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## CONSIDERATIONS ON THE SUSPENSION OF THE EDDY CURRENT RAIL BRAKES

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**Abstract:** *A main issue on using the eddy current linear rail brake is to maintain the imposed value of the air-gap during the braking action, as any variation of it concerns directly the security of traffic, due to substantial braking force modifications. On mechanical based analyses, this study considers the suspension of eddy current rail brake possibilities and the elastic and dumping characteristics in order to establish the constructive solutions to ensure an optimal functioning of the vehicle braking system.*

**Key words:** eddy current rail brake, safety of running, high-speed vehicles, suspension.

### INTRODUCTION

The correct functioning of the railway vehicles' brake system is a very important requirement for ensuring the safety of running. For high-speed vehicles, an additional braking system used for its advantages is the eddy current rail brake. Among these, it is very important to maintain a constant distance between the rail brake and the rolling surface of the rail during the braking action and to avoid accidental impacts between the rail brake and the rail. In this context, when adopting the rail brake's suspension system it is necessary to consider that it has to meet several requirements. Accordingly, the main requirements, which the suspension system of the eddy current rail brakes is supposed to solve, are the following: to assure, while braking, a constant distance within the brake shoe and the rail, in order to avoid significant braking fluctuations, to prevent a possible rude contact between the brake shoes and the rail and, respectively, their perfect accordance.

The fluctuation of the brake shoe – rail air gap should not overpass 1 – 1.5 mm while braking, in

order to avoid instantaneous braking force variations surpassing 10 to 15% [1].

Mechanically, the air gap fluctuation is equal with the relative displacement between the eddy current brake shoe and the rail, the main vibration source on vertical direction consisting in vertical irregularities of the rail.

Within this study, for reasons of simplicity, we considered these irregularities to be harmonically.

We choose to analyze a vehicle equipped with two levels suspension bogies, as common for passenger coaches.

To make the calculus simpler and clearer, from the mechanically point of view, we considered the vehicle as an oscillating system presuming two liberty degrees, since this approach would be particularly relevant for the vertical displacements of sprung masses, meaning respectively the superstructure of the coach (the box) and bogies.

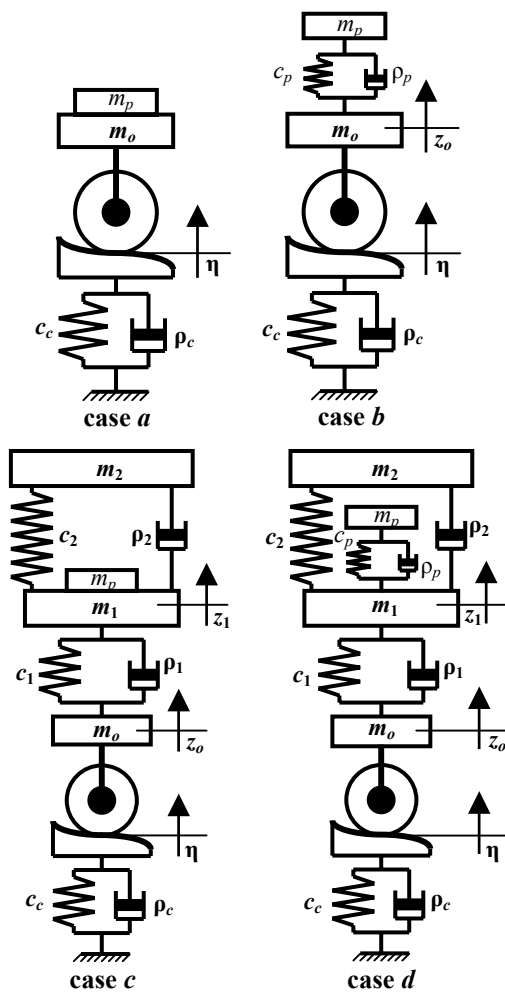
The suspension supports the mechanical tasks coming from unsprung masses, mainly the rolling system consisting in the mounted axles and the axle-boxes. In our study, we also took into

account the elastic and attenuation constants of the railway.

## MECHANICAL PATTERN-MAKING

Due to the big difference in values between the oscillation natural frequencies of the unsprung masses and of the suspension, these two elements were considered as mechanically independent [2,3].

Generally, the eddy current rail brake shoes are fixed within a metallic frame, which might be fixed elastically or rigidly on the mounted axles or on the bogie frame. We present the correspondent mechanical designs in fig. 1.



