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A METHOD OF DETERMINING ANGLE OF ATTACK BETWEEN WHEEL AND RAIL WITH ROLLING STOCK RUNNING IN CURVES

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Abstract: *The paper develops a method of determining the attack angle. It has been used to register the attack angles with rolling stock testing under real operational conditions for the first time. For the purpose analytical theoretical apparatus has been created with reading the possible replacements within the system body – bogie base - car axles – track including the horizontal straight body-base formations. The dependencies obtained are convenient for experimental determining the attack angle under real operational conditions.*

1. INTRODUCTION

The angle of attack of the rolling stock wheels and rails is one of the main indices of the interaction between the rolling stock and railroad [1,2]. It has a primary and determining role related to wear-out of flanges and to safety against derailing although some studies, otherwise deserving a high assessment, have emphasized on the directing flange force, respectively the total lateral pressure between the wheel axle and railroad as being the most important factor. It is evident that such interpretations can be explained with some concepts and approaches traditionally established and mostly with the lack of reliable methods to determine the attack angle between the wheel and rail. In fact the directing flange force is an after-effect factor and the primary factor is the attack angle because of its influence on it and mainly because of its direct connection with the geometry of contacts between wheels and rails: and through that with the geometry and kinematics of their friction and wear-out.
To be clearer and more detailed, the presentation stresses on double-axle railway rolling stock (bogie) and almost in all cases takes into consideration the classical type

of wheel axle with wheels hard-joined to the axle. But if necessary, the problem can be easily adapted to wheels not connected to the axle or independent wheels and also to multi-axle rolling stock.

2. Main Dependences: Theoretical Model

The attack angle between wheels and rails is one of the quantities that characterize the relative position and interaction between the railway rolling stock and railroad in a curve. As for that purpose the quantity (criterion) of "pole distance", i.e. from the pole of rotating to the respective wheel axle [2, 5] has been widely used up to now, we will start first with this quantity (criterion) trying to make its application wider and going out of the classical and widely-used simplified plain model of wheels that are hard-joined to the frame.

Let the initial position of the rolling stock (bogie) frame longitudinal axle in the "frame – wheel axles (axle journals) – rails" system presented in Fig.1 is marked with $\mathbf{a_0 b_0}$ and $\mathbf{S_a}$, $\mathbf{S_i}$ are the outer and inner rail thread respectively, conventionally brought near each other at a distance Δ equal to the total clearance between the wheel axle flanges and inner rail walls.

First, we shall follow the change of the pole distance in this system according to all possible crosswise displacements in the system (along axis $\mathbf{y}$); the signs of these displacements will be assumed to be positive or negative if they coincide with the positive or negative direction of axis $\mathbf{y}$.

However, taking into account the total railroad horizontal unevenness δ_{S1} and δ_{S2} (look at curve $\mathbf{S'_a}$) and having in mind the signs of the unevenness (displacements), angle θ_1 of axle $\mathbf{a_1 b_1}$ rotation in relation to the initial chord position $\mathbf{a_0 b_0}$ in the first and second wheel axles positions represented by points $\mathbf{a_1}$ and $\mathbf{b_1}$ will be:

$$(1) \qquad \theta_1 = (\delta_{S2} - \delta_{S1})/2\ell_D$$

The central angle between segments $\overline{\mathbf{CP_0}}$ and $\overline{\mathbf{CP_1}}$ that are perpendiculars towards the axle of the rolling stock frame drawn from the center of curve $\mathbf{C}$ will have the same value θ, therefore the pole distance for the first wheel axle with new position $\mathbf{a_1 b_1}$ and for the second wheel axle is:

$$(2) \qquad \chi'_1 = \overline{\mathbf{P_1 a_1}} = \ell_D + \theta_1 \mathbf{R} = \ell_D + \frac{\delta_{S2} - \delta_{S1}}{2\ell_D}\mathbf{R}$$

$$(3) \qquad \chi'_2 = \overline{\mathbf{P_1 b_1}} = -\ell_D + \theta_1 \mathbf{R} = -\ell_D + \frac{\delta_{S2} - \delta_{S1}}{2\ell_D}\mathbf{R}$$

