EXPERIMENT WITH SLIDING OF LOCOMOTIVE WHEEL SETS

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ABSTRACT

Experimental studies presented in the article have revealed that the unevenness of movement of the individual parts of the train during its driving along the rails leads to appearance of shocks that could cause sliding. The peculiarity of the proposed method of controlling the situation is that the absolute motion of the locomotive with respect to the fixed system is determined, its speed is set, according to the change of which sliding is calculated, since just decrease in speed when driving in traction mode indicates the occurrence of deviations.

Keywords: *railway, locomotive, wheel, rail, tangential traction force, speed, acceleration, inertia force, drag force, absolute and relative sliding speed.*

Background. *Among the works devoted to the study of sliding of wheel sets, one of the most famous belongs to N. N. Menshutin [1]. It describes the scale experiments conducted in the real operating conditions of the locomotive in the late 1950s. And then it was found that the relative sliding rate, equal to 1,5–2 %, corresponds to the maximum in adhesion and does not depend on speed of the locomotive. The peculiarity of those experiments was that the sliding speed was determined on the basis of a comparison of speeds of two wheel sets, one of which was loaded by the traction moment, while the other had a traction motor switched off.*

In a number of studies, various problems of the theory and practice of adhesion and sliding are considered [2, 3]. In work [4] it is asserted that the speed of sliding of a wheel set depends essentially on the technical condition of the track, in particular its longitudinal stiffness.

Objective. *The objective of the authors is to consider sliding of locomotive wheel sets on the experimental basis.*

Methods. *The authors use general scientific and engineering methods, experiment, mathematical apparatus, comparative analysis.*

Results. *In our case, we propose a method for studying the sliding of wheel sets of a locomotive, consisting of the following:*

– the law of the absolute motion of a locomotive relative to a fixed coordinate system is determined experimentally:

$$S' = f_1(t), \qquad (1)$$

where S′ is displacement of a locomotive, m;

– then, based on this dependence (1), locomotive speed (m / s) is fixed:

$$V' = \frac{dS'}{dt} = f_2(\mathrm{t}); \qquad (2)$$

– further, acceleration of a locomotive is determined as a magnitude of change in speed (m / s²):

$$a' = \frac{dV'}{dt} = f_3(\mathrm{t}); \qquad (3)$$

– areas are identified on which acceleration is negative (that is, sliding occurs).

Below is an example of a study of sliding performed on Ulan-Ude station tracks in a straight horizontal section at a temperature of +8°C in dry weather. The freight train was tested with a mass of 4370 tons with the locomotive VL-80ᴾ while starting.

The work was carried out in the following sequence:

– on the bodies of the locomotive and the first car, measuring tapes with sensitivity of 1 mm were fixed (Pic. 1);

– against them, on fixed supports, two digital cameras were fixed;

– according to the sound signal of the driver for departure, digital cameras were switched on and digital recording of movement of the locomotive and the first car (Pic. 1 shows two photographs of the measuring tape after a time interval of 0,25 s).

Thus, the distance covered by the locomotive over this time:

ΔS′ = 147,5–138,2 = 9,3 mm = 0,0093 m.

Average speed of the locomotive in this time interval:

$$V' = \frac{\Delta S'}{t_2 - t_1} = \frac{\Delta S'}{\Delta t} = \frac{0,0093}{0,25} = 0,0372\ m/\mathrm{s}.$$

Looking through the frame-by-frame video recording, we make reading of the main parameters:

– time t_i of this frame;

– the corresponding coordinate S_i' of the position of the locomotive and the coordinate S_i'' of the position of the first car;

– time t_{i+1} of the next frame;

– the corresponding coordinate S_{i+1}' of the position of the locomotive and the coordinate S_{i+1}'' of the position of the first car.

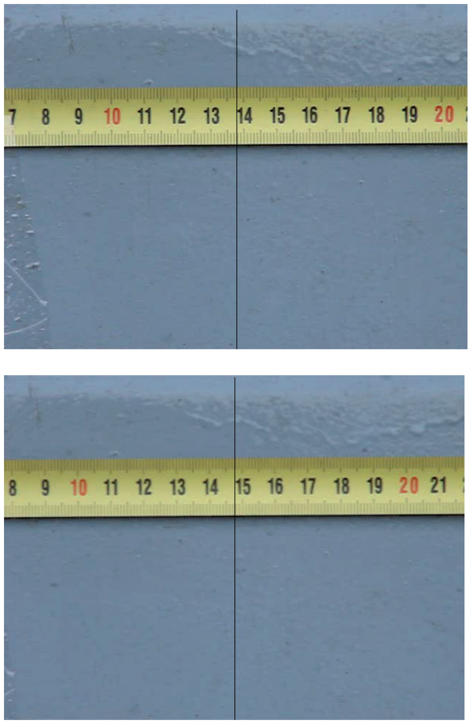
Next, we calculate average speed of the locomotive and the car in the time interval from t_i to t_{i+1}:

$$V_i' = \frac{S_{i+1}' - S_i'}{\Delta t}, \quad V_i'' = \frac{S_{i+1}'' - S_i''}{\Delta t}. \qquad (4)$$

Then we read from the video recording the coordinates of the locomotive S_{i+2}' and the car S_{i+2}'' at time t_{i+2}.

