Considerations on the V-block type shape suspension springs at the rail vehicles

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Abstract. In the paper is presented some theoretical considerations underlying the use of these springs in the railway vehicle constructions. The use of these springs as elastic suspension systems is justified by a few advantages that they offer in service, such as: simplicity, weight and low gauge, do not require guides, work without wear and have a high reliability. The elasticity in the three-principal: vertical, horizontal-transverse and longitudinal directions recommends the use of these springs in the axle’s suspension of the vehicle. As an application it is presented the axle suspension dimensioning elements in the case of a carload subway vehicle.

1. General considerations regarding the construction of suspensions

The type of the vehicle and its travel regime influence the adoption of a specific suspension solution. On subway vehicles in general, the suspension of the axles is like rubber springs and the central suspension with pneumatic springs [1-4].

Figure 1 shows a bogie construction, widely spread in Europe, America and Japan, a construction adopted at the subway in Bucharest.

Figure 1. Engine bogie used in electrical subways in Bucharest.

The axle suspension comprises the V-block rubber springs 2 which resiliently take up the vertical, longitudinal and transverse stresses to which the bogie of the vehicle is subjected.
The central suspension is made with pneumatic cushions 3 between the bogie frame and the dancing traverse 4. The pneumatic cushions are controlled by level 5 valves and have auxiliary air reservoirs 6.

Transmission of the traction-braking effort is done by longitudinal braces 7 mounted between the dancing crosspiece and the bogie frame by means of rubber bushings. In cross-section, the low-impact booster forces are taken over by the pneumatic cushions itself. Larger booster efforts are also taken over by the rubber swabs 8, which, when fully compressed, serve as limiters of the body's transverse displacements to the bogie.

In terms of vibration damping, the suspension of the axles with rubber elements provides a sufficient degree of damping for medium speeds but reduced in some (additional) (additional) (hydraulic) 9 damping for high speeds. In the centre suspension, the cushioned pneumatic cushion achieves a convenient damping factor in the vertical direction but requires additional transverse damping 10.

2. Suspension with block-type rubber elements in V

The shape of these springs is shown in Figure 2 resulting in a rubber block 1. Vulcanized on V-shaped metallic reinforcements 2. At large thicknesses of the rubber block, the internal metal fittings 3 (MEGI type springs) are interposed in the mass [5-7]

![Figure 2. Suspension block rubber block type V.](image)

![Figure 3. The rigidities of the block suspension in block V in the three main directions (X, Y, Z).](image)

Making suspensions with two pairs of springs (figure 3) ensures beyond the vertical elasticity in the direction of the main load P and the transverse and longitudinal elasticities which are generally experimental. For the rolling stock field on rails, respectively for vertical loads on a pair of arches of the order $P_z = (35K \, 100) \times 10^3 \, N$ and settlement angles $\alpha=10^\circ...14^\circ$ we can consider the values of the elastic constants $k_x$ and $k_y$ according to the elastic constant $k_z$, the values:

$$k_x = (8K \, 11) \cdot k_z; \quad k_y = (2K \, 5) \cdot k_z$$

The other dimensions in Figure 3 are generally indicated by the construction firms. The de facto design of an arc must be confirmed by experimental determinations.

In general, this system is used as a suspension of axles, but they are also constructions that use the same system in the central suspension of the oscillating traverse.
Suspensions with block V rubber elements have an important damping effect as also shown in (Figure 4) in which vertical and transverse acceleration values measured at a metro wagon at speeds 45-65 km/h in a relatively good way.

![Diagram of block V suspension](image)

**Figure 4.** The damping effect on a block suspension in V-block, at an axle bearing.

The damping effect, appreciated by the ratio between the bogies of the bogie frame and the axle box, has appreciable 0,18-0,04 in the vertical direction (z) and 0,33-0,02 in the transverse direction (y). There is a more pronounced damping at high frequencies.

3. **Suspension with block-type rubber elements in V**

In designing the suspension, the elastic constants of the suspension stages must be adopted so that the high coupled frequency of the suspension and the frequency of the bogie movement of the bogie are outside the area of the vehicle's own bending frequency.

Figure 5 shows the frequency ranges obtained from SNCF measurements for vehicles with speeds of up to 200 km/h.

