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INVESTIGATION OF THE FRICTION PHENOMENON IN THE WHEEL-ROAD INTERACTION

Introduction

Rolling contact has been investigated intensively during last decade [1, 2]. However, generation of corrugations, the fundamental problem of rolling in railway transportation, is still not completely explained. In the paper we consider dynamic phenomenon, which occur in rolling of the wheel over the rail, with lateral slip. Such cases are involved by wind blows (both on curved and straight tracks), deformation of wheels, wheelsets and rails, different linear velocity of wheels on curves and rotatory oscillations of wheelsets. Skew wheel plane related to the direction of rolling results in lateral slip in rail/wheel contact zone. The rail/wheel system oscillates and generates noise. In the same time the wear increases considerable and negatively influences the safety of transportation. Corrugations are visible results of this oscillatory wear (Fig. 1). However, the phenomenon can be observed also in rolling of a tire over the road and the contact of rolls with guide. In all cases friction is the main reason of the described phenomenon. The friction law influences it qualitatively and qualitatively.

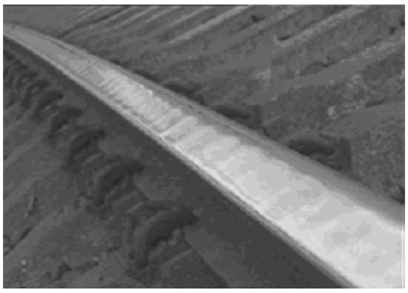

Fig. 1. Corrugations of a rail.

Experimental stand

The first attempt to the investigation of rolling with lateral slip has been made experimentally. The driven belt carrier is the main part of the stand. Various belt materials were tested. Polymer and rubber surfaces were characteristic of different elasticity, viscosity and friction.

The tested wheel was made of steel or polyamide. It was suspended elastically with the axle by two springs that enabled it horizontal lateral motion. The wheel could be placed on the elastic belt with the adjusted contact force (Fig. 2). Displacements in time in the direction of wheel axle were registered by using of laser distance transformers. They enabled us high resolution of measurement (over 0.01mm) and high frequency of recording (over 1000 registrations per second).

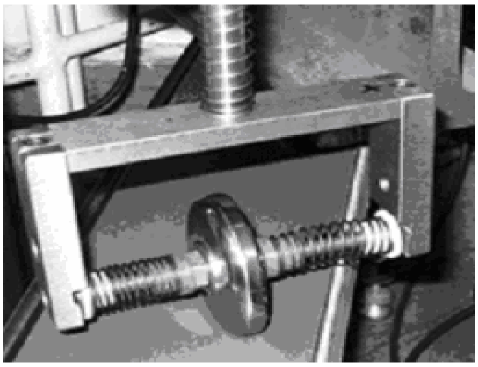

Fig. 2. Experimental model

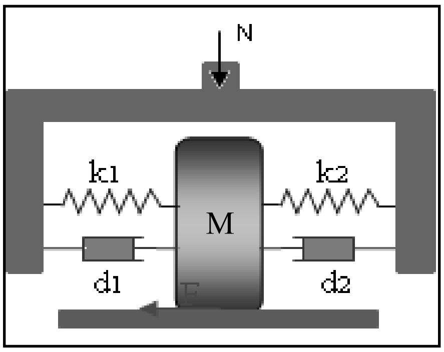

Fig. 3. Mechanical model.

Theoretical model

We consider our physical model as a system of two viscoelastic Kelvin-Voigt spring elements that hold a wheel as a lumped mass (Fig. 3). The motion of the wheel along its axle is excited by friction. The wheel is subjected vertically to an external force V and the self-weight of the wheel and the suspension. Friction force is equal to the force in the spring and increases until the maximum value F_{tsmax} is achieved (segment 0-A in Fig. 4). We have stick state. The final stage of the motion (A-B) is intermediate one in which both friction and inertial forces act. In the extremal position the slip state starts since the friction force is lower then the elastic spring force (B-C). Relative motion of the wheel exhibits two stages: the first one under the inertial load together with potential spring forces, and the second one under only the inertial forces (minor contribution of friction).