After that we calculate average speed of the locomotive and the car in the time interval from t_{i+1} to t_{i+2}:

$$V_{i+1}' = \frac{S_{i+2}' - S_{i+1}'}{\Delta t}, \quad V_{i+1}'' = \frac{S_{i+2}'' - S_{i+1}''}{\Delta t}. \qquad (5)$$



Pic. 1. Photographs of locomotive position in 0,25 s.

We find acceleration of the locomotive and the car in this time interval:

$$a'_{i+1} = \frac{V_{i+1}' - V_i'}{\Delta t},$$

$$a''_{i+1} = \frac{V_{i+1}'' - V_i''}{\Delta t}. \qquad (6)$$

We perform calculations in Excel and summarize the results in Table 1.

When comparing the previous and subsequent speeds of the locomotive V_i' and V_{i+1}' the following options are possible.

1st option: $V_i' > V_{i+1}'$.

In this case, acceleration of the locomotive is directed towards movement, and inertia force is opposite to it. Based on the d'Alembert principle, we have:

$F_k - R - F = 0$ (7)

where F_k is tangential traction force; R is resistance force; F is inertia force.

We transform the equation (7):

$F_k - R = F.$

Conclusion: the locomotive moves with acceleration in the normal traction mode.

2nd option: $V_i' < V_{i+1}'$.

Here acceleration of the locomotive,

$$a' = -\frac{V_{i+1}' - V_i'}{\Delta t},$$

will be negative and directed opposite to the direction of motion. The inertia force in this case coincides with the direction of motion. Based on the principle of d'Alembert, we get:

$F_k - R + F = 0;$ (8)

$F_k - R = -F.$ (9)

Hence, tangential traction force is less than resistance to motion. The equation (8) can be satisfied when:

– tangential traction force decreases F_k, i.e. sliding occurs;

– resistance to motion R increases.

Suppose that the force F_k has not changed. Then the resistance force will be $R = F_k + F$. This is unlikely, therefore it remains to assume that the tangential traction force has decreased and sliding has occurred.

Analyzing the results of Table 1, we can draw the following conclusions:

1. If acceleration of the locomotive and the first car are positive (in the table at t = 3,25 s), then they move in normal traction mode. In this case, the tangential traction force $F_k = R+F$. The inertia force of the train becomes part of the force R of resistance to its motion. There is no sliding.

2. If acceleration of the locomotive is negative, and acceleration of the first car is positive (for example, at t = 3,5 s), then the tangential traction force $F_k = R-F$. In this case, the resistance force increases due to the inertia force of the train, tangential traction force decreases due to sliding, and the absolute value of sliding speed appears as

$$V_c = V'_{3,25} - V'_{3,5} = 0{,}140 - 0{,}132 = 0{,}012\ m/s.$$

It should be noted that V_c is some average speed of sliding of all locomotive wheel sets, a value to some extent conditional, but very significant for the practice of conducting the train.

The relative speed of sliding can roughly be taken as:

$$v_c = \frac{V_c}{V_i'} = \frac{0{,}012}{0{,}14} \cdot 100\% = 8{,}57\%.$$

And it makes sense to recall: in [1] it was pointed out that at low speeds the relative sliding speed is more than 2 %.

Conclusion. *The proposed method makes it possible to determine with absolute accuracy the absolute and relative rates of sliding of wheel sets of*

Table 1

Time	Locomotive movement	Car movement	Difference in movements of locomotive and car	Locomotive speed	Car speed	Locomotive acceleration	Car acceleration
t, (sec)	S_i', (m)	S_i'', (m)	$S_i' - S_i''$, (m)	V_i', (m/s)	V_i'', (m/s)	a_i', (m/s^2)	a_i'', (m/s^2)
1	2	3	4	5	6	7	8
0	0	0	0	0,004	0	0	0
0,25	0,001	0	0,001	0,008	0,004	0,016	0,016
0,5	0,003	0,001	0,002	0,018	0,004	0,04	0
0,75	0,0075	0,002	0,0055	0,028	0,004	0,04	0
1	0,0145	0,003	0,0115	0,028	0,008	-5,6E-17	0,016
1,25	0,0215	0,005	0,0165	0,016	0,016	-0,048	0,032
1,5	0,0255	0,009	0,0165	0,026	0,024	0,04	0,032
1,75	0,032	0,015	0,017	0,022	0,028	-0,016	0,016
2	0,0375	0,022	0,0155	0,03	0,02	0,032	-0,032
2,25	0,045	0,027	0,018	0,056	0,024	0,104	0,016
2,5	0,059	0,033	0,026	0,08	0,028	0,096	0,016
2,75	0,079	0,04	0,039	0,096	0,032	0,064	0,016
3	0,103	0,048	0,055	0,128	0,068	0,128	0,144
3,25	0,135	0,065	0,07	0,14	0,08	0,048	0,048
3,5	0,17	0,085	0,085	0,132	0,12	-0,032	0,16
3,75	0,203	0,115	0,088	0,12	0,136	-0,048	0,064
4	0,233	0,149	0,084	0,116	0,136	-0,016	2,22E-16
4,25	0,262	0,183	0,079	0,096	0,14	-0,08	0,016
4,5	0,286	0,218	0,068	0,1	0,112	0,016	-0,112
4,75	0,311	0,246	0,065	0,104	0,112	0,016	4,44E-16
5	0,337	0,274	0,063	0,116	0,108	0,048	-0,016

the locomotive and on its basis to develop a device for automatic prevention of sliding.

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