Deformation Analysis of Clouth-type Springs of Railway Vehicles Suspension

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An increasing number of railway vehicles are using rubber springs as suspension elastic elements. Rubber is a suitable material for suspension purposes due to of its intrinsic properties and due to of the variety of forms into which it can be made. The clouth-type rubber spring may be used in both primary and secondary suspension of the vehicle and it may ensure the desired characteristics by setting the shape of its metallic components. In the present paper, a finite element static analysis was performed regarding the deformation of the clouth spring rubber under the action of various loads: vertical, longitudinal and transversal. The simulations allowed determining the distribution of deformations within the rubber element, the magnitude and the location of the largest deformation.

Keywords: rubber, railway vehicle, suspension, clouth-type spring

The tendency of increasing the traveling speed and the transport capacity of railway vehicles involves, among others, the necessity to optimize the vehicles suspension system, in order to ensure traffic safety and ride quality. During its runtime, a railway vehicle is subject to vibrations in both vertical and horizontal plane, the sources of these vibrations being track irregularities, rail discontinuities (at the joints, switches and crossings), wheel defects, the rigid fastening of the wheels to the axle, etc. Under these circumstances, the behaviour of the vehicle depends essentially on the capacity of its suspension system to attenuate these vibrations. The suspension system components must therefore contribute to the reduction of mutual forces between vehicle and track, keeping them within the limits determined by traffic safety and ride quality requirements, ensuring also the protection of both wheelset and track.

A suspension stage consists of elastic elements (springs), shock absorbers (dampers) and connection elements. Depending on the constructive type, railway vehicles may have one, two or more suspension stages. The suspension system usually consists of two stages: primary suspension between the wheelsets and the bogie frame and secondary suspension between the bogie frame and the car body [1].

The elastic elements of the suspension may be metallic (made of steel), of rubber or pneumatic. Their role is to accumulate a part of the vibration energy and then to return it over time, thus contributing to the reduction of the dynamic loads acting on the sprung and unsprung masses of the vehicle [4].

The interest in using rubber elements in the vehicle suspension system is justified mainly by its high elasticity (it supports large deformations under the action of external forces and recovers its original shape when the action of these forces ceases [2-5]). Rubber elasticity is an intrinsic property, which does not depend on the shape of the part, in contradistinction to steel, which, in order to have an appreciable elasticity, must be manufactured with special shapes (coil springs, leaf springs) i.e. the elasticity is a property of the form [2-4].

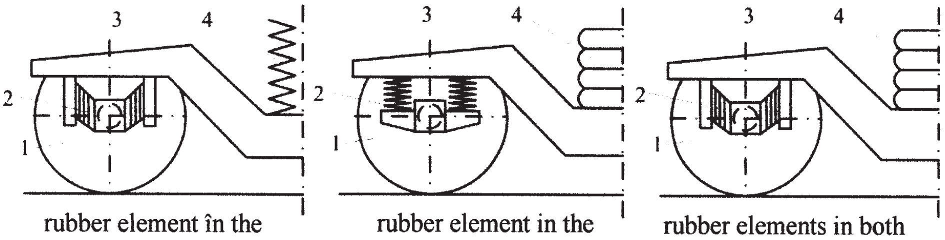
The rubber is an incompressible material: a volume of rubber subjected to a compressive stress in an enclosed space behaves as an undeformable material. Therefore, in order to provide elasticity the rubber part must have the possibility to modify its shape [2-4].

In figure 1 is shown schematically the arrangement of rubber elastic elements in the suspension stages of a railway vehicle.

Constructive and functional characteristics of clouth-type spring

The elasticity of this type of spring is provided by a rubber ring (torus shaped element) subjected to tensile-compressive and torsion stresses. These stresses are achieved by the motion of rubber torus 1, which is forced to roll between two conical surfaces (the central pin 2 and the metal housing 3) (fig.2).