Acting in the same way towards the rest crosswise displacements in the system, namely:

- the crosswise displacements (distances or clearances) between the flanges and outer rail $\boldsymbol{\sigma_1 = \overline{a_1 a_2}}$ and $\boldsymbol{\sigma_2 = \overline{b_1 b_2}}$ (for the first and second wheel axles respectively) and the rolling stock rotations caused by them at angle $\boldsymbol{\theta_2 = (\sigma_2 - \sigma_1)/2\ell_D}$ (not marked in Fig.1);

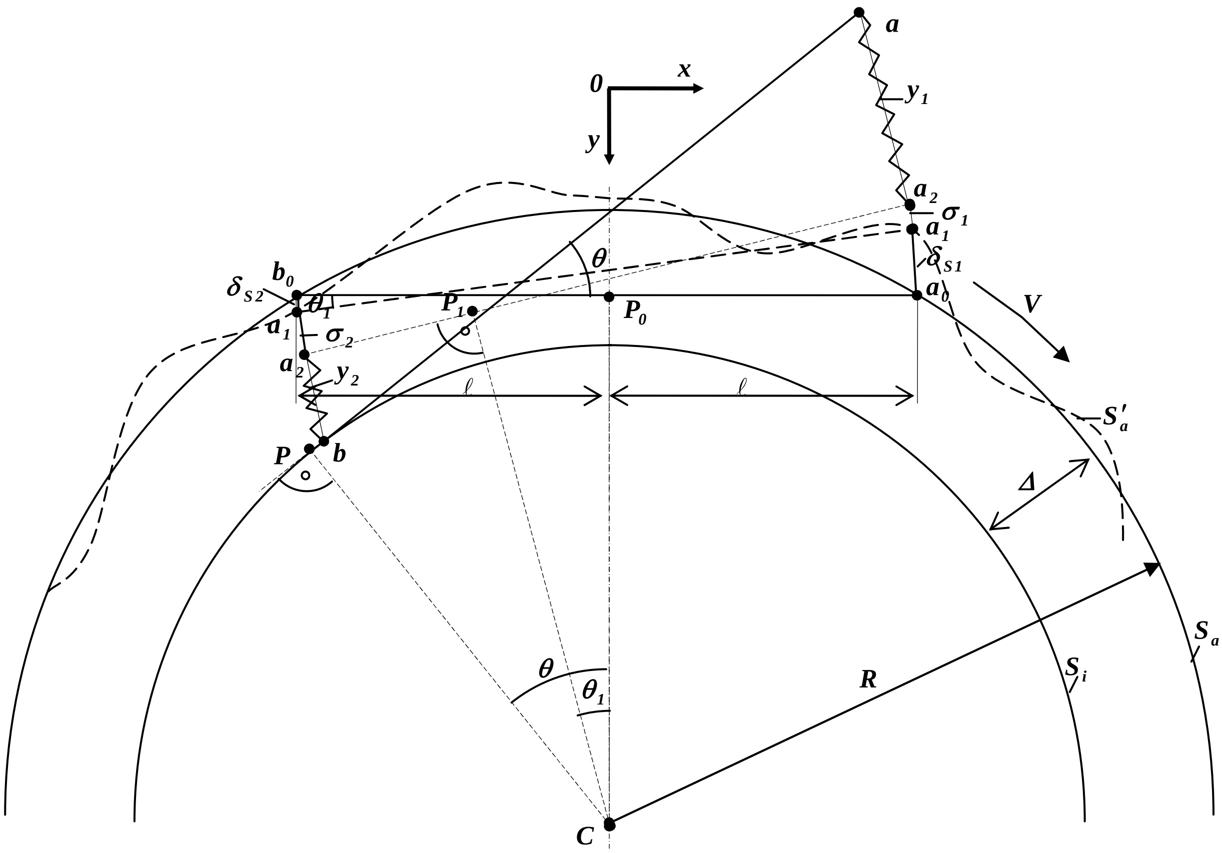

Fig.1

- the crosswise displacements of the rolling stock frame towards the wheel axles (axle journals) $\boldsymbol{y_1 = \overline{a_2 a}}$ and $\boldsymbol{y_2 = \overline{b_2 b}}$ (at the points of axle journals centers) and the rolling stock rotations caused by them at angle $\boldsymbol{\theta_3 = (y_2 - y_1)/2\ell_D}$,

then, with the final (and assumed as real) position of the rolling stock frame longitudinal axle **ab** the total (and assumed as real) angle of rotation θ towards initial chord position $\mathbf{a_0 b_0}$ will be:

