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STUDY CONCERNING A RAILWAY VEHICLE'S BOGIE-CAR BODY RELATIVE MOTION WHILE RUNNING IN CURVE

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Abstract: *In this paper, the geometrical positioning in curve of a railway vehicle is studied, in order to investigate if the available transversal gap between the bogie and the car body, allowed by a limiting device, is consumed when the vehicle is running in curves. For this purpose, analytical expressions of the angles between the longitudinal axes of the bogie and of the car body are determined for the extreme cases, taking into account the geometrical position in curve of the bogie, its position on the vehicle – front or rear - and various curve characteristics.*

Key words: *geometrical positioning in curve, bogie-car body angle, bogie-car body relative displacement.*

INTRODUCTION

The geometrical positioning in curve of a railway vehicle is influenced by its longitudinal dimensions, the radius of the curve, the track and wheelset's gauges and by the forces actuating on it. The vehicle's positioning with the flanges between the rails is ensured by the clearance σ which is given by the difference between the track's and wheelset's gauges:

$$\sigma = E_t - E_w \qquad (1)$$

When a vehicle is running in curve, its front wheelset's flange is forced to be always in contact with the outer rail of the track.

The rear wheelset can take different positions in track, depending on the contact between its flanges and the rails, defining thus the geometrical position of the vehicle, as follows: the vehicle has

♦a secant position, if the rear wheelset's flange is in contact with the inner rail;

♦a chord position, if the rear wheelset's flange is in contact with the outer rail;

♦an intermediate (free) position, if the rear wheelset's flanges are disposed between the rails.

The natural tendency of a vehicle when it is running in curves is to adopt the secant geometrical position. The increase of the unbalanced centrifugal force leads to the free geometrical position or, for even larger unbalanced centrifugal force (as a result of higher cant deficiencies) the vehicle will adopt the chord geometrical position.

The aim of this paper is to study the bogie-car body lateral relative displacement for a railway vehicle running in curve, vehicle which has as a specific feature the limitation of the transversal displacement between the bogie and the car body. It is then necessary to investigate if the available transversal gap between the bogie and the car body, allowed by the limiting device, is ever consumed while the vehicle is running in curves. For this purpose, we have to determine the angles between the longitudinal axes of the bogies and of the car body, induced when the vehicle is running in curves.

CONSIDERATIONS CONCERNING THE GEOMETRICAL POSITIONING OF VEHICLES IN CURVES

In fig. 1 is shown a *n* axles vehicle running in a circular curve of radius *R*. The vehicle is reduced to its longitudinal axis, so that the two rails of the track are represented distanced by the clearance σ and the wheelsets are represented by points on the longitudinal axis of the vehicle [1].

In fig. 1, *a* denotes the vehicle wheelbase, Ω – the pole, *p* – the polar distance, q_{Ai} - the distance between the wheel flange and the outer rail of the track for the *i* wheelset and α – the attack angles (defined as the angles between the axis of the wheelset and the radius direction at the contact point).

For the wheelset *i* we may write then (see fig.1) [1]:

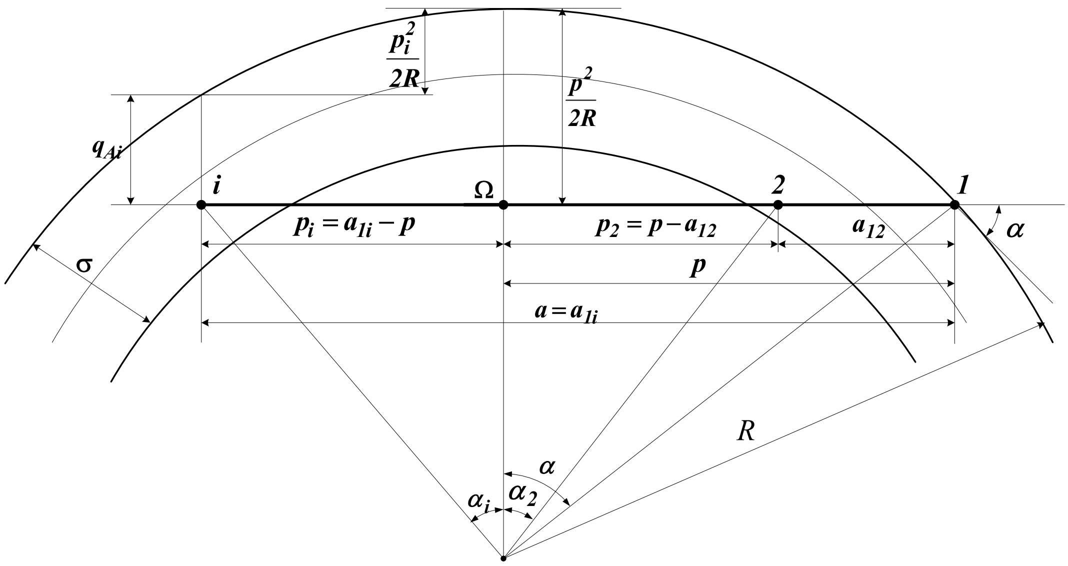

Fig. 1.

Geometrical positioning in curve of a vehicle.

$$q_{Ai} = \frac{\left(p^2 - p_i^2\right)}{2R} = \frac{\left[p^2 - \left(a_{1i} - p\right)^2\right]}{2R} = \left(\frac{a_{1i}}{R}\right)\left(p - \frac{a_{1i}}{2}\right) \quad (2)$$

The vehicle's polar distance is then

$$p = \frac{a_{1i}}{2} + R\frac{q_{Ai}}{a_{1i}} \ . \quad (3)$$

By particularizing equation (3) for the entire vehicle ($a_{1i} = a_{1n} = a$ and $q_{Ai} = q_{An}$) we obtain the polar distance for its extreme positions: for the secant position, when $q_{An} = \sigma$,

$$p_S = \frac{a}{2} + R\frac{\sigma}{a}, \quad (4)$$

and for the chord position, when $q_{An} = 0$,

$$p_C = \frac{a}{2}. \quad (5)$$

The attack angles are given by [1]

$$\alpha_i = \frac{p_i}{R} = \frac{p - a_{1i}}{R}; \quad (6)$$

by particularizing the expression above for the secant and chord positions, we obtain the attack angles for the front axle:

$$\alpha_s = \frac{p_s}{R} = \frac{a}{2R} + \frac{\sigma}{a} \quad (7)$$

and, respectively,

$$\alpha_c = \frac{p_c}{R} = \frac{a}{2R}. \quad (8)$$

ANALYTICAL DETERMINATION OF THE BOGIE-CAR BODY ANGLES

In order to evaluate the bogie-car body lateral relative displacement it is necessary to determine the angles between the longitudinal axes of the bogie and of the car body, induced when the vehicle is running in curve.

Because each bogie can adopt any of the three possible geometrical positions in track, it is theoretically necessary to take into consideration all the nine possible cases but, because we are interested only in the maximal values of the bogie-car body angles (which lead to maximal relative displacements) it is sufficient to analyze only the extreme geometrical positions of the bogies – secant and chord. In this situation, there are only four possible combinations of geometrical positions of the vehicle's front and rear bogies: secant-secant, secant-chord, chord-secant and chord-chord.

For example, the situation of the secant position of both bogies is illustrated in fig.2.

Because the radial distances between the bogie-car body articulation points and the outer rail of the track (which is of the order of millimeters) are negligible in comparison with the curve radius (which is of the order of hundreds of meters), we can assume that the car-body part which is situated between the pivots has a chord position in the track.

