On the Behaviour of Elastic Elements Belonging to the Elastic Tram Wheel at Particular Loading

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The paper proposes an analysis on the influence of the elastic rubber elements as component parts of the elastic tram wheels, as well of the railroad, on the stress state, on the wear and the loss in time of the mechanical properties under dynamic conditions. It is noticed the importance of the proping of the rubber elastic element (all degrees of freedom or vulcanized on a metallic support) going to a „brick" element shape proposal, which is absolutely „covered" for practical applications. This approximation leads to new correction coefficients, as well as to the validation of the simplified „brick" shape of specimens for a future experimental test standartization.

Keywords: elastic wheel, stress, mechanical testing, finite element analysis

Theoretical considerations

The rubber elastic element is used as a component of the elastic wheel of the urban transport vehicles, of the suspension system or as a part of the railroad infrastructure. As opposed to the railway vehicles, the light urban rail vehicles must present a silent rolling according to the noise pollution standards.

It is well kown that the mechanical properties of the rubber are influenced by the percentage ratio of the neopren (natural rubber) and its additives, but also by the curing regime, resulting a wide range of rubber with different hardnesses (between 40…80 Sh) [2].

A request of a maximum importance for the rubber used in the railway vehicles industry is represented by a strongly decreasing of the life-time resistance of these elements. This desideratum is feasible by using a increased neopren percentage ratio, higher than 60%, and eliminating the tensile loading by an initial compression when assembling [1].

The advantages of rubber utilization are, as follows [2]:

- a low value of the compression elastic modulus, which means an elastic energy storage four times higher than the stored energy in metallic springs at a same loading value;
- a three times diminution of the vibration mechanical energy, due to the internal friction process: the damping coefficient is approximately 10 % of the critical value;
- perfect molding properties;

Anyway, the drawbacks of rubber utilization are, as follows [2]:

- the elastic properties are strongly influenced by the temperature: at 513K (240°C) it looses the mechanical properties whereas at low temperatures its hardness increase (the artificial elastic elements did not present such a rigorous behaviour);
- a loss in time of the mechanical properties;

The requests to be imposed to the rubber elements - as parts of the light urban rail vehicles - are [2]:

- high mechanical strength, especially under dynamic loading;
- keeping a long period of time the same level of mechanical properties;
- a good resistance to chemical and atmosphere agents;
- a high deformation capacity in order to store a high quantity of potential elastic energy.

Between the Young's modulus (longitudinal elastic modulus) (E) and the transverse modulus (G), the well known relation is valid:

$$E = 2(1 + \mu) \cdot G \qquad (1)$$

However, the Poisson's ratio μ presents a $\mu = 0{,}5$ value (for steel, $\mu = 0{,}3$), so E = 3G, and the above mentioned elastic coefficients present an approximately linear dependece versus the hardness χ [Sh], (fig. 1).

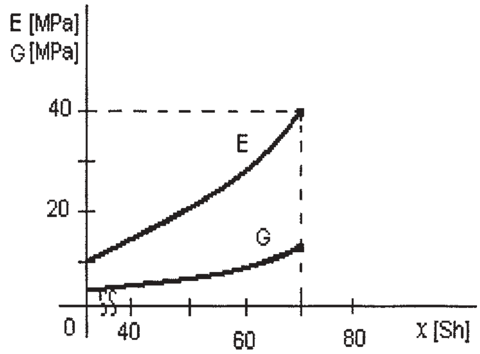

Fig. 1. The dependence betweem the elastic coefficients and the hardness

Function on the propping of the rubber element on the metallic element (vulcanization procedure), when a compression loading takes place, the value of the longitudinal calculus module $E_c > E$ will increase when the shape coefficient λ also increases, as follows:

$$\lambda = \frac{S_b}{S_l} \qquad (2)$$

where:

S_b – base surface of the element ;

S_l – free lateral surface of the element .

The ratio represents an essential element to understand the behaviour of different elastic or plastic elements used both for wheels and for rails.

The rubber elastic element presents a particular behavior under repetead traction-compression tests on an hydraulic fatigue machine, namely a particular histerezis area, which will result after the experimental tests [2].