(4) $$\theta = \theta_1 + \theta_2 + \theta_3 = \frac{\delta_{S2} - \delta_{S1}}{2\ell_D} + \frac{\sigma_2 - \sigma_1}{2\ell_D} + \frac{y_2 - y_1}{2\ell_D}$$

and the pole distance for real position **ab** corresponding to it with the displacements in the system examined above can be expressed as follows:

(5) $$\chi_1 = \overline{\mathbf{Pa}} = \ell_D + \theta.\mathbf{R}$$ (6) $$\chi_2 = \overline{\mathbf{Pb}} = -\ell_D + \theta.\mathbf{R},$$

With the most common case, with examining multi-axle rolling stock with **n**-number axles, pole distance χ_j for any wheel axle (with № j) can be presented by the expression:

$$\chi_j = \ell_D - \ell_j + \left(\frac{\delta_{Sn} - \delta_{S1}}{2\ell_D} + \frac{\sigma_n - \sigma_1}{2\ell_D} + \frac{y_n - y_1}{2\ell_D} + \right) R \qquad (7)$$

where: ℓ_j is the distance from the first wheel axle to a random wheel axle with № j (j = 1, 2 … n) that is examined.

If the possible longitudinal displacements in the system are examined as well, namely:

- according to Fig.2 the longitudinal displacements of the wheel axles (journals) located at crosswise distance **2b** in relation to frame x_{1k} and $x_{1k\pm1}$ (for the journals on the side of the outer (attacking), respectively the inner wheel of the first wheel axle) and x_{2k} и $x_{2k\pm1}$ (for the journals on the side of the outer, respectively the inner wheel of the second wheel axle), causing wheel axle rotations towards the frame at angles γ_1 and γ_2 determined by the expressions:

$$\gamma_1 = \left(x_{1k} - x_{1k\pm1}\right)/2b, \qquad \gamma_2 = \left(x_{2k} - x_{2k\pm1}\right)/2b \qquad (8)$$

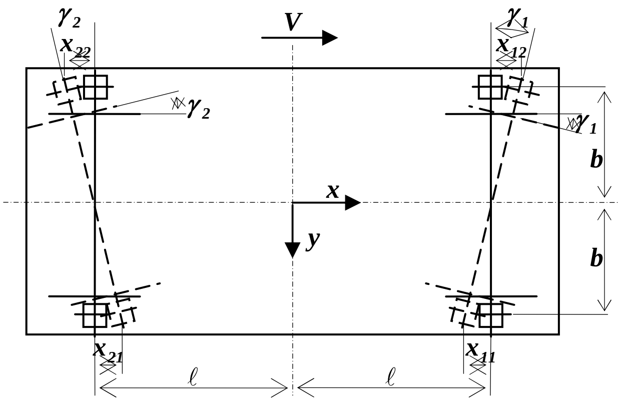

Fig. 2

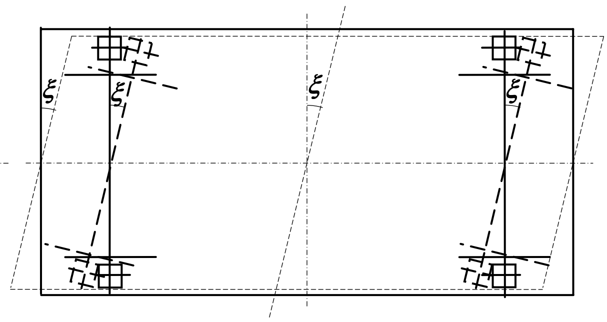

Fig. 3

- the horizontal skew strain of rolling stock frame at angle ξ (see Fig.3) causing the wheel axle rotation towards the longitudinal frame axle at same angle ξ, it is seen that these displacements do not change pole distances χ_1 and χ_2 respectively. However, on the other hand, it is evident that the longitudinal displacements mentioned above are part of quantities characterizing the relative position of the "frame – wheel axles (journals) – rails" system elements and at that being important quantities, determining even the rolling stock quality of "cross-country capability" in curves.