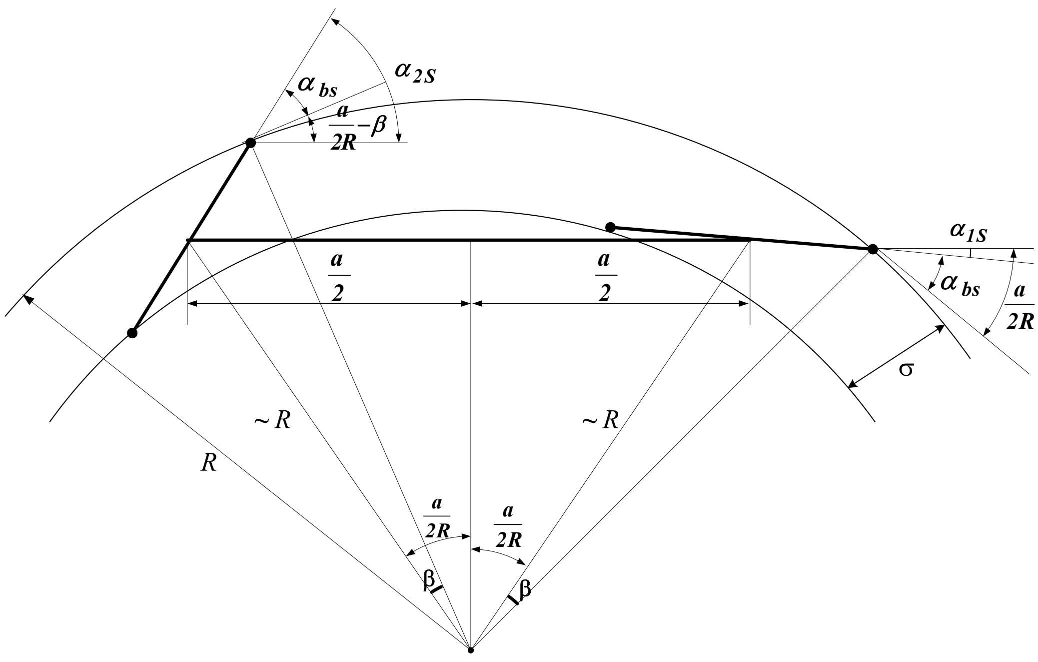

Fig. 2. Bogie-car body angles for the secant geometrical position of the bogies.

In the situation of the chord position of the car body and of the secant position of the bogies, the angles between the longitudinal axes are (see fig.2):

$$
\alpha_1 = \frac{a}{2R} + \beta - \alpha_{bs}
$$
$$
\alpha_2 = \frac{a}{2R} - \beta + \alpha_{bs} \tag{9}
$$

In equations (9) α_{bs} denotes the angle between the longitudinal axis of a bogie in secant position with the tangent at the outer rail in the contact point with the front wheelset's flange, which is given by

$$
\alpha_{bs} = \frac{a_b}{2R} + \frac{\sigma}{a_b}, \tag{10}
$$

where a_b denotes the bogie's wheelbase.

The angle β in equation (10) can be determined as a function of the curve radius R, clearance σ, bogie's wheelbase and polar distance, a_b and p_s, respectively (see fig.3)

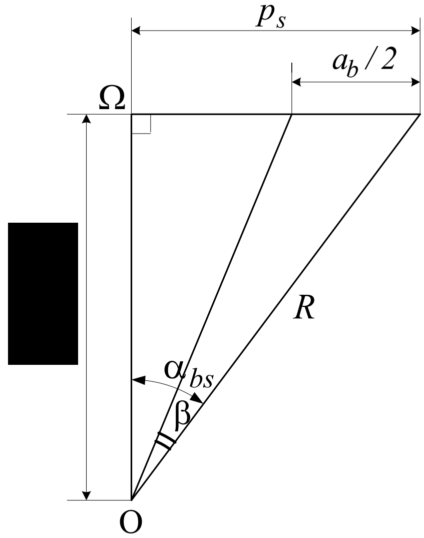

Fig. 3. Determination of angle β.

$$\beta = \alpha_{bs} - \frac{\pi}{2} + \arctan\frac{\sqrt{R^2 - p_s^2}}{p_s - \frac{a_b}{2}} = \alpha_{bs} - \frac{\pi}{2} + \arctan\frac{\sqrt{R^2 - p_s^2}}{R\frac{\sigma}{a_b}} \quad (11)$$

In a similar manner were determined the bogie-car body angles corresponding to the remaining three cases. The analysis showed that the angle of a bogie with the car body is not influenced by the other bogie's geometrical position.