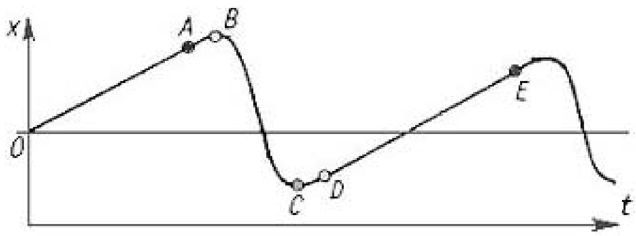

Fig. 4. Diagram of displacement in time.

The friction law is the fundamental question. We assume it as nonlinear one depending on the relative velocity of the belt and wheel and the path of displacement. The friction force in practice depends also on the adhesion time t_s and the force rate Δ (Fig. 5). The periodic motion depends on the spring stiffness k, the belt velocity and, mainly, physical properties of the friction pair (wheel-belt).

In our theoretical model we assume several simplifications. The wheel is assumed to be a rigid one, springs exhibit linear elasticity and low internal viscous damping, and the belt is undeformable in plane. Its moving velocity is constant.

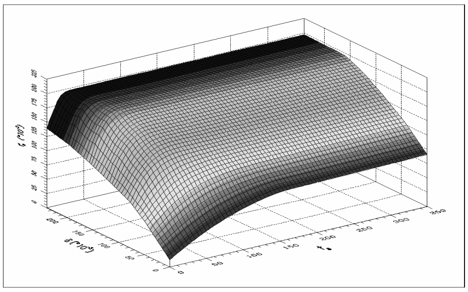

Fig. 5. Static friction force f_S as a function of adhesion time t_S and force rate δ.

Statical friction force

The real physical problem of rolling with friction is complex. The friction law varies in each real engineering problem. A set of coefficients, which describe the material properties, also significantly differs for each friction pair.

We can recall here the experimental measurement of the friction law in the static case [5]. The force rate Δ and time of stick τ_s are two fundamental factors that influence the friction force, where

$$F_s = F_s(\tau_s, \Delta) \ , \qquad \Delta = \frac{dF_s}{d\tau_s} \tag{1}$$

The static friction force, determined experimentally and approached by the regular function [5] is depicted in Fig. 5. We notice that time of adhesive stick of relative motion of two bodies is significant in the case of low values of time. For greater stick time value it stabilizes. Higher force rate also increases static friction force.

Experimental results

Below we present our experimental results. Displacements in time of the wheel related to the belt speed were registered. Velocities were derived by differentiation. We must emphasize that diagrams obtained experimentally were repeatable with good accuracy. Double periodicity was observed in all cases. The following equation describes generally the problem:

$$x = -\cos(t) - a \cdot 0.5\cos(2t + b),\ \ u = \sin(t) + a \cdot \sin(2t + b) \tag{2}$$

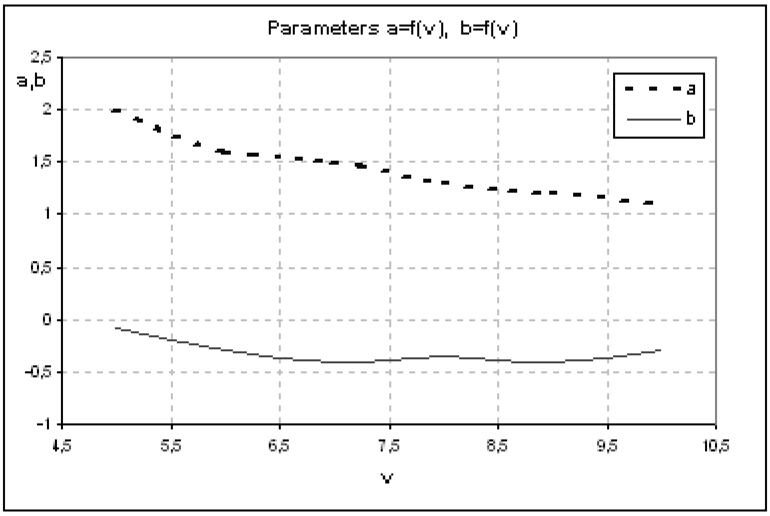

Fig. 6. Schemes of parameters *a* and *b* versus belt speed (v=5÷10 cm/s).