**Fig. 1. Mechanical patterns for studying the eddy current rail brake suspension:**

- a – rigid fixing on the mounted axles;
- b – elastic suspended on the mounted axles;
- c – rigid fixing on the bogie frame;
- d – elastic suspended on the bogie frame.

Considering the constructive, the geometrical and the charging symmetry of the vehicle, while

neglecting the possible differences in vertical load on the mounted axles and wheels, we used the following notations:  $m_2 = m_c/4$ , where  $m_c$  means the mass of the vehicle's box;  $m_1 = m_{sb}/2$ ,  $m_{sb}$  is the sprung mass of a bogie;  $m_o$  – the unsprung mass corresponding to an equipped mounted axle;  $m_p$  – the mass of an eddy current rail brake shoe;  $c_1, c_2, c_p$  and  $c_c$  – the correspondent equivalent rigidity of the axles and of the central suspension, of the rail brake shoes and of the railway;  $\rho_1, \rho_2, \rho_p$  and  $\rho_c$  – the dumping equivalent coefficients of the axles and of the central suspension, of the rail brake shoes and of the railway.

Considering the situation of straight rigid fixed shoes' metallic frame support on the mounted axles and taking into account the before mentioned hypotheses, according to the mechanical pattern presented in fig. 1-a, the relative displacement  $u_o$  between the eddy brake shoes and the rail might be determined with the relation [2,3]:

$$u_o = \eta \cdot \frac{\lambda^2}{\sqrt{(1 - \lambda^2)^2 + 4 \cdot D_c^2 \cdot \lambda^2}}, \quad (1)$$

where  $\eta$  is the amplitude of the railway's vertical imperfections,  $\lambda = \omega/\omega_o$  the pulsation disaccord,  $\omega_o = \sqrt{c_c/(m_o + m_p)}$  the system's natural pulsation,  $\omega = 2 \cdot \pi \cdot \frac{V}{3,6 \cdot L}$  the excitation's pulsation,  $L$  is the wave length of the rail vertical irregularities, while  $D_c$  represents the dumping ratio of rail.

As for the case of elastic suspended eddy brake shoes on the mounted axles, according to fig. 1-b, also presuming the above mentioned hypotheses and considering separated the two oscillation systems, the  $u$  relative brake shoes – rail displacement could be figured by adding the relative displacements between the unsprung mass and rail  $u_o$ , respectively between the shoe and the unsprung mass  $u_p$ :

$$u = u_o + u_p \quad (2)$$

Each of these could be calculated using relation (1), considering the natural pulsations  $\omega_o = \sqrt{c_c/m_o}$ , respectively  $\omega_{op} = \sqrt{c_p/m_p}$  and taking into account the dumping ratio  $D_c$  and  $D_p$ ,

for both the railway and braking shoes suspension.

For the eddy current braking shoes, the  $z_o$  excitation amplitude consists in the oscillating amplitude of the unsprung mass and can be determined with the relation [2,3]:

$$z_o = \eta \cdot \sqrt{\frac{1 + 4 \cdot D_c^2 \cdot \lambda^2}{(1 - \lambda^2)^2 + 4 \cdot D_c^2 \cdot \lambda^2}} \quad (3)$$

On rigid brake shoes fixing within the bogie frame, as mentioned before and mechanically figured in fig. 1-c, also considering the unsprung mass and the mechanical oscillating independence, the  $u$  relative displacement between brake shoes and rail could be determined by adding the  $u_o$  relative displacement between the unsprung mass and the rail, calculated as above mentioned, to the one between the bogie frame and the unsprung mass, i.e.  $u_1$ :

$$u = u_o + u_1 \quad (4)$$

Considering the two freedom degrees of the vehicle's suspension, the latter could be determined with the relation [2,3]:

$$u_1 = z_o \cdot \frac{1}{N} \cdot \sqrt{A^2 + B^2} \quad (5)$$

where  $z_o$  means the unsprung mass oscillation amplitude, to be calculated based on (3) relation,  $A = \gamma \cdot \lambda^2(1 + \mu) - \mu \cdot \lambda^4$ ,  $B = \lambda^3(1 + \mu) \cdot \delta_2$ ,  $N = \sqrt{a^2 + b^2}$ ,  $a = (\Gamma - \lambda^2 \cdot \delta_1 \cdot \delta_2)$ ,  $\delta_1$  and  $\delta_2$  the dumping ratio of the axles, respectively the central suspensions,  $\gamma = c_2/c_1$ ,  $\lambda = \omega/\omega_o$ ,  $b = [\Lambda \cdot \lambda \cdot \delta_2 + (\gamma - \lambda^2) \cdot \lambda \cdot \delta_1]$ ,  $\omega_o = \sqrt{c_1/m_2}$ ,  $\mu = (m_1 + m_p)/m_2$ ,  $\Lambda = 1 - \mu \cdot \lambda^2 - \lambda^2$ ,  $\Gamma = (1 - \mu \cdot \lambda^2) \cdot (\gamma - \lambda^2) - \gamma \cdot \lambda^2$ .

