic load of railway vehicles are reduced because suspension elements take over part of the kinetic energy, which leads to the safer and smoother running of the vehicle. In order to reduce the amplitude of oscillation of the vehicle in running and to avoid the risk of resonance, special devices for damping of oscillations are applied. Damping is usually solved through the appropriate friction surfaces, installation of the hydraulic, pneumatic or rubber absorbers, etc. This paper provides the necessary guidance for the application of reinforced rubber elastic elements in suspension of railway vehicles. The concrete solutions of rubber elastic elements, developed and realized in Railway Vehicles Center and Laboratory for testing of constructions at the Faculty of Mechanical and Civil Engineering in Kraljevo, are shown.*

1. INTRODUCTION

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. 1 and 2). The connection of the leaf springs with the underframe of the vehicle is realized over the suspension brackets and spring hangers.

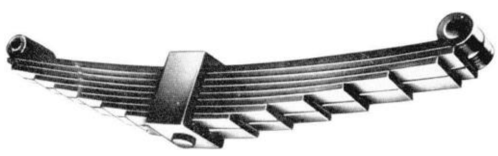

Fig. 1 Leaf spring

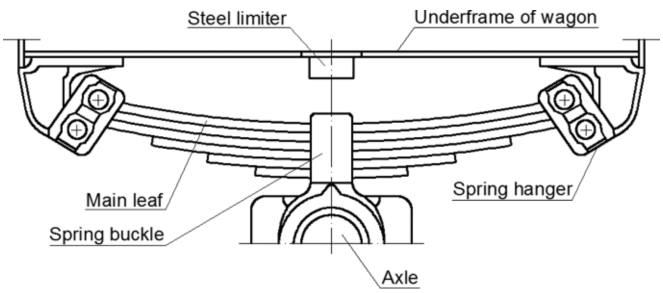

Fig. 2 Connection of leaf spring and underframe

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. On the other hand, in case of suspension with coil springs, the deflection of suspension is limited with the stroke limiter (Fig. 4).

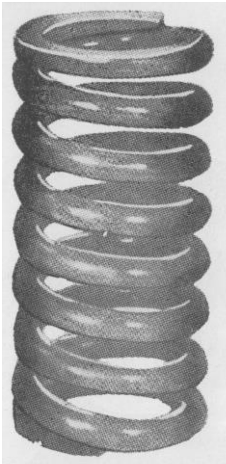

Fig. 3 Coil spring

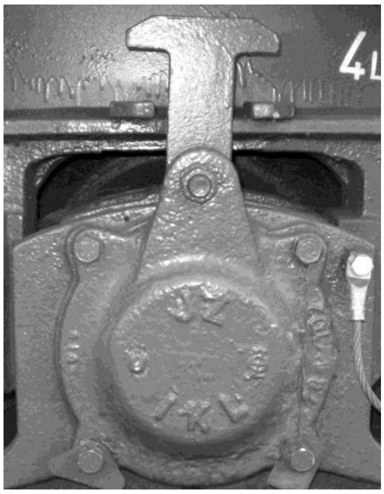

Fig. 4 Stroke limiter

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. 5.

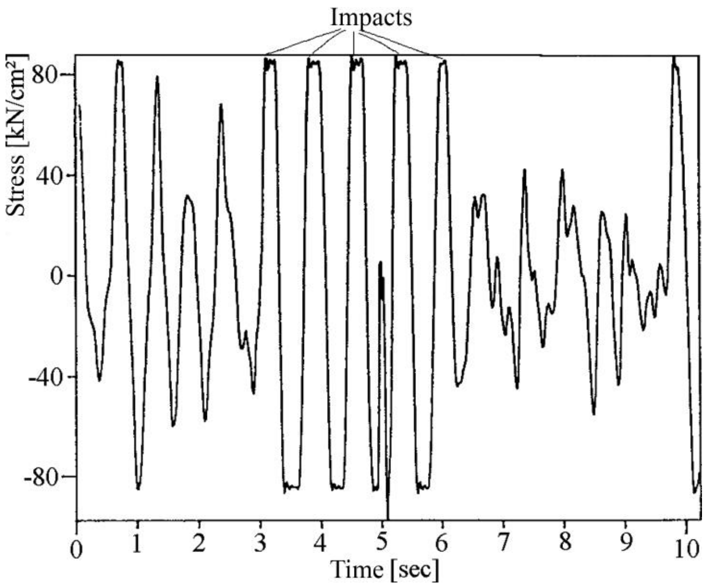

Fig. 5 Diagrams of change of stress on the elements of suspension during the time

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 $\theta_{max} = 20 \div 25^{o}$, 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:

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

Where:

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

$k_f = \frac{A_o}{A_b}$ - 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}:

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

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.