Hence, even in the simplest case of two-axle rolling stock the traditionally used index of "pole distance" cannot be a criterion meeting the requirements of adequate characterizing the relative position of the rolling stock elements and railroad and of unambiguous assessment of the most important rolling stock qualities. These requirements are met by the quantity of "attack angle" between wheels and rails. It is expedient and even necessary to use that quantity itself for modern and perspective rolling stock (bogies) and mostly for those with radial directed wheel axles (for implementing the so-called radial inscribing in curves) as an index (criterion) of characterizing the relative position of the elements in the system "frame – wheel axles (journals) – rails" and of estimating some particularly important rolling stock qualities with its inscribing in curves.

Thus, taking into account only the crosswise displacements in the system as it can be seen from the geometry dependencies in Fig.1, the values of the attack angles for the first and second axle (of two-axle rolling stock) and for j-wheel axle (of n-axle rolling stock) are respectively:

(9) $\alpha_1 = \chi_1/R$, $\alpha_2 = \chi_2/R$, $\alpha_j = \chi_j/R$

Taking into account both the crosswise and longitudinal displacements in the system, the values of the attack angle will be obviously obtained by adding the angles of wheel axle rotation towards the longitudinal frame axle γ_1, γ_2, γ_j and ξ to expression (9).

Hence, in general setting, considering all possible horizontal displacements in the "frame – wheel axles (journals) – rails" system, the angle of attack can be presented by the following expressions for the j-wheel axle (j = 1,2, … n) of multi-axle rolling stock with n axles:

(10) $$\alpha_j = \frac{\ell_D - \ell_j}{R} + \frac{\delta_{Sn} - \delta_{S1}}{2\ell_D} + \frac{\sigma_n - \sigma_1}{2\ell_D} + \frac{y_n - y_1}{2\ell_D} - \frac{x_{jk} - x_{jk\pm1}}{2b} - \xi$$

Examining the first (leading and directing) wheel axle of the most wide-spread two-axle rolling stock (bogie) that deserves the greatest attention, the following terms of expression (10) can be dropped approximately:
- the second term because of the comparatively small values of displacements (the total real unevenness δ_{S1} and δ_{S2}), at that presenting random stationary functions with zero mathematical expectation and not able to change the average value of the attack angle formed in quasi-static aspect:
- the last term, i.e. the angle of the frame horizontal skew strain ξ because of its comparatively small values with most modern structures;
- quantity σ_1, i.e. the distance between the attacking wheel flange and rail, as its values no matter positive or negative are comparatively small in absolute value.

Considering that, the angle of attack α_1 for most modern structures could be determined with moderate approximation according to the formula:

(10a) $$\alpha_1 \approx \frac{\ell_D}{R} + \frac{\sigma_2}{2\ell_D} + \frac{y_2 - y_1}{2\ell_D} - \frac{x_{1k} - x_{1k\pm1}}{2b},$$

and for the cases with comparatively hard "journal – frame" tie in horizontal crosswise and longitudinal direction, in the presence of sufficient reasons for that, formula (10a) could be applied without the last two terms with even rougher approximation, , i.e.

(10b) $$\alpha_1 \approx \frac{\ell_D}{R} + \frac{\sigma_2}{2\ell_D}.$$

3. Conclusion

1. The quantity "angle of attack" between the wheels and rails is not only a main criterion of interaction between the rolling stock and railroad with running into curves but also a criterion of adequate characterizing the relative position of the "frame – wheel axles – rails" system elements. Because of that, it is expedient and necessary to use it for modern rolling stock (bogies) and particularly for those with radial directed wheel axles.

2. The angle of attack between wheels and rails is determined for the most common case with taking into account all possible horizontal displacements in the system using the equations expressing the relative position of the "frame – wheel axles – rails" system elements in the theoretical dependencies developed above; because of that the equations mentioned and particularly the dependences of determining the attack angle between wheels and rails can be applied without any limitations: with various schemes and structures of rolling stock running part.

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