In the case of eddy brake shoes springing suspended within the bogie frame, as presumed, according to fig. 1-d, the  $u$  relative displacement between brake shoes and rail might be determined by adding the  $u_o$  relative displacement between the unsprung mass and the rail, that between the unsprung mass and the bogie frame  $u_1$ , respectively that between the latter and the eddy current brake shoes  $u_p$ .

$$u = u_o + u_1 + u_p \quad (6)$$

The relative displacement between the unsprung mass and rail  $u_o$  could be figured with the relation (1), taking into account that the natural pulsation is  $\omega_o = \sqrt{c_c/m_o}$  and considering the  $D_c$  rail dumping ratio.

The relative displacement between the unsuspended mass and bogie frame  $u_1$  could be determined under relation (5), considering the oscillate system of vehicle's two liberty degrees suspension and taking into account that  $\mu = (m_1 + m_p)/m_2$ .

The relative displacement  $u_p$  between the eddy current brake shoes and the bogie frame could be calculated:

$$u_o = z_1 \cdot \frac{\lambda^2}{\sqrt{(1 - \lambda^2)^2 + 4 \cdot D_p^2 \cdot \lambda^2}} \quad (7)$$

accounting that the system's natural pulsation is  $\omega_o = \sqrt{c_p/m_p}$ ,  $D_p$  is the eddy current brake shoes suspension's dumping ratio, while  $z_1$  means the vertical oscillation amplitude of the bogie frame which might be calculated, according to [2, 3]:

$$z_1 = z_o \cdot \frac{1}{N} \cdot \sqrt{[(\gamma - \lambda^2)^2 + \lambda^2 \cdot \delta_2^2] \cdot (1 + \lambda^2 \cdot \delta_1^2)} \quad (8)$$

accounting that  $\mu = m_1/m_2$ , and  $z_o$  is the vertical oscillation amplitude of the unsuspended mass which could be calculated using relation (3) in which one take into account that  $\omega_o = \sqrt{c_c/m_o}$ .

## CASE RESEARCH

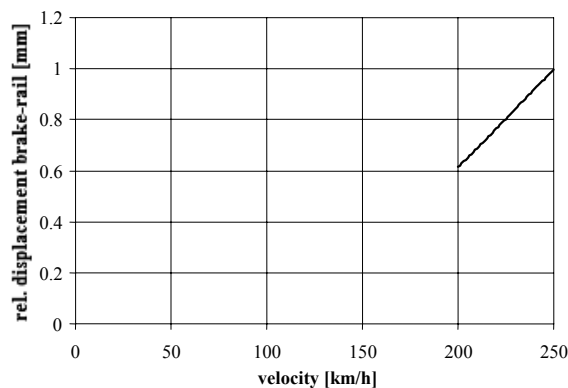
The research was performed on a particular case of four axle passenger coach, having a mass of the vehicle's box  $m_c = 30$  tons, a sprung mass of one bogie  $m_{sb} = 2000$  kg, an unsprung mass corresponding to an equipped mounted axle  $m_o = 1500$  kg and a mass of an eddy current rail brake shoe  $m_p = 250$  kg.

The main characteristics of the considered vehicle's suspension are the equivalent rigidity and dumping ratio of the axles' suspension  $c_1 = 2.1 \cdot 10^6$  N/m and respectively  $\delta_1 = 0.3$ ; the equivalent rigidity and dumping ratio of the

central suspension  $c_1 = 2.1 \cdot 10^6$  N/m and respectively  $\delta_2 = 0.1$  [2].

Concerning the railway characteristics, we considered its rigidity  $c_p = 65 \cdot 10^6$  N/m and the correspondent dumping ratio  $D_c = 0.4$  [3]. As specified, we considered the vertical irregularities of the railway as harmonically. Their amplitude and the wavelength used for calculus were respectively  $\eta = 1$  mm and  $L = 3$  m. As for the elasticity of the eddy current brake shoe suspension, we considered an equivalent rigidity  $c_p$  of  $10^4 \dots 10^7$  N/m and the correspondent dumping ratio  $D_p$  of  $0.1 \dots 0.4$ .