The axial load P moves the housing towards the pin, causing the rubber to roll as shown by arrow A in figure 2. At manufacturing, the rubber ring has a circular section of diameter d, as indicated in figure 3 in dashed line, section



rubber element în the primary suspension

rubber element in the secondary suspension

rubber elements in both suspension stages

Fig. 1 Layout of rubber elements in vehicles suspensions stages
1- wheelset, 2 - primary suspension, 3 - bogie frame, 4- secondary suspension

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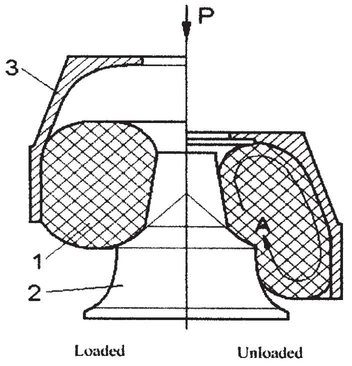


Fig. 2. Operating principle of clouth-type springs [2]

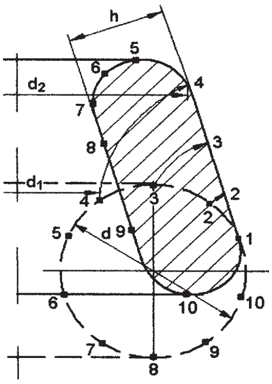


Fig. 3. Deformation of rubber element of clouth-type springs [2]

that deforms when it is mounted and, under load, takes the form shown in solid line.

The deformation of torus section between manufacturing and the situation where it is subjected to a load is defined by the coefficient

$$\psi = [(d-h) / d]\ 100\ [\%] \qquad (1)$$

which must not to exceed $45 \div 50\ \%$.

The operating characteristic of this type of spring is dependent on the shape of the two roll surfaces, on the deformation coefficient ψ and on the rubber hardness. This characteristic can be varied within wide limits, ensuring suitable adaptation to any required operating conditions. In figure 4 is shown the influence of the shape of the rolling surfaces on the spring operating characteristics, respectively on the axial stiffness characteristic. Housing cone angle α may vary between 10 - 30 deg. and the pin angle β is also in the range of 10 - 30 deg., various combinations being possible within these ranges of values. Obviously, the high values of the slope are leading to high stiffness springs [2].

Besides the stiffness in axial direction, the clouth-type springs have also a radial (transversal) elasticity, which is depending on the axial load. This feature makes the clouth springs able to perform also the function of wheelset guidance.

From the point of view of the spring structure, the metal parts (pin and housing) are made of steel, nodular cast iron and rarely, only for low loads, of aluminium. The rubber has to be of very good quality, due to the complex stresses to which it is subjected in service.

To ensure the roll without sliding of the rubber torus on the metallic surfaces of the pin and housing these surfaces are engraved with circular striations with rounded edges.

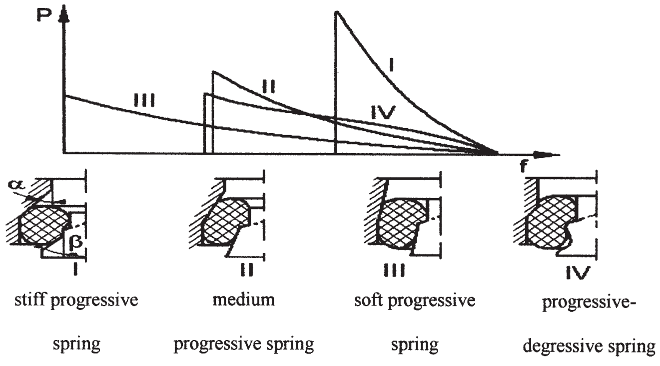


Fig. 4 Influence of the shape of the rolling surfaces on the clouth-type spring axial stiffness characteristic [2]

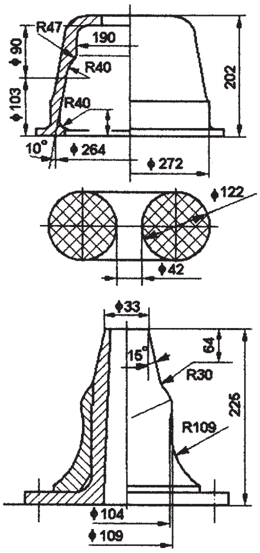


Fig. 5 Dimensional data of a Clouth-type spring components [2]

In figure 5 is shown the assembly of components, with the corresponding dimensional data, of a clouth-type spring able to support a maximum load of 50 kN. This type of spring is placed on a metro train car bolster.