The angles are depending on the geometrical position of the bogie, on the vehicle characteristics – wheelbases a and a_b, on the track characteristics – curve radius R and clearance σ – and, only in the case of the secant position, on the position of the bogie on the vehicle – front or rear.

The angles are given by:

$$\alpha_{1c} = \alpha_{2c} = \alpha_c = \frac{a}{2R} \quad (12)$$

for the chord position of any of the bogies (front or rear);

$$\alpha_{1s} = \frac{a}{2R} - \left(\frac{\pi}{2} - \arctan\frac{\sqrt{R^2 - p_s^2}}{R\frac{\sigma}{a_b}} \right), \quad (13)$$

in case of the secant position of the front bogie and

$$\alpha_{2s} = \frac{a}{2R} + \left(\frac{\pi}{2} - \arctan\frac{\sqrt{R^2 - p_s^2}}{R\frac{\sigma}{a_b}} \right) \quad (14)$$

for the secant position of the rear bogie.

It can be seen from equations (12), (13) and (14) that the most unfavourable situation, which leads to the largest values of the bogie-car body angle, is of the secant position of the rear bogie.

If both bogies are in secant position, the difference between the bogie-car body angles for the rear and front bogie respectively is increasing with the increase of the clearance σ and of the bogie's polar distance p_s. For a given vehicle (a_b fixed) running in a curve of radius R, the polar distance p_s is increasing with σ (see equation 4), so we can say that the difference between the rear and front bogie angles is increasing with the increase of σ only.

The bogie-car body lateral relative displacement is given by

$$j = d \cdot \alpha \quad (15)$$

where α denotes the bogie-car body angle, which can be α_c, α_{1s} or α_{2s} and d denotes the longitudinal distance between the geometrical center of the bogie and the lateral displacement limiting device.

CASE RESEARCH

In order to numerically evaluate the bogie-car body angles, calculations were performed on the particular case of a sleeping car with Gorlitz Va bogies. The main characteristics of the assumed vehicle, necessary for the numerical determination of the bogie-car body angles and lateral relative displacements are:

$a = 19.5\ m;\ a_b = 2.5\ m.$

Calculations were made by considering domains of values for the curve radius R and for the clearance σ, taking into consideration also the correlation between these values because, for some curve radius values, the clearance σ has to comprise also the prescribed gauge-widening.

The influence of the clearance σ on the bogie-car body angles α_C, α_{1S} and α_{2S}, considering three values of the curve radius, is illustrated in figs. 4, 5 and 6.

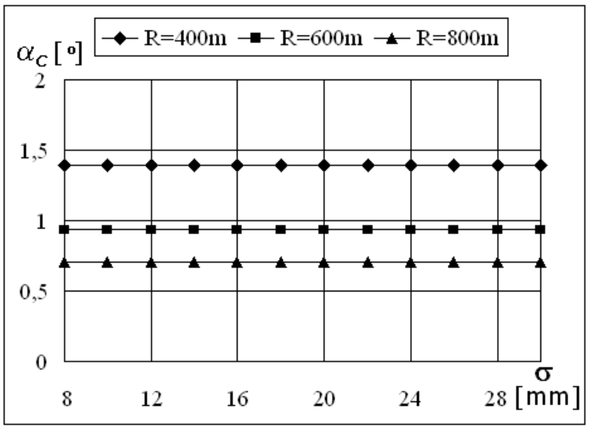

Fig. 4. The influence of the clearance σ on the angle α_C.

In fig. 4 we can see that the clearance σ has no influence on the angle between the car body and the bogie in chord position. This can be explained by the fact that in the case of the chord geometrical position of the bogie, its both wheelsets' flanges are in contact with the outer rail of the track, so that bogie's disposition is not depending on the inner rail's position.

On the other hand, it comes out from fig. 4 that the angle α_C is influenced by the curve radius: as expected, the decrease of the radius produces the increase of the angle.