Calculation revealed that in case of rigid fixing of the eddy current brake shoes on the mounted axles (see fig. 1-a) the relative displacements between the brake shoes and rail increases while the velocity also increases (see fig. 2). In the analyzed case, it is not exceeding 1 mm, which is much more than acceptable, in terms of instant braking force slipping.

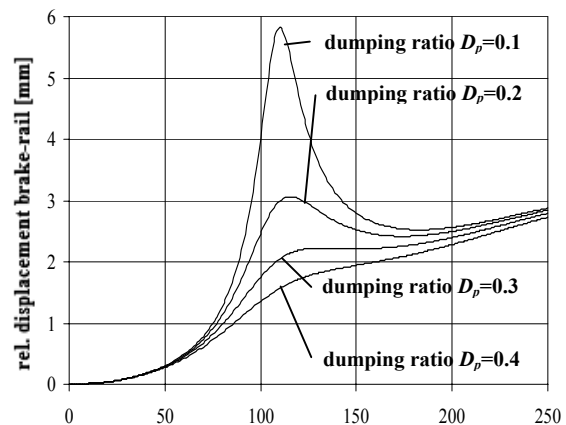


**Fig. 2. Vertical relative displacements in case of rigid fixing of the eddy current brake shoes on the mounted axles.**

On conditions (see fig. 1-b), the theoretical obtained results show that for rigidities of the brake shoes suspension of  $10^4 \dots 10^6$  N/m, under the mentioned initial hypothesis, the vertical air gap attains 5 – 6 mm at 10 to 120 km/h. Closing to 250 km/h, the relative displacement decreases to 2.5 – 2.9 mm. Generally, inconvenient troubles might occur while the vehicle's velocity is greater than 50...70 km/h, when the eddy current brake is active and efficient. It has been also noticed that for the high-speed running domain, the dumping ratio did not influence significantly the vertical oscillations' amplitude of the eddy current brake shoes. Instead, within the low speed running (10...110 km/h) might appear accidental

brake shoes contact with the rail when the vertical oscillations' amplitude become higher than the recommended height of brake shoes, usually 7...10 mm (see fig. 3). Avoiding this situation requires a stronger absorption capacity of the brakes vertical suspension, which lowers the oscillation amplitude.

For brake shoes' suspension rigidities stronger than  $c_p = 10^7$  N/m it seems that air gap between the brake shoes and rail increases, reaching maximum values at the highest velocity we considered, 250 km/h. It becomes very important the influence of the shock absorbers. The maximum oscillation amplitude decreases by about 25 % while the dumping ratio  $D_p$  increases from 0.1 to 0.4.



**Fig. 3. Vertical relative displacements in case of elastic suspended on the mounted axles ( $c_p = 10^6$  N/m equivalent rigidity).**

The most desirable purposed solutions in case of elastic suspended eddy brake shoes dictates a high dumping ratio ( $D_p = 0.4$ ) and also a greater elasticity ( $c_p = 10^7$  N/m). To notice that a lower rigidity of brake shoes suspension (e.g.  $10^4$  N/m) leads to a relative vertical displacements increasing up to 33%. In case of a relative stronger rigidity about  $10^5$  to  $10^6$  N/m, the same amplitude would increase up to 25%.

When eddy current brake shoes fixed into the bogie frame (see fig. 1-c), the maximum relative vertical displacement occurs around 17 km/h, growing up significantly under 50 – 250 km/h. Notably, at both low and high speed, the vertical relative displacements are no bigger than 2.5 – 3 cm.

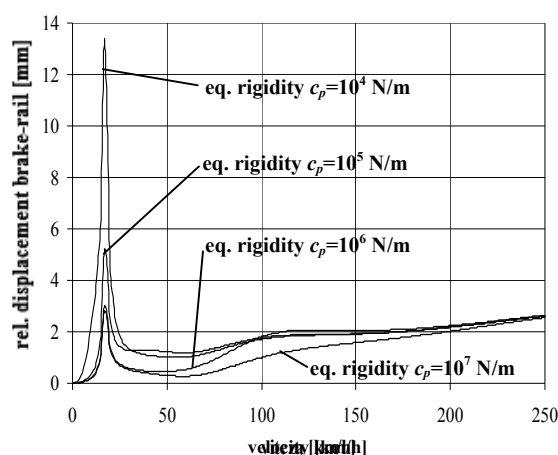
When eddy current brake shoes are elastically suspended on the bogie frame (see fig. 1-d), the theoretical results reveal that, for a  $10^4 \dots 10^6$

N/m rigidity, a maximum vertical relative displacement of about 16.5...5.5 mm occurs between 10-110 km/h. For running speeds exceeding these velocities and up to 250 km/h, under the above-mentioned initial conditions, the air gap is not more than 2.6 mm.

