Dynamic Interaction of the TE-33A Diesel Locomotive and the Track in a Curve with a Radius of 600 Meters

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***Abstract*—This article deals with the indicators of dynamic properties that ensure road safety, compliance with the rules of maintenance and servicing were determined, with geometric labelling, the forces acting on the crew were not determined, but it was assumed that they affect the position of the crew in the curve. The loads on each axle of the locomotive were calculated taking into account the weight of the TE-33A. In order to determine the forces acting on the crew and the path as a function of the stationary movement speeds along the curve, the so-called dynamic insertion of the crew into the curve is carried out. As part of the study, the indicators of frame forces and the coefficients of vertical dynamics of the first suspension stage of the TE-33A locomotive were determined when passing through a curve with a radius of 600 m at speeds of 40, 60, 85, and 100 km/h. At the same time, the largest forces acting on the crew were determined. At the same time, the largest forces were determined, which occur during the movement of this TE-33A locomotive along the curve, when individual elements of the locomotive (wheel pairs, wagon, body) perform complex movements when traveling in the transition curve. As a result of the experimental tests, it was found that the obtained frame force indicators and dynamic indicators of the first stage of the suspension of the TE-33A diesel locomotive meet all the requirements of the permissible standards.**

***Keywords*—railway track, diesel locomotive, wheelset, dynamic indicators, dynamic comfort of locomotive**

I. Introduction

To study the dynamic properties of the crew, its mechanical model consists of solid or deformable bodies connected by means of certain elements, specifying the geometric characteristics of the crew. Then, using the methods of mechanics, a mathematical description of the model is created in the form of a system of differential equations for its motion. The model together with the system of differential equations is called mechanical-mathematical or dynamic. The dynamic model should reflect the basic properties of the system in question to the extent that it can be used to assess the dynamic properties of the crew with the required accuracy. The crew model is characterized by a number of parameters: Inertial properties (masses of individual bodies and their moments of inertia), properties of articulated elements (stiffness and damping indicators), geometric dimensions [1].

The investigation object of this work is a mainline freight locomotive TE-33A with asynchronous traction motors and electric drive. The locomotive was manufactured by the Joint-Stock Company “Locomotive Kurastyru Zauyty” in Astana in 2010. The axial formula of the locomotive is 30–30. Design load from the axle to the rails is (227.65 ± 2%) kN. The service weight of the locomotive is (138 ± 2%) tonne. The construction speed is 120 km/h. The locomotive is designed to work with freight trains and has a two-stage spring suspension. The static deflection of the first stage of suspension is 131.5 mm.

II. Literature Review

The second stage of the suspension consists of a central and two lateral return supports (on the carriage). The static deflection of the central support is 13.7 mm, that of the lateral supports 10.3 mm. The first stage consists of coil springs, the second stage of rubber–metal blocks. The tractive and braking forces from the trolleys to the car body are transmitted via the pin. The locomotive uses axial suspension of the traction motors and motor axial roller bearings. The bogie frame is connected to the wheel pairs via the shoe boxes [2, 3]. To determine the dynamic properties, a kinematic diagram of the TE-33A diesel locomotive was created (see Fig. 1).