Phase diagrams allowed us to select characteristic features of the motion in the case of various angle of rolling, belt speed and contact pressure (Fig. 7). For various belt speeds from the range v=5÷10 cm/s parameters *a* and *b* have following values:

v [cm/s]	5	6	7	8	9	10
a	2	1,6	1,5	1,3	1,2	1,1
b	-0,09	-0,3	-0,4	-0,35	-0,4	-0,3

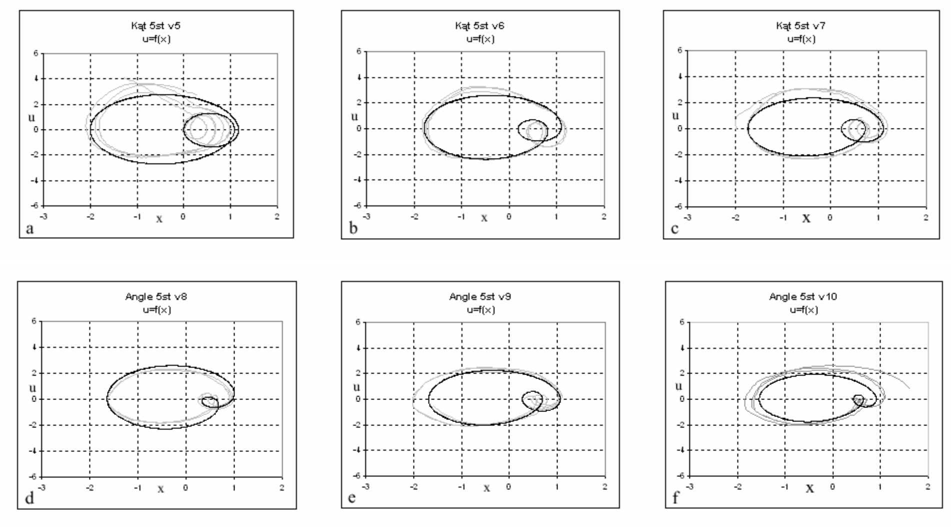

Fig. 7. Theoretical and experimental phase trajectories
(u-speed, x-displacement, angle α=5° and belt speed v=5÷10cm/s).

An interesting observation has been made. The increase of the belt speed increases the amplitude of the first mode vibration and decreases the second mode amplitude.

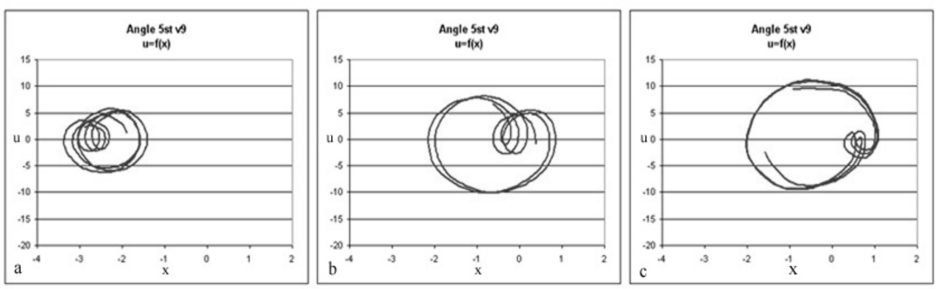

Fig. 8. Experimental phase trajectories (u-speed, x-displacement) for different pressure forces: a) low, b) middle, c) high.

The level of the pressure force between the wheel and the belt also influences the displacement diagrams. With the increase of the vertical force we notice higher amplitude of displacements related to the first, lower frequency mode. The second mode amplitude remains unchanged.

The pressure alteration results in another interesting feature. The phase shift between two modes strongly depends on the contact pressure (Fig. 8). This effect is well visible for small angle values. When α>10°, the phase shift is less influenced by the pressure value.

Conclusions

Experimental investigations of the problem of skew rolling allowed us to prove double periodicity of the lateral motion of the wheel. In the case of small angle α between the wheel plane and the belt rolling direction the phase shift of two modes strongly depends on the contact pressure. For higher values of α this dependency is not so direct. Stick-slip type of vibrations can be noticed for small α. For higher values the stick phase disappears.

Further research will enables us to define the elementary mechanical system which produces displacement/velocity characteristic in time identical with experimental ones. Single degree of freedom system with strongly non-linear friction law applied to the vibrating mass does not allow obtaining satisfactory results. That is why two degree of freedom system seems to be appropriate to result in double periodic vibrations. It coincides with our physical model. First degree of freedom is related to lateral motion of the wheel while the second one corresponds to wheel rotations. Soft coupling is promising in preliminary self excited response investigation.

References

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