While taking into account the braking forces variations, the maximums vertical displacements attained for running speeds less than 50...60 km/h are irrelevant since on this velocity domain, the eddy current rail brake is not active. The only troubles might occur should the rail quality would determine vertical displacements higher than 7 to 10 mm, possibly causing rail to brake shoe harsh contact. That is the reason why an enhanced absorption of shocks is required, in order to decrease significantly the amplitude oscillations. Noticeably, over speeding and surpassing the two maximum amplitude domains, the dumping ratio has little influence concerning the vertical relative amplitude of oscillations between the eddy brake shoe and rail.

For enhanced rigidities of brake shoe suspension ( $c_p=10^7$  N/m), on the already considered speed domains, it must be noticed that vertical relative brake shoe – rail displacement apogee occurs under 20 km/h, and also at maximum speed, for the last situation not passing over 3 mm, as noticed, within 0.1 – 0.4  $D_p$  factor.

Nevertheless, one may notice that for this situation, the influence of the shock absorbers is almost irrelevant overall running speed domain considered. The maximum vertical displacements amplitude for a 250 km/h velocity modifies with less than 3% for dumping ratio variations  $D_p$



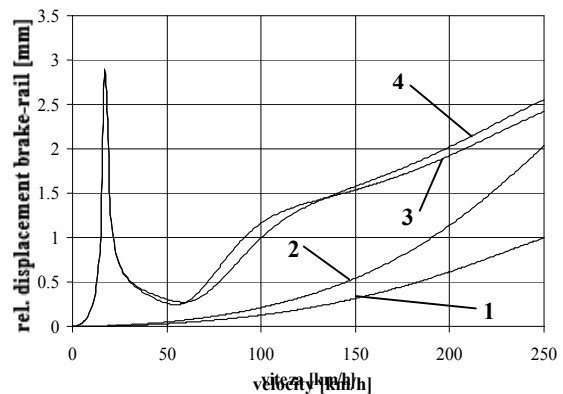
**Fig. 4. Vertical relative eddy brake shoes displacements in case of elastic suspended on the bogie frame, for different equivalent rigidities and dumping ratio  $D_p=0,4$ , within the 0.1 to 0.4 limits.**

Fig. 4 presents the most desirable solutions for the studied problem in the case of springing suspension of the eddy current brake shoes on the bogie frame. That means when imposing an enhanced dumping ratio ( $D_p=0.4$ ) corresponding to the analyzed rigidities  $c_p$ .

It is easy to see that the best solution in this case means higher suspension rigidity ( $c_p=10^7$  N/m), which is much more convenient for all speed range, since it determines the less as possible eddy current brake shoe - rail vertical displacements. Reduced rigidity, such as  $10^4$  N/m, could increase vertical displacement, at low speed, up to 370%. For a stronger rigidity, such as  $10^5$  N/m, might enhance - for low speed – up to 85 % increasement of the air gap, and even double it for speeds between 50 and 150 km/h, close to high rigidity brake shoes. Upper than  $10^6$  N/m brake shoes suspension's rigidity and high shock absorption, the eddy current brake shoes' response is practically the same for low speeds, getting double on 50...150 km/h, as amplitude.

## RESULTS ANALYSIS

Analyzing the optimal solutions for eddy current brake suspensions (see fig. 5), there came out some basic aspects we present as follow.



**Fig. 5. Vertical relative brake shoe displacements in the case of:**

- 1** - rigid fixing on the mounted axles;
- 2** - elastic suspended on the mounted axles ( $c_p=10^7$  N/m,  $D_p=0,4$ );
- 3** - rigid fixing on the bogie frame;
- 4** - elastic suspended on the bogie frame ( $c_p=10^7$  N/m,  $D_p=0,4$ ).