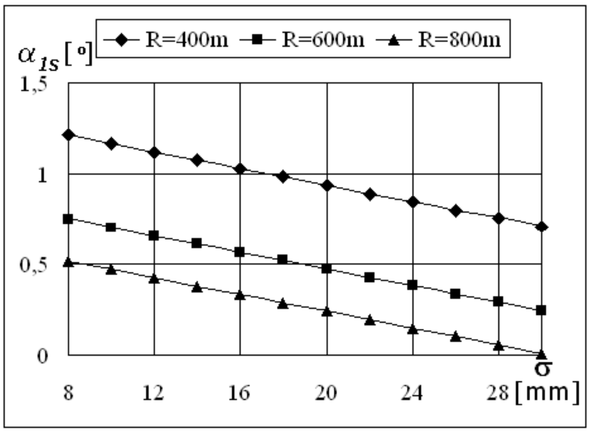

Fig. 5. The influence of the clearance σ on the angle α_{1S}.

The angle α_{1S} is influenced by the clearance σ, being decreased by its increase (see fig. 5). In other words, the front bogie in secant position tends to line up with the car body when the clearance σ is increasing. This is explainable by the enlargement of the bogie's polar distance when σ is increasing, the bogie-car body angle becoming equal to zero when the bogie's pole coincides with the geometrical center of the car body (when bogie's polar distance is half of vehicle's wheelbase – see equations 4 and 5).

From fig. 5 it comes out also that the angle α_{1S} is increased by the decrease of curve radius.

The influence of the clearance σ on the angle between the car body and the rear bogie in secant position is inverted with respect to the previous case, the angle α_{2S} being decreased by the enlargement of σ (see fig. 6).

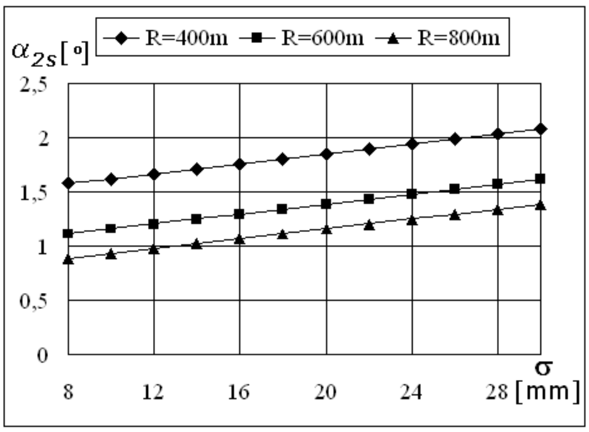

Fig. 6. The influence of the clearance σ on the angle α_{2S}.

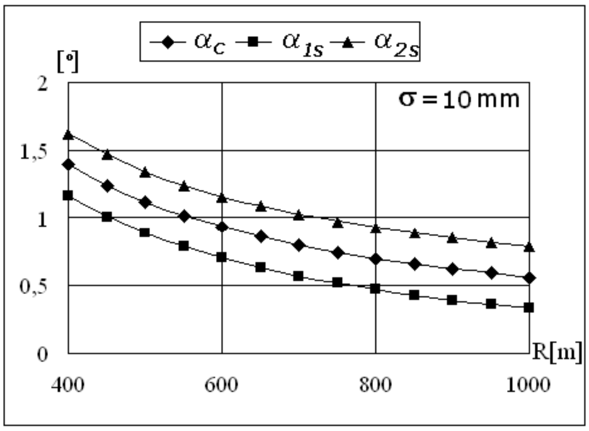

Fig. 7. The influence of the curve radius on the bogie-car body angles.

In fig. 7 is shown the influence of the curve radius on the angles corresponding to the three possible situations. It comes out that all angles are decreased when the curve radius is increased.

We can say that the curve radius has the same influence in all the possible cases, while the clearance σ has different influences: the angle corresponding to the chord position is not depending on it, while the angle corresponding to the secant position of the bogie is either decreased by the enlargement of clearance σ (in the case of the front bogie) or increased when the clearance σ is increasing (in the case of the rear bogie).