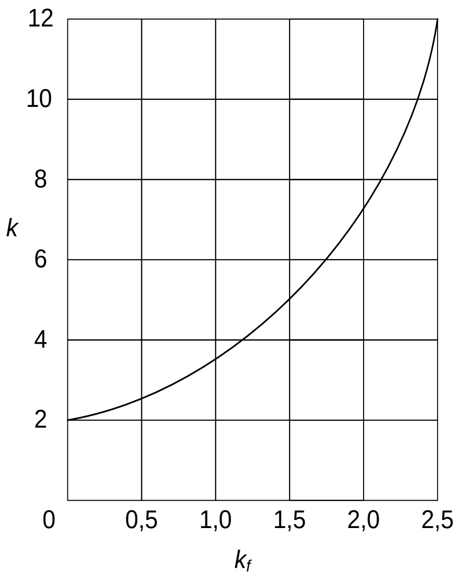

Fig. 6 The dependence of coefficient of shape k_f and coefficient of enlargement k

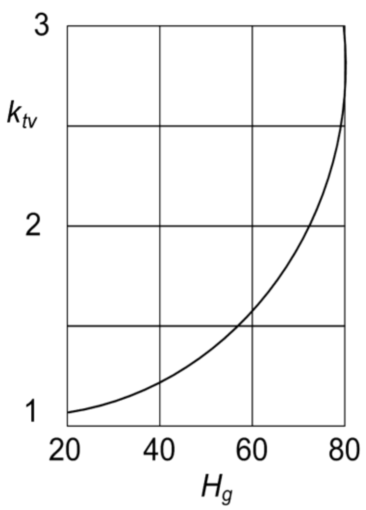

Fig. 7 The dependence of dynamic coefficient k_{tv} on the hardness of the rubber H_g

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:

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

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

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

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:

(5) $$G \approx \frac{E_{pr}}{3}$$

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*.

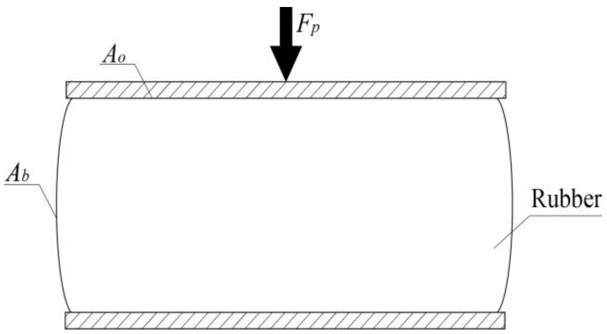

Fig. 8 The reinforced rubber elastic element

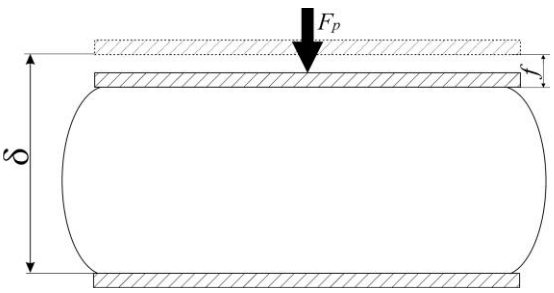

Fig. 9 The rubber elastic element loaded on the pressure

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:

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

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*:

(7) $$F_p = c_p \cdot f$$

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

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

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.

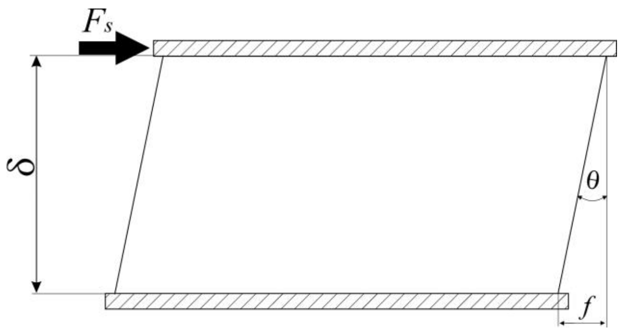

Fig. 10 The reinforced rubber elastic element loaded on the shear

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

(9) $F_s = A_o \cdot G \cdot \theta$

where:
θ – angle of shear

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

(10) $tg\theta \approx \theta = \dfrac{f}{\delta}$

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*:

(11) $F_s = c_s \cdot f$

Expression (5) gives:

(12) $G \approx \dfrac{E_{pr}}{3} = \dfrac{k \cdot E_{ist}}{3}$

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

(13) $c_s = \dfrac{k \cdot E_{ist} \cdot A_o}{3 \cdot \delta}$

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. PRACTICAL APLICATION OF RUBBER ELASTIC ELEMENTS

The suspension of railway vehicles has the aim to prevent rigid contact between the running gear and car body of the vehicle, as well as to absorb the high frequency oscillations, which significantly increase the safety and ride comfort. The designer of railway vehicles has a wide range of rubber and other (polymer) materials which can be used for damping of high frequency oscillations. It is necessary to take into account the strength, weight, production technology, price, temperature impacts, maintenance, durability of rubber elastic element and sub-assembly in which it is incorporated.

When combining rubber and other elastic elements, energy of oscillation is amortized on the account of non-linear resistances that result from the intermolecular friction in the rubber material. The concrete examples of application of reinforced rubber elastic elements in constructions of railway vehicles are given in the following pictures.

Fig. 11 Combined suspension with leaf spring and reinforced rubber elastic element

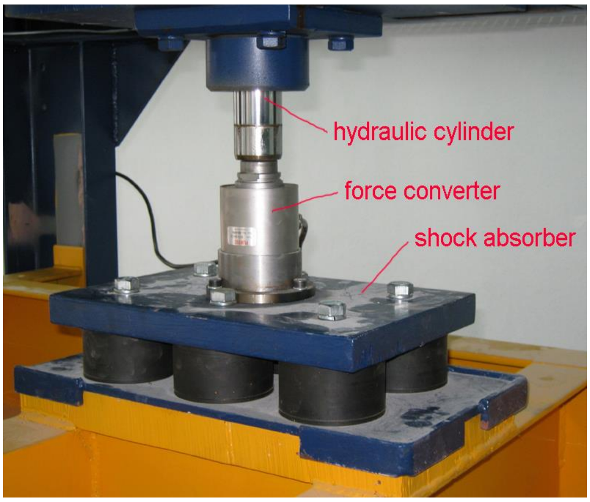

Fig. 12 The reinforced rubber elastic elements on the test stand for calibration of instrumented wheelsets

4. CONCLUSION

Leaf springs and coil springs are the most frequently used elements of suspension of railway vehicles. Their main task is to provide appropriate elasticity of the system. In addition to elasticity, a very important characteristic of the suspension is damping. 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.

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ПРИЛОЖЕНИЕ НА ГУМЕНИ ЕЛАСТИЧНИ ЕЛЕМЕНТИ В РЕСОРНОТО ОКАЧВАНЕ НА ЖЕЛЕЗОПЪТНИ ПРЕВОЗНИ СРЕДСТВА

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Ключови думи: *гума, ресорно окачване, еластичност, железопътни превозни средства.*

Резюме: *Интензивността на динамичното натоварване на железопътните превозни средства, в допълнение към качеството на релсовия път, зависи от еластичните и демпфериращите характеристики на ресорното окачването. За съществуващите пътни условия може да се каже, че качеството на динамичното поведение и безопасността на железопътните превозни средства зависи главно от характеристиките на системата за ресорно окачване. Ресорното окачването намалява динамичното натоварване и по този начин намалява напреженията в колоосите, буксовите лагерите, талигите, коша, релсовия път и т.н. Динамичното натоварване на железопътните возила се намалява, тъй като елементите на ресорното окачване поглъщат част от кинетичната енергия, което води до по-плавно движение на превозното средство. За да се намали амплитудата на трептене на превозното средство при движение и да се избегне рискът от резонанс, се прилагат специални устройства за поглъщане на трептенията. Демпферирането обикновено се реализира, чрез подходящи фрикционни повърхности, монтаж на хидравлични, пневматични или гумени демпфери и т.н. Тази статия представя необходимите насоки за прилагане на усилени гумени еластични елементи в ресорното окачване на железопътни превозни средства. Показани са конкретни решения на гумени еластични елементи, разработени и реализирани в Центъра за железопътни превозни средства и Лаборатория за изпитване на конструкции във Факултета по машинно и строително инженерство в гр. Кралево - Сърбия.*