Static and Dynamic Tests Performed on Rubber-Metal Elements Used in Primary Suspension of Railway Vehicles

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Rubber is widely used for rolling stock and railway infrastructure parts. Rubber plates are used for rail – sleeper fastening systems and rubber parts are used for primary suspension of the Romanian (and abroad) electrical locomotives, of metro (underground) trains, of tramways; at tramways wheels are made as metal – rubber assembly with the purpose to minimize the unsprung mass. From above examples, it easy to see that rubber parts are used in railway field as elements which are directly involved in safety of circulation.

Keywords: tests, locomotive, primary suspensions, rubber-metal

Rubber, as material with technical applications appeared in 1839 when Charles Goodyear discovered and materialized the vulcanization process which allowed to transform plastic rubber in elastic rubber, with better characteristics for different applications [5].

The interest for rubber is justified by its properties and started during time many research and tests studies which guide the engineers to establish recipes, mixtures and technologies for building rubber parts of different sizes and shapes, with specific characteristics for wide usage, among rolling stock (rubbers which stand to a wide range of temperatures, oil proves and with insulation properties from the point of view of electricity, rubber-metal elements etc.) [3].

The main characteristics of the rubber are its great elasticity, the capacity to endure large deformations under the action of external forces and to came back to the original form when the external forces action is removed. The rubber elasticity is an intrinsic property which is not dependent on part form as it is in the case of steel that, with the purpose to have a large elasticity must be specially build (spring, leaf springs etc.), so we can say that for steel, the elasticity it is also a characteristic of its form. The rubber as material it is not compressible, meaning that a volume of rubber in a closed space behaviour as a rigid and in purpose to use its elasticity, the rubber part must have the necessary space to drive out, altering his form during that process. We also must say that rubber allows before fracturing large elongations (1000% for the natural rubber).

Rubber elements used for railway vehicles suspension are made from vulcanized mould pieces, where plastic rubber mixture in contact with sulphur and peroxides get transformed in elastic rubber and takes the form of the mould. Because after vulcanization process the dimensions of the rubber part become smaller, the dimensions of the mould must be larger than the final dimensions of the rubber part. The dimensions of the mould are established based on contraction of each rubber mixture.

If we have assembly of combined rubber – metal, the metal plates are glued on rubber during vulcanization process, by using special adhesives that ensure a great resistance of the gluing [3].

Before putting in service, railway products are tested in purpose to certificate the quality to be used in railway systems. The tests are performed on infrastructure and rolling stock parts or on rolling stock vehicles. For the railway vehicles, steel, aluminum alloys, plastic, rubber, composite materials and woods are the basic materials.

The construction of the railway must ensure through its strength and stability the guiding safety and ride quality of the railway vehicles at necessary speeds and loads [4].

Today, the trend in railway business is to use vehicles with large possibilities of cargo at high speeds, so the problem of suspensions improvements has special attention for railway engineers [3].

For the motorized rolling stock vehicles, variation of the axle load due vibrations have a direct influence over the tractive force [5].

The construction of the motorized railway vehicles is different than of road vehicles. For road vehicles the body stands directly on wheels through suspension. For the railway vehicles with more than two axles, the chassis or the body of the vehicles stands on two or more bogies. The bogie is a device made from a rigid frame with two or many axles linked between them with elastic elements. In figure 1 is presented the six axles Romanian electrical locomotive. This locomotive was manufactured in Romania by Electroputere Craiova for more than half a century for Romanian Railways and for other abroad railways companies.

In figure 1 it is easy to see that vehicles body stands on two bogies, each bogie with three axles. For the railway vehicles with bogies the elements of the suspension (springs, dumpers etc.) that link axle and bogie frame are the primary suspension and the elements of the suspension between the bogie and the locomotive body are the secondary suspension. Locomotives and passenger vehicles always have primary and secondary suspension while freight wagons have only one stage of suspension even if the freight wagon has bogies or not. In Europe, most of the freight wagon use Y25 bogie. This bogie has only primary suspension. In U.S.A., Canada, Asia etc. the railway operators use Diamond bogie. This type of bogie has only secondary suspension.

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Fig. 1. Six axles Romanian electrical locomotive

Fig. 2. Primary suspension of the electrical locomotives manufactured in Romania

This paper present the tests performed at rubber-metal parts from the primary suspension of the 060-EA electrical locomotives manufactured in Romania.

Rubber – metal spring

Electrical locomotives manufactured in Romania under ASEA license have primary suspension with elastic elements made from rubber – metal springs (fig. 2).

Dumping of the vibrations from the primary suspension of the 060-EA electrical locomotive is made by hydraulic dumpers connected in parallel with the rubber spring. The same type of metal – rubber spring is presented in figures 3 and 4.

Rubber springs occur as a necessity of permanent increasing of requirements due to passenger comfort and noise dumping [1]. The V block springs are used in mounted pairs which allows that rubber block or rubber layers between metal plates to be under compression and shear forces as we can see in figure 6; figure 6 presents a section made on a rubber – metal spring. To ensure the compression state of the rubber on entire working domain, the height “H” of the spring from the figure 5 must be made so that H-L difference to be 1,5...2 larger than maximum flexure of the spring during service. The deformation direction is given by mounting assembly because the blocks have flexure “f” under the force “P” [3].