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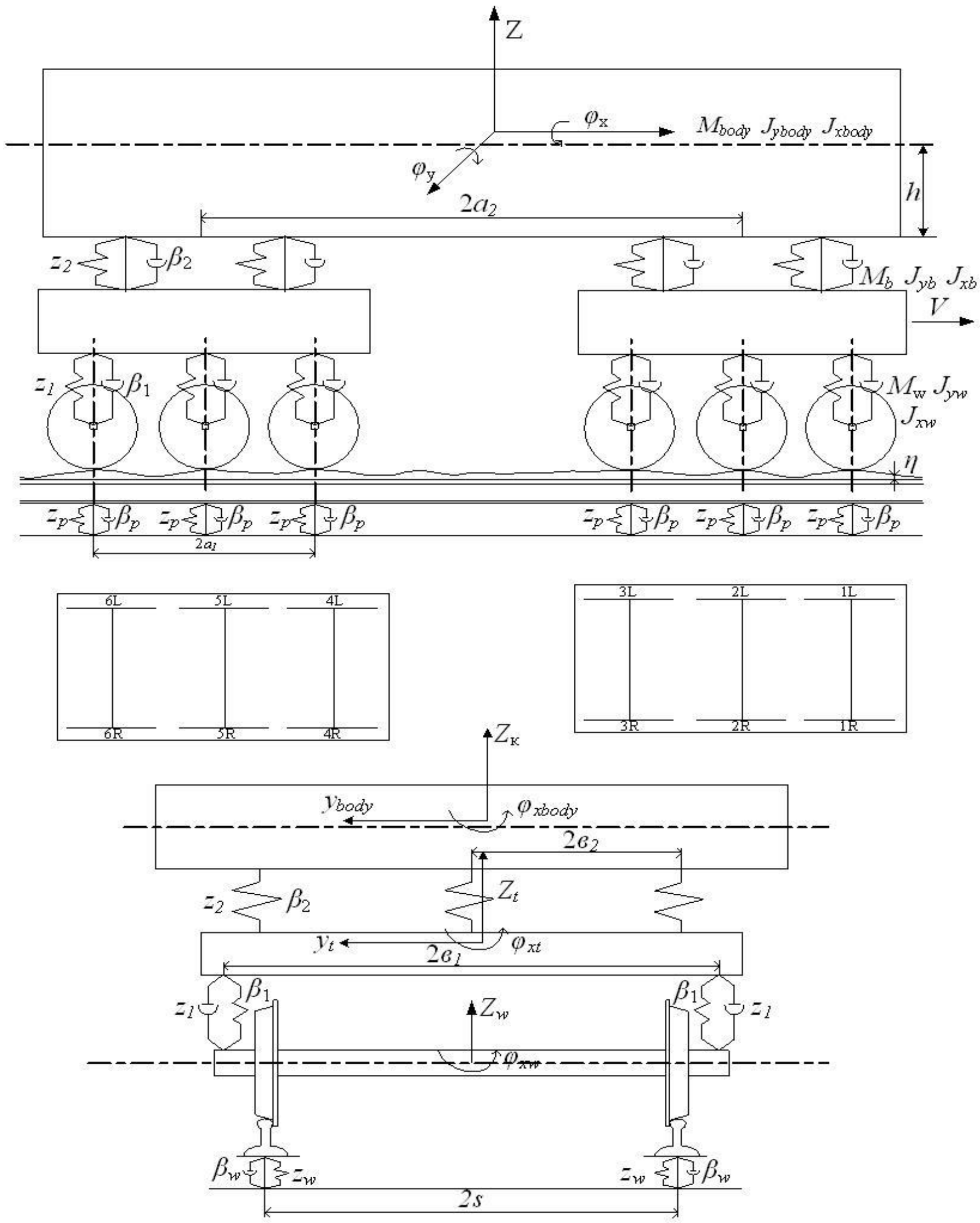

Fig. 1. Kinematic diagram of the TE33A diesel locomotive model.

On the calculated kinematic scheme, the following designations are accepted:

M_{body}, M_t—mass of the body and track;

M_b – sprung mass of bogies;

M_w – masses of wheelsets;

J_{ybody}, J_{xbody}—moments of inertia of the body relative to the *y* and *x* axes;

J_{yb}, J_{xb}—moments of inertia of bogie frames relative to the *y* and *x* axes;

J_{yw1}, J_{xw2}—moments of inertia of the wheel pairs of the first and second bogies relative to the *x* axis;

β_1—the damping factor in the box stage of the spring suspension;

z_1—rigidity of the box stage of the spring suspension;

β_2—the damping coefficient in the central stage of the spring suspension;

z_2—rigidity of the central stage of the spring suspension;

β_w—attenuation coefficient in the way;

z_p—rigidity of the path;

$2a_2$ and $2a_1$—the base of the body and bogies;

$2b_2$ and $2b_1$—the distance between the elastic and dissipative elements of the central and pedestal stages of the spring suspension across the track axis;

$2s$—the distance between the points of contact with the rails of the wheels of one wheel pair;

η_r and η_l—equivalent geometrical irregularities on the right and left rails, taken as a disturbance.

III. Materials and Methods

In the first phase, the weight indicators of the locomotive were determined under stationary conditions.

Strain gages were glued to the side walls of the frame of the first carriage to measure the frame forces. The strain gages of the two wheel sets on the left and right were included in a bridge circuit. These systems were then calibrated using a special device. To measure other dynamic indicators, the locomotive was equipped with displacement sensors [4, 5]. The dynamic performance of the locomotive and the level of its impact on the upper structure of the track and the switches were measured on the existing main tracks of the company “Kazakhstan Temir Zholy”.