Using the mounted axles support, either rigid fixed (curve 1) or elastic suspended based one (curve 2) ensures the lowest instantaneous eddy current braking force variations between braking shoes and conducting rail, i.e. air-gap, mentioning that the latter solution presumes a

high both rigidity and dumping ratio. Even though, the air-gap becomes twice as big compared to direct, rigid support, for all the considered speed range.

Using direct bogie frame fixing (curve 3), respectively through a one level suspension (curve 4) leads to much more air-gap instability between the braking shoes and rail and consequently important instantaneous braking force variations. This phenomenon is mainly obvious for higher running speeds, exceeding 100 km/h, when the vertical relative displacements become 2.7 to 7 times higher. For lower running speeds, there is a higher maximum than the one corresponding to the maximum considered velocity. Since the eddy current rail brake is not effective at a speed lower than 20 km/h, the air-gap has no influence on the braking force, presenting also no risk for accidental direct brake shoe – rail hit. One must notice that the vertical oscillation amplitude is significantly low for small speed, and not too high when running faster. Therefore, it is much more advantageous, considering the data, to fix the brake shoes straight to the bogie frame, taking into account that this is obviously a much simpler constructive solution. Using a classical suspension for the eddy current brake shoes, based on elastic and strong enough shock absorbent elements, would induce in this case up to 6 % higher air-gaps on higher speed.

## CONCLUSIONS

As relating to suspending the eddy current rail brake shoes, both on maintaining a constant braking power at all speed range and avoiding a side-walk weighty trouble for the train, along with dismantling the danger of accidental harsh brake shoe – rail contact, the best mechanical yard solution is that of rigid fixing the assembly directly to the mounted axles.

Of course, that rigid solution presumes periodical checks on wheels, in order to be aware of any wear able to modify the air-gap figure. That means that the fixing system must have an easy handling possibility for recurrent adjustments when necessary. This solution is anyway much simpler, because it does not require an over-system to control and assist the brake shoes when the eddy current rail brake system is not active.

The main disadvantage of the system is that of an increase of the vehicle's unsprung mass due to the weight of the eddy current brake shoes and of

the whole fixing assembly. This aspect may lead to higher dynamic vertical forces at the wheel-rail contact level, increasing with the assembly mass and with the running speed. Further studies on that item are yet to come, since the safety of traffic is a major problem. In such cases, we consider that studies and tests to reveal the above mentioned dynamic forces would be necessary in order to appreciate if these may affect the safety of traffic, especially while high speed running.

Should this solution be unacceptable, the recommendable alternatives remain the elastic suspension of the eddy current brake shoes on the mounted axles, or a rigid fixing on the bogie frame. The first solution looks more convenient not only from the point of view concerning the air-gap problem, but also for the other items above mentioned. Yet, mostly if it is a motorized vehicle, the bogie available space for the assembly might become a problem.

In such case, fixing the eddy current brake shoes straight into the bogie frame and accepting a higher air-gap while braking might be the last resort. Anyway, a case study concerning the vertical relative displacements between the eddy brake shoes and the rail must be performed, particularly on the vehicle's constructive characteristics and specifications, mostly on low speed. That is necessary in order to determine the brake shoes disposal height to avoid accidental direct brake shoe – rail hit, since the eddy current rail brakes is not active.

If one appears that such phenomena might occur, a possible solution is to use a supplementary support system for vertical control and initial positioning of the eddy current brake shoes similar to the one used in case of the electromagnetically high suspended rail brake.

We underline the particularity of this test-studied case, but we want to notify especially its methodology, hoping that similar ones would be performed.

Yet, we must add, as an observation, that in practice the vertical relative displacement between the brake shoes and rail should be lower, due to the vertical attraction force generated by the eddy currents.

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## **СЪОБРАЖЕНИЯ ПРИ ОКАЧВАНЕ НА ЖЕЛЕЗОПЪТНИ СПИРАЧКИ С ВИХРОВИ ТОКОВЕ**

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**РУМЪНИЯ**

**Резюме:** Основен проблеми при използване на линейна железопътна спирачка с вихрови токове е да се поддържа наложената стойност на въздушно разстояние по време на спирачното действие, тъй като всяко изменение засяга директно сигурността на движение поради значителните модификации на спирателната сила. На основата на механичен анализ това изследване се отнася до възможностите за окачване на спирачка с вихрови токове и до еластичните и разтоварващи характеристики, да се намерят конструктивни решения за осигуряване на оптимално функциониране на спирачната система на возилото.

**Ключови думи:** железопътна спирачка с вихрови токове, безопасност на движение, високоскоростни возила, окачване.