Fig. 3. Primary suspension of the metro trains manufactured in Romania

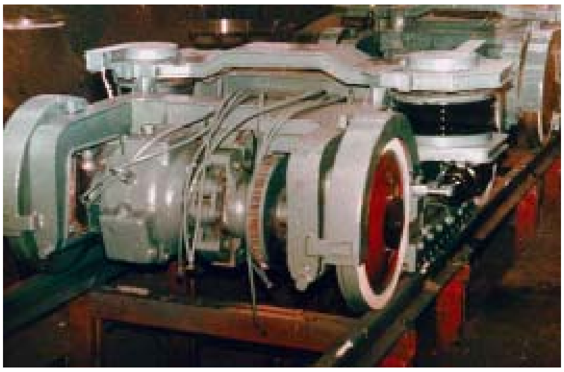

Fig. 4. The bogie of Bucharest tramways

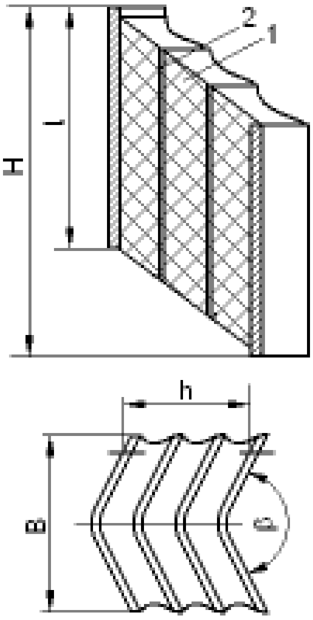

Fig. 5. Rubber – metal suspension block spring

For the rubber - steel spring with rubber layers between steel plates used in railway vehicles suspension, due the metal plates vulcanized in rubber block the compression stiffness grows very much without shear stiffness modification [1].

For the bogies with metal springs in primary suspension, when the bogie negotiates a curve, wear occur due the rigid link between axle box and the frame of the bogie. The wear is larger if the bogie have three axles; for these bogies, the flange of middle axle is thinner with the purpose to avoid derailment. If, in primary suspension we have rubber springs or rubber – metal springs, a small movement of the axle parallel with his symmetry axe is allowed so we can say that rubber – metal suspension have transversal elasticity which allows the bogie a better curve negotiation.

In figure 5 we have: 1 – rubber layer between metal plates 2 – metal plate. “B” is the wide of the spring and usually $\beta=120^{o}$.

The transversal stiffness c_y of rubber – metal spring is larger than longitudinal stiffness c_x and vertical stiffness c_z. The lateral elasticity is necessary for lateral shocks and longitudinal elasticity diminishes longitudinal shocks. The higher longitudinal stiffness is necessary to maintain the axles parallel. The stiffness of the spring depends on rubber quality and angle α [1].

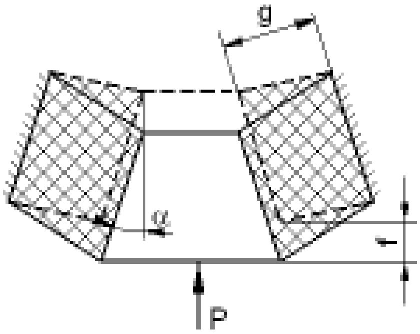

Fig. 6. Rubber spring under compression and shear efforts

The three axles bogie of 060-EA electrical locomotive usesd for primary suspension elements with three layers of rubber (for extreme axles) and five layers rubber for middle axle – figure 7.

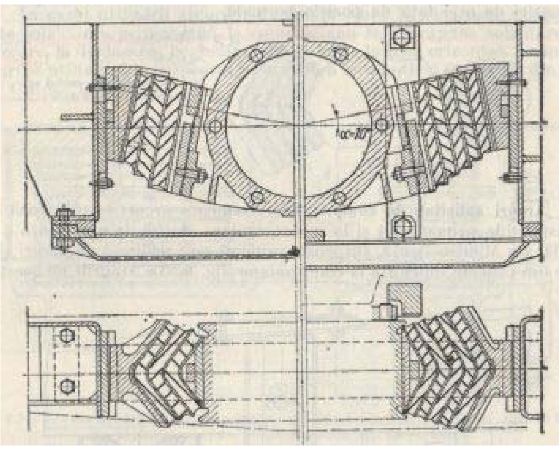

Fig. 7. Rubber – metal spring used at locomotives [1]

Fig. 8. Rubber – metal element [8]

In figure 8 is presented a photo of rubber – metal elastic element:

Universal testing machine WPM ZD 200/400

Universal testing machine WPM ZD 200/400 is a testing machine that allows to apply static and dynamic, tensile, compression and bending efforts on a prove. Since 2004, the machine was involved in a large refurbishment process with the purpose to replace the hydraulic and command installation to perform data acquisition and testing using a computer and appropriate software. On the same testing machine, it is possible to test rails, jointed rails (by welding for example), sleepers etc.