Prior to the start of testing, the locomotive was operated in the Almaty Operational Locomotive Depot.

By the beginning of the tests, the mileage of the locomotive was 111.07 km. The weight indicators of the locomotive were measured at the locomotive-building plant “Locomotive Kurastyru Zauyty”, in Astana. Weighing was carried out at the station for the control of the distribution of diesel locomotives LLP “Salmak”, having certificate No. 937 dated 01.08.07 issued by the Department of Standardization, Metrology and Certification of JSC “National Center for Expertise and Certification”. The station has a certificate of verification No. 02/1647. The results of weighing the locomotive are shown in Table I.

TABLE I. DIESEL LOCOMOTIVE WEIGHING DATA, KN

Sides	Wheelset Number						Total
	1	2	3	4	5	6	
Right Side	111.92	112.99	111.92	115.93	114.27	114.46	681.49
Left Side	113.58	114,56	114.27	116.23	113.19	118.38	690.21
Total	225.50	227.55	226.19	232.16	227.46	232.84	1371.70

According to Table I, the actual weight of the locomotive is 1371,70 kN.

- deviation of the actual value of the locomotive weight from the calculated value:

$$\delta = \frac{P_a - P_p}{P_p} \times 100\% = \frac{1371.70 - 1352.40}{1352.40} \times 100\% = 1.43\ \% \quad (1)$$

where P_a—actual weight of the locomotive;

P_p—the project weight of the locomotive.

The project weight of the locomotive is defined as the product of the service weight of the locomotive by 9.8. Deviations of the actual load value from each wheelset on the rails from the value specified in the technical specification are calculated by the Eq. (1) [6]. At the same time, it is indicated: P_a is the actual value of the load from each wheel on the rail, P_p is the value of the load from each wheel on the rail specified in the terms of reference.

- the difference of loads on the wheels of the wheelset according to the formula:

$$\delta = \frac{P_{max} - P_{min}}{P_{max} + P_{min}} \times 100\%, \quad (2)$$

where P_{max}—the highest value of the load from the wheel to the rail;

P_{min}—the lowest value of the load from the wheel on the rail.

The calculation results are summarized in Table II.

TABLE II. DEVIATION OF THE ACTUAL VALUE OF THE LOAD OF EACH WHEELSET ON THE RAILS AND THE DIFFERENCE IN THE LOADS ON THE WHEELS OF THE WHEELSET %

No of Wheelset	Deviation	Load Difference
1	0.95	0.74
2	0.04	0.69
3	0.60	1.04
4	1.98	0.13
5	0.09	0.47
6	2.28	1.68

- the difference of loads along the axes in one trolley according to the formula:

$$\delta = \frac{F_{max} - F_{min}}{F_{max} + F_{min}} \times 100\%, \quad (3)$$

where F_{max}—the greatest value of gravity acting on the rail along the axes of one trolley;

F_{min}—the smallest value of gravity acting on the rail along the axes of one trolley.

- the load difference on the sides of the locomotive according to the formula:

$$\delta = \frac{P_{max} - P_{min}}{P_{max} + P_{min}} \times 100\%, \quad (4)$$

where P_{ma}—the greatest value of gravity acting on the rail on the sides of the locomotive;

P_{min}—the lowest value of gravity acting on the rail on the sides of the locomotive.

The load difference on the sides of the locomotive is 0.64%.

The data obtained show that the distribution of the locomotive meets the requirements of the OST 02-98 standard [7, 8]. However, the deviation of the actual load value from the sixth wheelset on the rails from the value specified in the technical specification exceeds 2%. Thus, according to this indicator, the locomotive does not meet the requirements of the technical specification.

At the stage of preparing the locomotive for sea trials, the parameters of the locomotive were measured by a specialist of the plant “Locomotive Kurastyru Zauyty”. The locomotive is equipped with hydraulic dampers of the company “Koni”. The nominal parameters of hydraulic dampers are given in Table III.