![Frequency zones for vertical vibrations](image)

**Figure 5.** Frequency zones for vertical vibrations.

On two-storey suspension vehicles, the two own frequencies of the vertical suspension (low and high) depend on the ratio of the two-story flexibility. The port adopts either close flexibility to the two suspension stages, with additional damping in the center suspension (but then increases gallop movement of the bogie) or greater flexibility of the suspension of the axles than that of the central suspension but with high damping in suspension axles.

Adopting a higher elasticity of the vertical suspension causes a reduction in the box rolling frequency, adversely affecting the transverse behavior; the vehicle must be equipped with an anti-roll bar (stabilizer device).
3.1. Determination of the elastic constants of the suspensions on the basis of realization of imposed own frequencies

Considering a mechanical model equivalent to two degrees of freedom of a vehicle on bogies and noting with \( f_1 \) and \( f_2 \) the static arrows of the springs in the central suspension or the axle suspension, the elastic constants of the model will be:

\[
k_1 = \frac{m_1 \cdot g}{f_1} \quad \text{and} \quad k_2 = \frac{(m_1 + m_2) \cdot g}{f_2}
\]

where \( m_1 \) is half the body mass of the vehicle and \( m_2 \) is the bogged mass of the bogie.

Depending on the system's own vertical frequencies \( f_{z1} \) (low) and \( f_{z2} \) (high) static arrows of the suspension will be:

\[
f_{1,2} = \frac{g}{8 \cdot \pi^2} \cdot \frac{v_{z1}^2 + v_{z2}^2 \pm \sqrt{(v_{z1}^2 + v_{z2}^2)^2 - 4 \cdot (1 + m_1/m_2) \cdot v_{z1}^2 \cdot v_{z2}^2}}{v_{z1}^2 \cdot v_{z2}^2}.
\]

By imposing the values of his own frequencies, the static arrows of the suspension springs and then the relationship 1 with the corresponding elastic constants are calculated.

Ignoring the term \( 1/v_{z2}^2 \) to \( 1/z_2^2 \) results in the approximate relationship of the total static arrow

\[
f = f_1 + f_2 = \frac{g}{4 \cdot \pi^2 \cdot v_{z1}^2} \approx \frac{1}{4 \cdot \pi^2} v_{z1}^2
\]

considering \( g \approx \pi^2 \).

Relationship 3 is often used in the literature.

Considering that good passenger comfort is obtained if your own low frequency is \( v_{z1} \approx 1 \)Hz a total arrow will result for the suspension \( f=0,25m=250mm \).

Based on experimental relationships, there are recommendations in the literature about the amount of static darts depending on the type of vehicle.

At the bogies of passenger transport vehicles it is recommended that the total static arrow \( f=250mm \) be distributed on each floor of the suspension corresponding to the optimal ratio:

\[
\eta_1, \eta_2 = 0,15 \, 0,25 \quad \text{or} \quad 0,75 \, 0,75
\]

where \( \eta_1 \) and \( \eta_2 \) are coefficients of distribution of total stiffness

\[
k_2 = k_1 \cdot \frac{k_2}{k_1 + k_2} \approx \frac{(m_1 + m_2) \cdot g}{f}.
\]

Namely

\[
\eta_1 = \frac{k_2}{k_1} \approx \frac{f_1}{f} \quad \text{and} \quad \eta_2 = \frac{k_2}{k_2} \approx \frac{f_2}{f}.
\]

Based on the research conducted on the quality of locomotive driving, it is recommended to adopt a total static arrow until 150...200mm, the axis of the axle suspension must be at least 60mm, and the central suspension not less than 50...60mm.

Considering that in the project phase of the suspension it is necessary to have its own oscillation frequencies can be adopted:

- the frequencies of the vertical, low and high coupled movements are 1 Hz and respectively 5..7Hz;
- the box's own frequency (as an element on two supports) 9-10Hz;
- the actual velocity of the winding motion of the box 0,8-0,9Hz;
- the frequencies of the oscillations associated with the roll-rolling are the lowest 0,5-0,6Hz and the high 1,2-1,3Hz.
Depending on the required elastic characteristics, the most elastic elements are chosen for a well-defined construction and use.

In the transverse direction, the elastic constant $k_y$ is determined by the self-imposed frequencies for the winding and rolling motion.