Tests

For rubber – metal springs used in primary suspension of the railway vehicles, product and material tests are necessary, according with standards.

Fig. 9. Universal testing machine WPM ZD 200/400

As probes it is necessary to use:

- rubber plates made from the same rubber mixture as the spring is;
- cylindrical probes;
- elastic elements made from metal plates and three layers of rubber;
- elastic elements made from metal plates and five layers of rubber;
- pairs of elastic elements with three and five layers (two pairs for each element).

For above materials it is necessary to perform:

On rubber:

- Shore A hardness test in initial stage;
- fracture strength tests in initial stage;
- fracture elongation test in initial stage;
- 100% elongation module tests in initial stage;
- 25% residual compression deformation tests after 22 h at 70°C;
- testing of mechanical and physical characteristics variation after accelerated aging for 72 h at 70°C (Shore A h- testing of mechanical and physical characteristics variation after immersion in ASTM 1 oil for 2 h at 23°C (Shore A hardness variation, fracture strength, fracture elongation variation, volume variation);
- determination of lower temperature strength for 2 h at -40°C;

On metal plates:

- mechanical characteristics tests (tensile strength, fracture elongation, proportionality limit);
- checking of base material from the point of view of temperature influenced area;
- on elastic elements with three and five rubber layers: behavior at dynamic tests.

The dynamic tests were performed with minimum force F_{min} = 100 kN, maximum force F_{max} = 150 kN and frequency of 5 Hz.

In figure 10 is presented a rubber – metal element where a defect occur during dynamic tests. The defect occur due to the bad rubber vulcanization on metal plates.

Fig. 10. Rubber defect

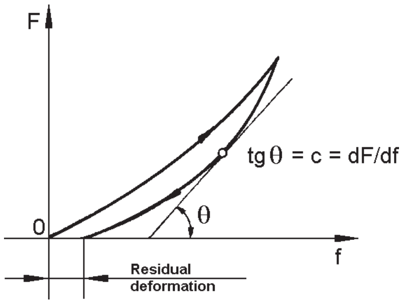

Fig. 11. Elasticity characteristics of a rubber spring

The curve $F(f)$ of a rubber spring (fig. 11), is straight until a specific deformation and then from a large deformation became curved because the stiffness is $c = \mathrm{d}F/\mathrm{d}f$. If we reduce or remove the force, the spring does not come to initial state due the residual deformation. On the other hand the rubber presents hysteresis phenomena due the internal friction during deformation; the surface bordered by loading curve and unloading curve it is equal with mechanical work of the friction forces [4].

Rubber deformation is a time consuming phenomena. A static load applied on a rubber element produce an instantaneous elastic deformation and then time deformation due creeping.

After the load is removed, the elastic element came to initial state in two stages: first is instantaneous and second takes time through creeping.

The elasticity characteristic of the spring depends on deformation speed due the late reaction of the rubber.

If we have a large speed deformation, rubber presents a larger stiffness.

But usually, a rubber suspension element it is loaded with a static force F_0 that produce the flexure f_0. For this situation the stiffness of the elastic element is $c = \mathrm{tg}\theta$.

In service, an alternative dynamic overload occurs applied with high speed that produce also a deformation of the rubber. The rubber element loaded alternant with $F_o - \Delta F$ and $F_o + \Delta F$, works after a cycle witch theoretically has an elliptical shape (fig. 12). For this case, the rubber elastic element will present a higher stiffness than static stiffness; the dynamic stiffness is $c_d = \mathrm{tg}\theta_d$ due rubber deformation speed.

The surface bordered by service cycle represent the lost due hysteresis phenomena at dynamic load [5].

The dumping factor due lost is given by formula:

$$d = 100 \cdot \frac{A_1 - A_2}{A_1} \quad [\%] \qquad (1)$$

where A_1 is the surface (*aibc*) and A_2 – is the surface (*adbc*), both of them are mechanical work necessary for deformation and mechanical work given by rubber elastic element.

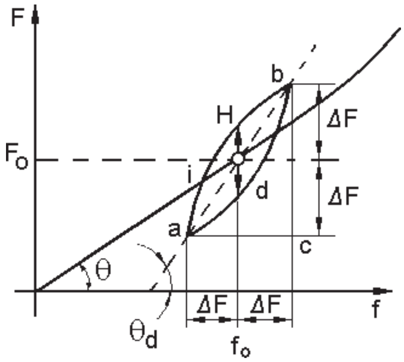

Fig. 12. Theoretical characteristic of a rubber spring loaded with alternant sinusoidal force

If the deformation speed is larger, the stiffness of the element is larger so lost due the hysteresis are large and the dumping factor is higher.

Conclusions

The tests performed on railway vehicles parts are very important because those parts are directly involved in safety of the railway system. The use of the parts, or of subsystems (infrastructure or rolling stock) is made only after accurate tests and only if the project is validated through tests. Other steps are approved of the documents by the final user of the products.

The tests used in certification process are type tests. The manufacturer must also perform manufacturing tests and lot tests.

After putting in service, the behaviour of the products is observed.

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