TABLE III. PARAMETERS OF HYDRAULIC DAMPERS

Purpose and Designation	Quantity (Pieces)	V_n, (m/s)	F_C, (N)	F_C, (N)
The first stage is vertical 02A 2077	8	0.1	7,000	7,000
Decongestants	2	0.1	7,000	7,000
Anti-militant 04R1769	4	0.012	15,000	15,000

IV. RESULT AND DISCUSSION

To measure the level of the locomotive's impact on the track in curved sections of the track with a radius of 600–800 m, a section on an even track of 113 km of the stage "Yerkenshilik"—"Yereimentau" was selected. The dynamic parameters of the locomotive were determined at the same site. On the site, the track is laid with rails R65 on reinforced concrete sleepers with lashes of 800 m. crushed stone ballast. Plot of sleepers 2000 pcs/km [9]. The reduced deterioration of the rails does not exceed 6 mm. At the fifth picket 40 days before the start of chassis trials, 10 reinforced concrete sleepers were replaced with wooden sleepers. According to the results of the passage of the track measuring car, the condition of the track corresponds to the assessment "good." Before the chassis trials, manual measurements of the track width, the elevation of the outer rail and the boom of the curve chord were performed [10, 11]. The 20 m long chord boom was measured in the middle of the chord with an interval of 2 m. Based on the obtained data, Fig. 2 is constructed. to calculate the radius of the curve, the following formula was used:

$$R = \frac{1000a^2}{8f} \tag{5}$$

where a—chord, m;

f—bending arrow, mm.

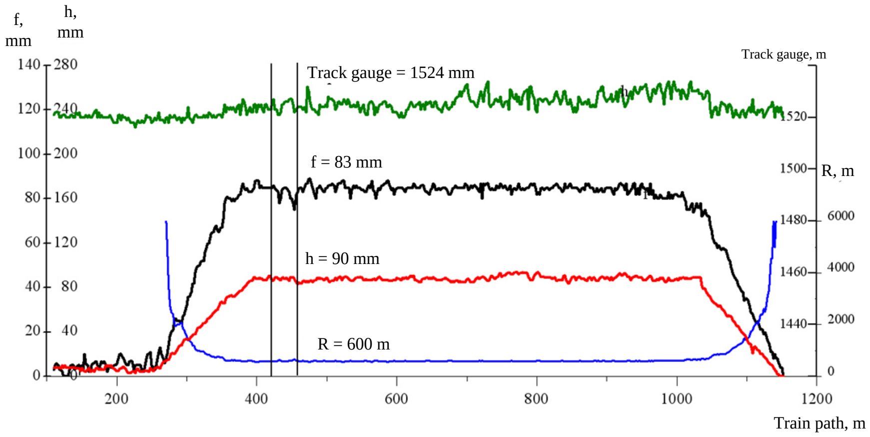

Fig. 2. Parameters of a curved section of the path with a radius of 600 m.

As can be seen from Fig. 2, the elevation of the outer rail on the selected section is 90 mm, the radius of the curve is 600 m. Fig. 3 shows the dependence of the outstanding acceleration on the speed of movement for this section [12, 13]. Calculations are performed according to the formula:

$$\frac{V^2/R - 0.08h}{13} \tag{6}$$

where V – is the speed of movement, km/h;

R – radius of the curve, m;

h – is the elevation of the outer rail, mm.

While testing in a curve with a radius of 600 m, the ambient temperature was from 4 °C to 13 °C. The wind speed wasn't more than 7 m/s.

The arrivals were carried out at speeds of 40, 60, 85 and 100 km/h.

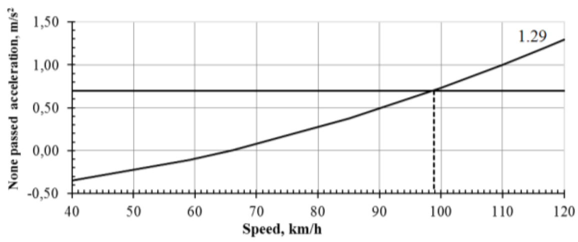

Fig. 3. None passed acceleration in a curve with a radius of 600 m.

The data for determining the estimated values of the frame forces, the coefficients of vertical dynamics of the first and second stages of suspension were processed according to the same method as for the switch and the straight section of the track [14, 15]. The vertical dynamics coefficient was determined without taking into account quasi-static components.

The results of processing are shown in Figs. 4 and 5 and Table IV.