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The elastic tram wheel structure. The influence of the elastic elements

The elastic tram wheels (figs. 2, 3) used for the light rail trams circulating in the city of Timisoara - Timis 2, present some particular component parts; consequently, the rubber elastic element plays an important role regarding the life-time, respectively the stress state and wear of the entire structure:

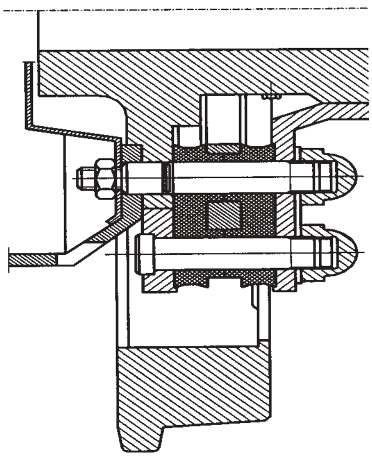

Fig. 2. Half cross - section through the elastic tram wheel

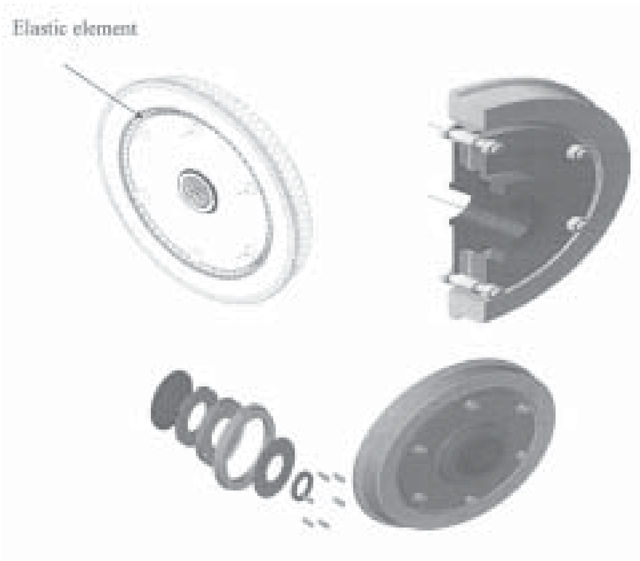

Fig. 3. Component parts of the elastic tram wheel

After the geometrical and loading conditions are imposed, the damping role of the rubber elastic elements will be emphasized (especially the influence about the state of stress).

The finite element analysis

The analysis has been performed by using the Ansys code [7].

Afterwards (fig. 4) the configuration of the geometry for the elastic tram wheel in contact with the counterpart rail is presented in figure 4.

Then (fig. 5) the three-dimensional meshing process both for the whole elastic wheel and the rail in contact is presented:

During the post-processing stage, the equivalent Von Mises stresses will be obtained (fig. 6).

Since the equivalent Von Mises stresses do not exceed 22 MPa in the rubber elastic element, the excellent damping properties of the elastic element are obviously proved.