At higher dynamic loads the spring acts as an elastic buffer, since the upper part of the housing rests directly on the rubber element.

Among the main advantages of this type of spring there are noteworthy:

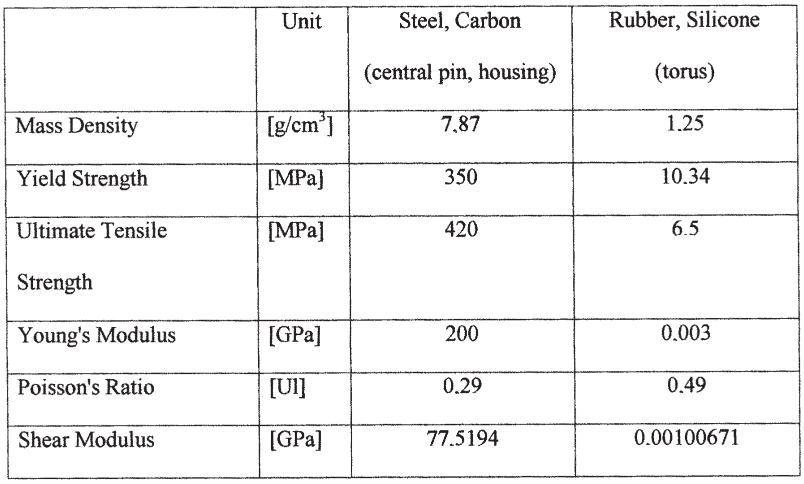
- the possibility to ensure the desired load-deflection characteristics (progressive, degressive or progressive-degressive) in vertical direction;
- the use of a rubber element which does not require vulcanized metallic armatures (steel plates);
- provides radial stiffness, which can be used in taking horizontal loads (longitudinal and transversal);
- does not require slideways or other links between the sprung elements;
- simplicity and light weight;
- low maintenance;
- high reliability.

Clouth-type spring modelling and operation simulation under load

In order to simulate the operation of a clouth-type spring it was achieved a geometrical model on a 1: 1 scale of the elements presented in figure 5. Using this geometrical model, a finite element static analysis was performed regarding the deformation level under the action of various loads. Within this analysis, for each considered case (each analysed loading situation) the clouth-type spring components were discretized in 26887 triangular elements, which required 42096 nodes. The values for the vertical force acting on the spring considered in this analysis were: 20kN, 30kN, 40kN and 50kN.

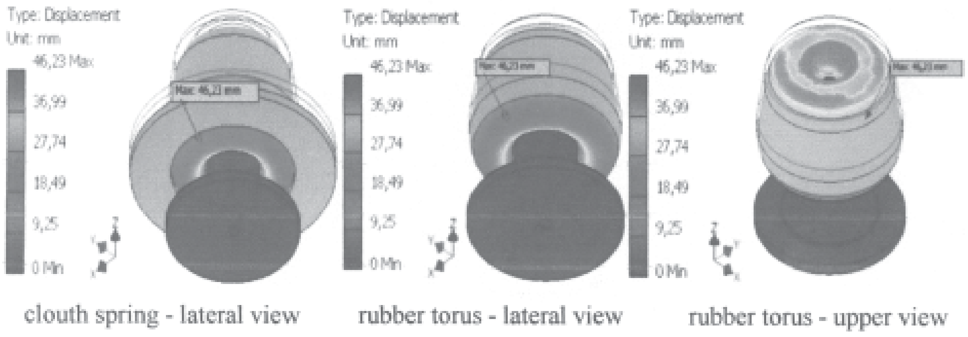
As regards the spring longitudinal and transversal loads, there were considered forces generated by aerodynamic phenomena, respectively by transversal shocks. Since the aerodynamic drag values are dependent on the vehicle speed, it was considered for the force generated by aerodynamic phenomena the unfavourable situation in which the vehicle travels at the maximum speed, in the presence of frontal wind gusts. Under these conditions, the aerodynamic force applied on the clouth-type spring does not exceed 500 N. For the transversal force it was considered a magnitude of 5 kN.