The analysis above showed that the largest values of the angle between the longitudinal axes of the bogie and of the car body are obtained for a secant position of the rear bogie, in the situation of a small curve radius and a large clearance.

If we refer to the bogie-car body transversal relative displacement, its largest value is obtained in the most unfavorable situation, consisting of the secant geometrical position of a rear bogie of a vehicle running in a curve of minimum radius and largest possible clearance.

In order to determine the maximum value of the bogie-car body lateral relative displacement, the following conditions are considered:

- ♦ minimum curve radius :

$$R = 80\ m;$$

- ♦ minimum admissible wheelset gauge:

$$E_w = 1410\ mm;$$

- ♦ maximum admissible track gauge in alignment:

$$E_t = 1445\ mm;$$

- ♦ maximum gauge widening:

$$s = 25\ mm;$$

- ♦ maximum admissible clearance:

$$\sigma = (1445+25) - 1410 = 60mm;$$

Considering also the secant position of the rear bogie of the vehicle and knowing the longitudinal distance between the geometrical center of the bogie and the lateral displacement limiting device (*d = 200 mm)* we can determine the maximum bogie-car body lateral relative displacement using equations (14) and (15):

$$j_{max} = 29.26\ mm,$$

which is corresponding to the maximum bogie-car body angle:

$$\alpha_{2s} = 8{,}831^{\circ}\ .$$

The maximum value j_{max} calculated above is smaller than the prescribed value of the transversal gap between the bogie and the car body, which is of *55mm* for the assumed vehicle.

We can say therefore that the available transversal gap between the bogie and the car body allowed by the limiting device is never consumed when the vehicle is running in curves, even if the most unfavorable conditions are simultaneously considered.

CONCLUSIONS

In this paper a study of the bogie-car body relative motion for a railway vehicle running in curve was performed, in order to investigate if the available transversal gap between the bogie and the car body, allowed by a limiting device, is ever consumed when the vehicle is running in curve.

For this purpose, the angles between the longitudinal axes of the bogies and of the car body induced when the vehicle is running in curves were determined for the extreme geometrical positions in curve of the bogies.

Analytical expressions of the angles were determined taking into account the geometrical position in curve of the bogie and its position on the vehicle. The analysis showed that the angle of a bogie with the car body is not influenced by the other bogie's geometrical position but it's depending on its own geometrical position, on the characteristics of the vehicle and of the track and, only in the case of the secant position, on the position of the bogie - front or rear - on the vehicle.

In order to numerically evaluate the bogie-car body angles and relative displacements, calculations were performed on the particular case of a sleeping car with Gorlitz Va bogies, by considering domains of values for the curve radius R and for the clearance σ, fact that allowed us to establish the influences of these parameters on the bogie-car body angles.

Concerning the bogie-car body transversal relative displacement, numerical results indicated that the available transversal gap between the bogie and the car body is never consumed when the vehicle is running in curve, even if the most disadvantageous conditions are simultaneously considered.

We would like to mention the opportunity of this paper, a similar study being requested this year to our department by S.C. Atelierele CFR Grivita S.A., which is a prestigious Romanian industrial unit in the domain of the rolling stock.

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ИЗСЛЕДВАНЕ НА ОТНОСИТЕЛНОТО ДВИЖЕНИЕ ТАЛИГА-КОШ НА ЖЕЛЕЗОПЪТНО ВОЗИЛО ПРИ ПРЕМИНАВАНЕ НА КРИВА

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Abstract: *В този доклад се разглежда геометричното позициониране на железопътно возило в крива, за да се изследва дали наличието на напречно разстояние между талигата и коша, позволено от ограничаващото устройство, се консумира, когато возилото си движи в крива. За тази цел се определят аналитичните изрази на ъглите между надлъжните оси на талигата и на коша за екстремални случаи, като се вземе предвид геометричното положение на талигата в криви, неговото положение на возилото – предно или задно и характеристиката на различните криви.*

Key words: *геометрично позициониране в крива, ъгъл между колело и талига, относително преместване на талига – возило.*