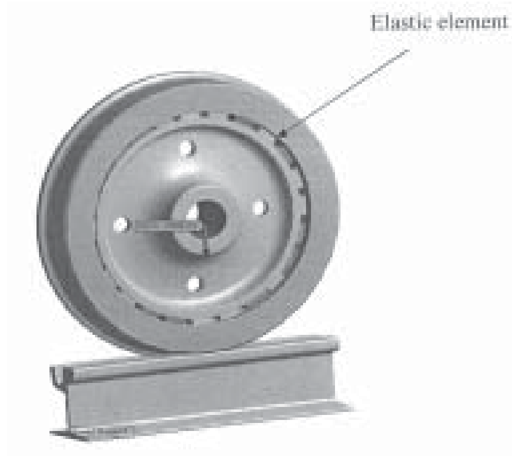

Fig. 4. Geometrical simulation of wheel and rail in contact

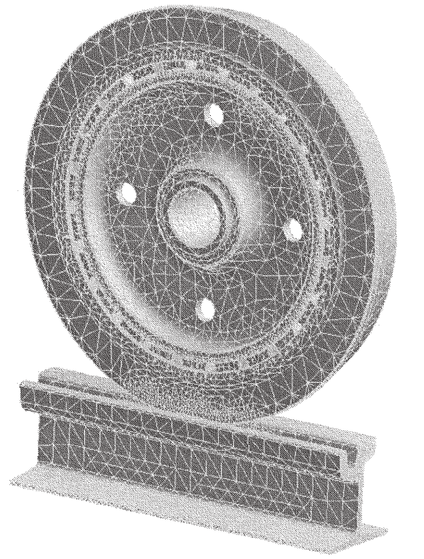

Fig. 5. The finite element meshing of wheel and rail

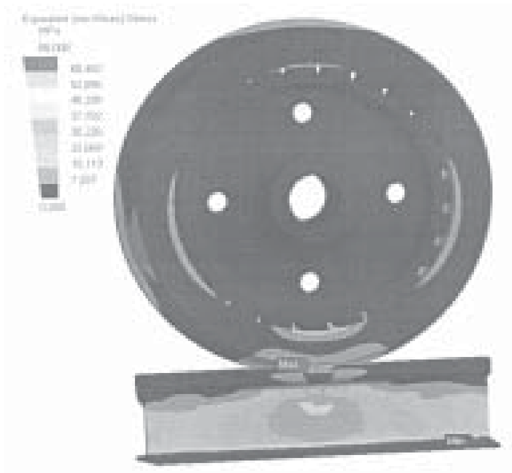

Fig. 6. The equivalent Von Mises stresses both in wheel and in rail

In case of similar size and loading level, but in the absence of the elastic element, the level of stresses may be approximately three times higher in the wheel body.

Experimental part

The tests have been performed on a traction-compression testing machine, respectively on a hydraulic fatigue machine which allows a simultaneous recording of the displacement on two-axis.

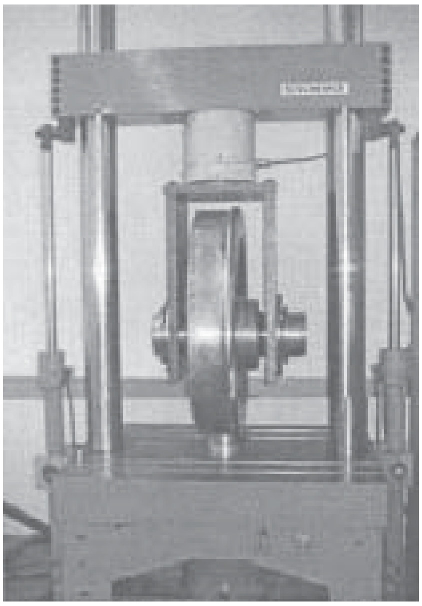

Fig. 7. Experimental test bench

The rubber elements allow high deformations, but it will not follow entirely the Hooke's law $\sigma = \varepsilon$. E. This is valid only for deformations lower than ε <10…12%, presenting a linear relative dependence.

The working temperature has an influence on the elastic properties, so the rubber presents a reverse dependence between the hardness χ and the temperature. The rubber became hard at low temperatures, but soft at high temperatures.

Internal frictions are present during the deformation process, so a part of the deformation work became heating energy. Its value is proportional with the area of the histerezis curve, experimentally obtained after the elastic element testing (fig. 8).The damping is proportional with the same area.

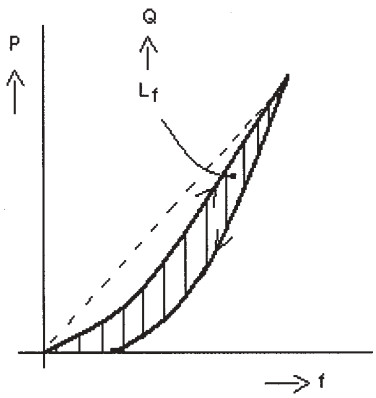

Fig.8. The loading - relaxation histerezis curve

The shape of the element influences the compression behaviour of the spring because the deformation may be hindered. For the same deformation, the stress increases proportionally to the increasing of the shape coefficient .

So, for two different shapes of the elastic elements such as those presented in figure 9, subjected on a loading process, the following shape coefficients will be obtained:

$$\lambda_1 = \frac{S_{b1}}{S_{l1}} = \frac{2 \cdot a^2}{6 \cdot a \cdot h} = \frac{a}{3h} \qquad (3)$$

$$\lambda_2 = \frac{S_{b2}}{S_{l2}} = \frac{a^2}{4 \cdot a \cdot h} = \frac{a}{4h} \qquad (4)$$

so $\lambda_1 > \lambda_2$ and $E_{c1} > E_{c2}$, but with $\sigma = E\,\varepsilon$ at ε= constant, it results also $\sigma_1 > \sigma_2$.