The characteristics of the materials of the clouth-type spring components used in the analysis are presented in table 1.



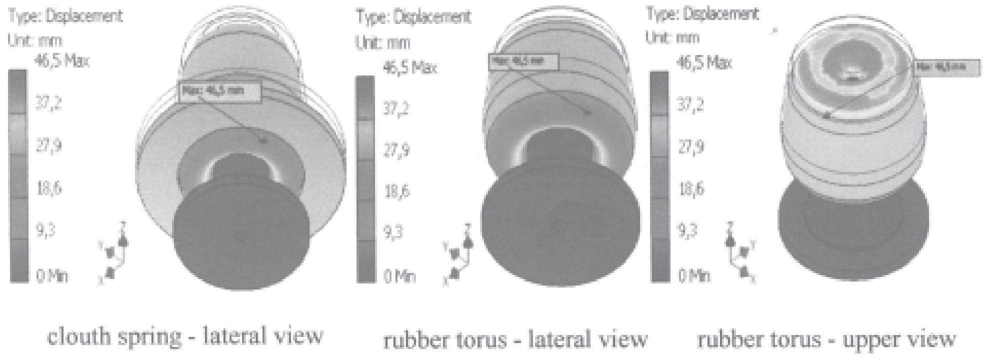
	Unit	Steel, Carbon (central pin, housing)	Rubber, Silicone (torus)
Mass Density	[g/cm^3]	7.87	1.25
Yield Strength	[MPa]	350	10.34
Ultimate Tensile Strength	[MPa]	420	6.5
Young's Modulus	[GPa]	200	0.003
Poisson's Ratio	[Ul]	0.29	0.49
Shear Modulus	[GPa]	77.5194	0.00100671

Table 1
MATERIALS CHARACTERISTICS



clouth spring - lateral view
rubber torus - lateral view
rubber torus - upper view

Fig. 6 Displacements in the case of the maximum vertical load



clouth spring - lateral view
rubber torus - lateral view
rubber torus - upper view

Fig. 7 Displacements in the case of the maximum vertical and longitudinal loads

In figures 6-8 are presented the deformations of the clouth-type spring (of the rubber elastic element) obtained as results of the simulations performed considering three cases, corresponding to three types of maximum loads: vertical load, vertical load cumulated with longitudinal load and vertical load cumulated with longitudinal-transversal load.

For each considered case, rubber deformation is shown using lateral and upper view, being specified also the precise value and exact location of the maximum displacement.

It can be seen in figure 6 that the largest displacements of the rubber element are in the lower part of the torus, in this area being then the most important material fatigue. It is also to be noted that the deformation is basically symmetric with respect to the vertical z-axis.

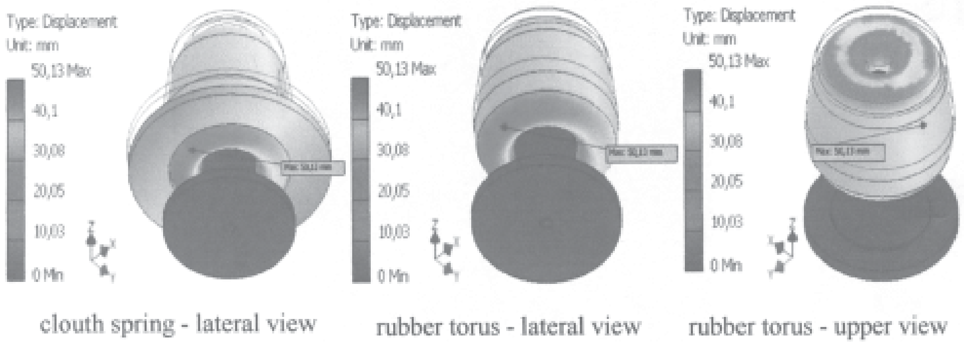
In figure 7 are shown the results of the simulation when longitudinal load is added to the vertical one. Since the magnitude of the longitudinal load is reduced compared with the vertical load one, there are not significant differences compared with the previous case: the largest displacements are in the lower part of the rubber element and the deformation is basically symmetric. However, a slight increase of the maximum deformation can be observed, as a result of the additional longitudinal load.