If the suspension is pendular, the length of the suspension is determined by $k_y$:

$$\lambda = \frac{m \cdot g}{4 \cdot k_y} = \frac{g}{2 \cdot \pi \cdot \nu_{y,2}^2} \approx \frac{T_{y,2}^2}{4},$$  

(6)

in which $T_{y,2}$ represents the period of shifting movement of the box and $m$ - the mass corresponding to a swing with four pendulums.

On bogie vehicles, it is very important to minimize the influence of the bogie winding movement on the roll rolling motion of the box. This is done if $T_{y} \approx 1,2 s$. This period was obtained with vertical inclined suspensions with an angle of about 6° which have the length $\lambda = 500 \text{ mm}$.

3.2. Establishment of elastic constants in subway vehicles.

The specific conditions of operation and operation of subway vehicles impose some constructive and sizing solutions for the specific suspension elastic elements of these vehicles.

Travel-induced disturbances that have relatively high frequencies recommend the extensive use of suspension elements for both the damping of the transmissions transmitted to the box and the rolling noise mitigation.

The actual vibration frequency of the suspended mass depends on the stiffness of the suspension elements that is variable within wide limits on this type of vehicle.

Subway vehicles intended for the transport of passengers are recommended that the suspension components be determined according to the frequency of 1Hz that is a total static arrow of 0,25, but for a mass of the vehicle loaded with 50% gives the maximum payload.

The rigidity of the suspension of the axle and of the central suspension depends on certain structural elements of the bogie assembly.

For axle suspension, in particular, the required braking performance (brake shoe positioning) or transmission (in the case of motor vehicles) limits the maximum axle suspension volume.

If we refer to transmissions regardless of the type of construction adopted (suspended semi-suspended), the vertical displacements of the axle to the bogie frame are limited by the admissible gaming in the transmissions.

On shaft axle drive systems (Secheon, Brown-Boveri, Thomson Hurth) this game is limited by the available space that can be constructed constructively between the hollow shaft gap and the transmission shaft or axle. On couplings with toothed sleeve the limitation is determined by the kinematics of the coupling.

Generally, in urban transport vehicles, the play is in the order of 50-60mm, limiting the value of the axle suspension static.

As the amplitude of the primary suspension vibrations generally does not exceed 12mm, a maximum 48mm axle suspension arrow results. This value should be considered as a first case between the fully loaded vehicle and the unladen bogie (no body) situation.

Restricting the operating range or maintaining the low 1Hz frequency for the entire load range requires the use of suspensions with progressive load stiffness. Such a feature can be obtained either by using multiple springs with different height components, either with Clouth or with pneumatic pads.

In designing the suspension with rubber elements, consideration should be given to the need to ensure axial alignment (to reduce wear on the wheel-rail contact surfaces) and to achieve a critical winding speed imposed by the vehicle’s running regime.
On subway vehicles it is necessary to ensure the axial radial orientation (negotiation of radius of curvature). This is because the underground subway has relatively small curves that cause relatively large wheel-rail friction forces and important wear for both the profile of the wheel and the rail. In order for the axle to occupy a radial position, a greater elasticity of the axle guidance system (of the block type arcs in V) is required. Also, the basic condition is that the wheel profile to be "of wear", a profile that provides longitudinal frictional forces oriented in the direction of the axle binding to occupy the radial position. As shown in [1], the radial axle orientation reduces the transverse friction forces and if the axle performs the "conical" run, the longitudinal friction forces are also reduced.

4. Conclusions
Block V-type springs are increasingly found in the axle suspension on railway vehicles. By their construction they have the ability to resiliently retrieve the path-induced disturbances in the rolling process of the vehicle in vertical, horizontal-transverse and longitudinal directions.

In addition, due to the rubber hysteresis phenomenon, these springs also have the ability to dampen the oscillation and to isolate noise from rolling noise.

In the paper is also presented the method of suspension design (valid also for suspensions with other types of springs) based on the necessity of realization of own frequencies imposed on the oscillating system of the vehicle.

For metro vehicles, the limits imposed by the traction force transmission mode and the need for a central (progressive) spring suspension (pneumatic springs) are required.

From the paper presented, it follows that V-block springs are recommended for axle suspension on subway vehicles because it has enough elasticity to isolate the vehicle from the disturbances from the tread path in the three directions.

The hysteresis phenomenon also provides vibration damping. The temperature variations occurring in the subway operation do not lead to significant changes in the dynamic performance of the suspension.

In addition, these springs have enough elasticity to ensure the axial radius of the axles in the curve.

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