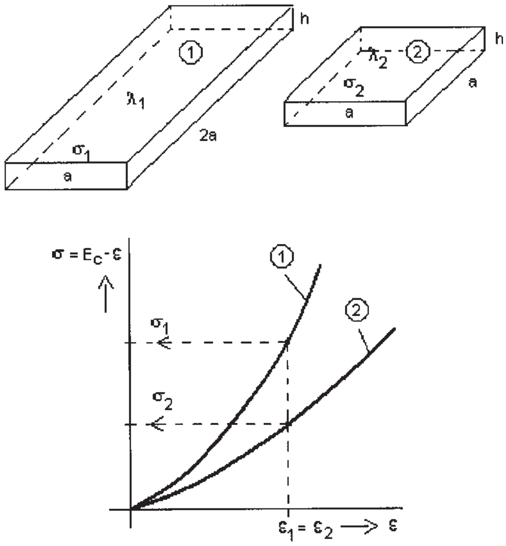

Fig. 9. Comparison between simplified "brick" elasto-plastic element shapes

When S_{b1} =2 S_{b2}, results P_1 > 2 P_2

For a rubber element which is vulcanized on a metallic support, the elastic behaviour will change according to the relationship between the „calculation" coefficients, [2]:

$$E_c = \lambda_c \,.\, G \qquad (5)$$

The relative dependence $\lambda_c = f(\lambda)$ is presented in figure 10:

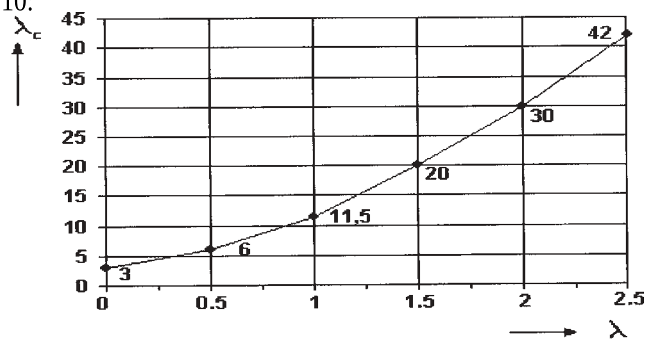

Fig. 10. The dependence between the theoretical and the calculation shape coefficients

So, for a compression loading, which is particular for the initially compressed rubber elements introduced when assembling, both parts of the elastic tram wheel and the railroad (fig. 11), function of the real cross-section area, the compression force will be:

$$P = \sigma \cdot S_f = \varepsilon \cdot E_c \cdot S_f \qquad (6)$$

According to figure 12, $S_f = S_b \cdot \frac{h}{h-f}$ (7)

it results: $P = \frac{f}{h} \cdot E_c \cdot S_b \cdot \frac{h}{h-f} = E_c \cdot S_b \cdot \frac{f}{h-f}$ (8)

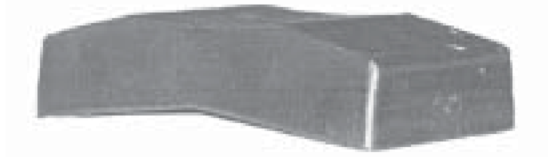

Fig. 11. Elastic rubber element in the railroad

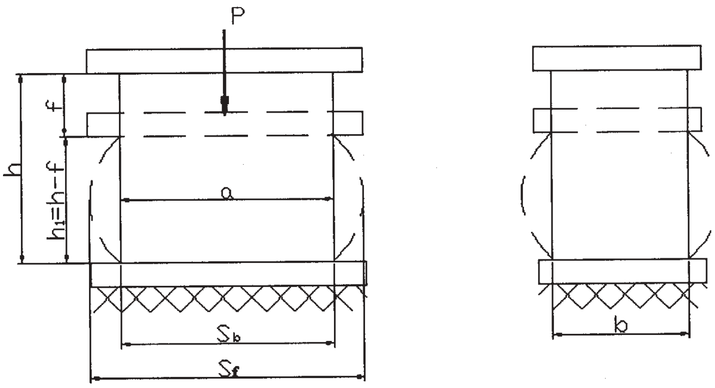

Fig. 12. Simplified shapes of elastic -plastic elements

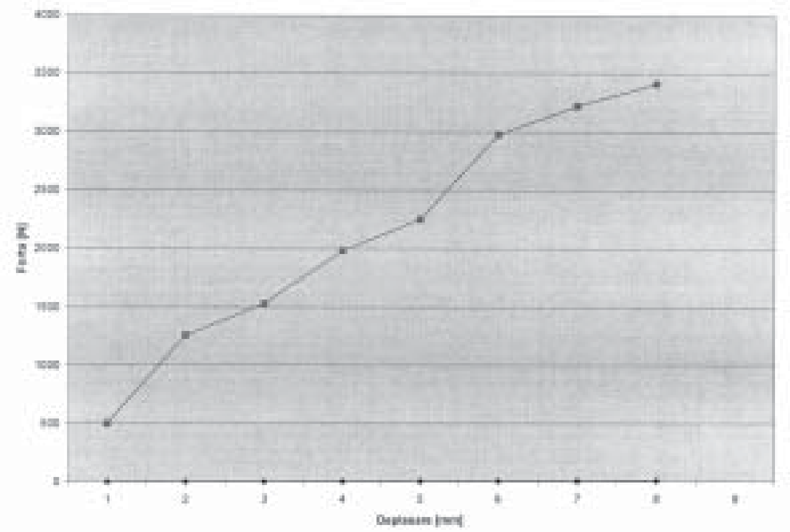

Fig. 13. The loading force - displacement dependence

If an 8-node "brick" shape of the elastic element is proposed, in order to simplify the calculation volume, it will result:

$$\left.\begin{aligned} S_b &= a \cdot b \\ S_l &= 2\cdot(a+b)\cdot h \end{aligned}\right\} \text{ and } \quad \lambda = \frac{a\cdot b}{2\cdot(a+b)\cdot h} \qquad (9)$$

when , according to figure 11, it will be obtained λ_c and $E_c = \lambda_c \cdot G$.

So, it results:

$$P = \lambda_c \cdot G \cdot a \cdot b \cdot \frac{f}{h-f} = \frac{\lambda_c}{3} \cdot E \cdot a \cdot b \cdot \frac{f}{h-f} \qquad (10)$$

a non-linear P(f) dependence , and the static stifness will be :

$$k_\sigma = \frac{dP}{df} = \lambda_c \cdot G \cdot a \cdot b \cdot \frac{h}{(h-f)^2} = \frac{\lambda_c}{3} \cdot E \cdot a \cdot b \cdot \frac{h}{(h-f)^2} \qquad (11)$$

Concluding, the static stiffness of the rubber element subjected under a compression test increases when the height of the element h decreases and when the shear modulus G, the hardness χ and the cross-section area S_b=a . b, respectively the elongation (deformation) f will increase too. All these theoretical results are experimentally validated, the methodology presenting a practical utility.

The flexibiliy of the rubber element will be:

$$X_\sigma = \frac{1}{k_\sigma} = \frac{(h-f)^2}{\lambda_c \cdot G \cdot a \cdot b \cdot h} = \frac{3h\left(1-\frac{f}{h}\right)^2}{\lambda_c \cdot E \cdot a \cdot b} \qquad (12)$$

As a result of the dynamical tests on the hydraulic fatigue machine, [6] at a loading frequency of 2 Hz, there have been recorded the following average main results, as those presented in figure 13.

According to figure 13, it may be observed a relative linear dependence between the loading force and deformation. The deviation from a strictly linear dependence is probably due to the recording data system of the testing machine, but also to the different elastic behaviour of the rubber elements in comparison with the metallic elastic elements.

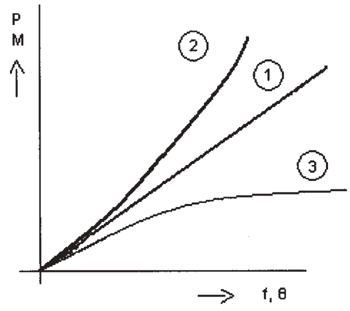

Fig. 14. Force-displacement respectively torque-rotation dependences

As the metallic springs present a 100 % linear dependence, the rubber elements present a theoretical non-linear one, progressive or regressive [2], as in figure 14 where:

- 1 - linear dependence-metallic springs;
- 2 - non-linear progressive dependence –pneumatic springs and the major part of the rubber springs;
- 3 - non-linear regressive dependence-some of rubber springs.

Conclusions

As it was mentioned above, the shape coefficient λ is influenced by the supporting or propping on system of the specimen. These may cause a lot of test difficulties because of the vulcanization process on the different areas.

In order to propose a standardization, a lot of tests will be performed to eliminate the influence of the geometrical shape about the elastic behaviour, respectively the relative dependence stress-strain. For the moment, the authors recommend an initial 8-nodes "brick" specimen for tests.

Since only the deformation recording on the force direction is not conclusive for the dynamic tests because of the friction forces between the support (or the catching system) and the elastic element, the authors consider that the adaptation of a testing system with possibilities to record simultaneously deformations under two perpendicular directions is essentially needed to appreciate the shape coefficient.

The "calculation" shape coefficient of the elastic element λ_c represents a most accurate appreciation regarding the flexibility in comparison with the simple shape coefficient λ.

In the near future, the authors intend to continue the same field researches in the railway field, on the braking sabots manufactured on composite materials: a rubber or synthetic resin (as main substance), metallic elements (cast iron, copper) and an abrasive material (silicone), which will follow the same testing procedure [3].

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