In figure 8 are presented the results of the simulation considering all three types of maximum loads – vertical, longitudinal and transversal acting simultaneously. It can be seen that the maximum displacement is located, once again, in the lower part of the rubber torus and its value is increased by approximately 8 %, as a result of the additional transversal load. Another effect of the transversal load is that, in contradistinction to previous analysed situations, this time the deformation is no longer symmetric with respect to the vertical z-axis.

In figure 9 is presented a graph of the applied load versus maximum displacements (deformations of rubber), considering the three loading cases and a range of values for the vertical force. It can be observed that a linear dependence is obtained for all the loading situations considered.

Conclusions

Rubber-metal springs are widely used in both primary and secondary suspension of rail vehicles, as being reliable elastic-damping elements. These springs are also compact, combining elastic and damping properties and do not require operational maintenance. Their role is very important since the ride quality and the traffic safety are highly influenced by the vehicle suspension. One of the



clouth spring - lateral view rubber torus - lateral view rubber torus - upper view

Fig. 8 Displacements in the case of the maximum vertical, longitudinal and transversal loads

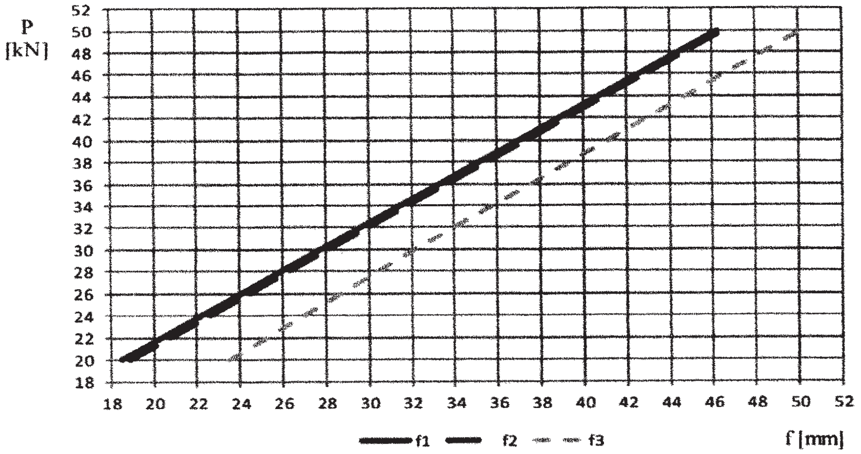


Fig. 9 Clouth-type maximum deformations for the analysed loading situations
f1 – vertical loads; f2 – vertical and longitudinal loads; f3 – vertical, longitudinal and transversal loads

most interesting rubber springs is the clouth-type spring, which may take both vertical and horizontal loads and also offers the possibility to ensure the desired characteristics by modifying the shape of its metallic components.

In the present paper a finite element static analysis was performed regarding the deformation level of the clouth spring rubber under the action of various loads. Simulations were performed considering three types of loads: vertical load, vertical load cumulated with longitudinal load and vertical load cumulated with longitudinal and transversal load. In all analysed cases, the simulation has shown that the largest displacement (deformation) of the rubber element was located in the lower part of the rubber torus. In the case of vertical load the deformation was also basically symmetric with respect to the vertical z-axis.

When horizontal loads (longitudinal and transversal) were added to the vertical one, the rubber maximum displacement was found again in the lower part of the torus, but its value was increased. Also, in this case, the deformation was no longer symmetric with respect to the vertical z-axis.

Performing simulations for an entire range of values for the vertical force it was found a linear dependence between the load and the maximum displacement (rubber deformation) for all the three loading situations considered.

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