TABLE IV. The Coefficient of Vertical Dynamics of the First Stage of Suspension During the Movement of a TE-33A Locomotive in a Curve with a Radius of 600 m

Value	Speed (km/h)	Direct course		Wheelset Number		Return course	
		1		3	1		3
		left	right	left	left	right	left
Maximum Probable	40	0.13	0.10	0.10	0.11	0.11	0.09
	60	0.11	0.11	0.13	0.16	0.17	0.16
	85	0.18	0.13	0.16	0.20	0.17	0.19
	100	0.20	0.21	0.15	0.25	0.19	0.21
Maximum Observed	40	0.09	0.08	0.07	0.10	0.09	0.07
	60	0.10	0.10	0.11	0.14	0.14	0.13
	85	0.16	0.12	0.14	0.17	0.14	0.16
	100	0.19	0.19	0.14	0.22	0.16	0.18

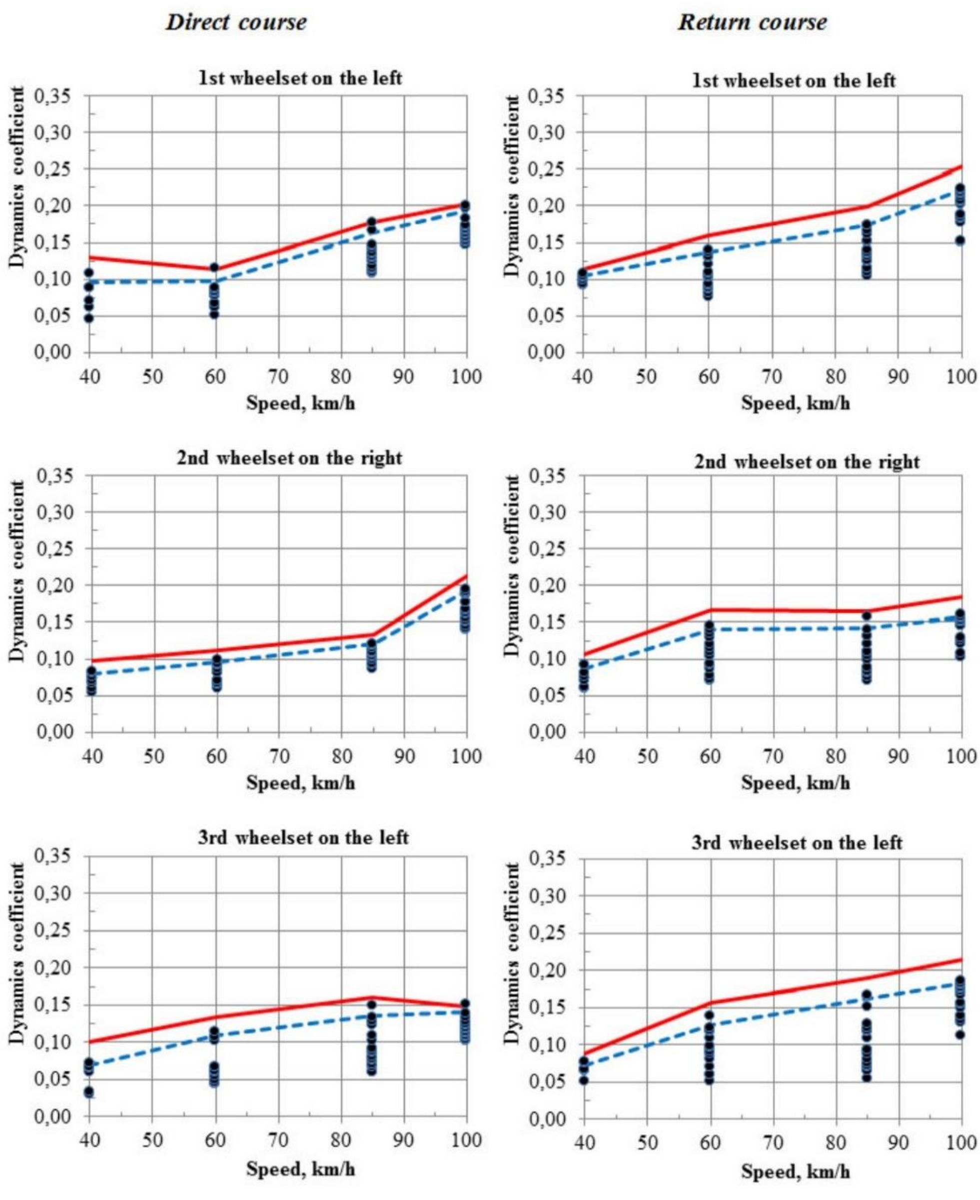

Fig. 4. The coefficient of vertical dynamics of the first stage of suspension during the movement of a TE-33A locomotive in a curve with a radius of 600 m.

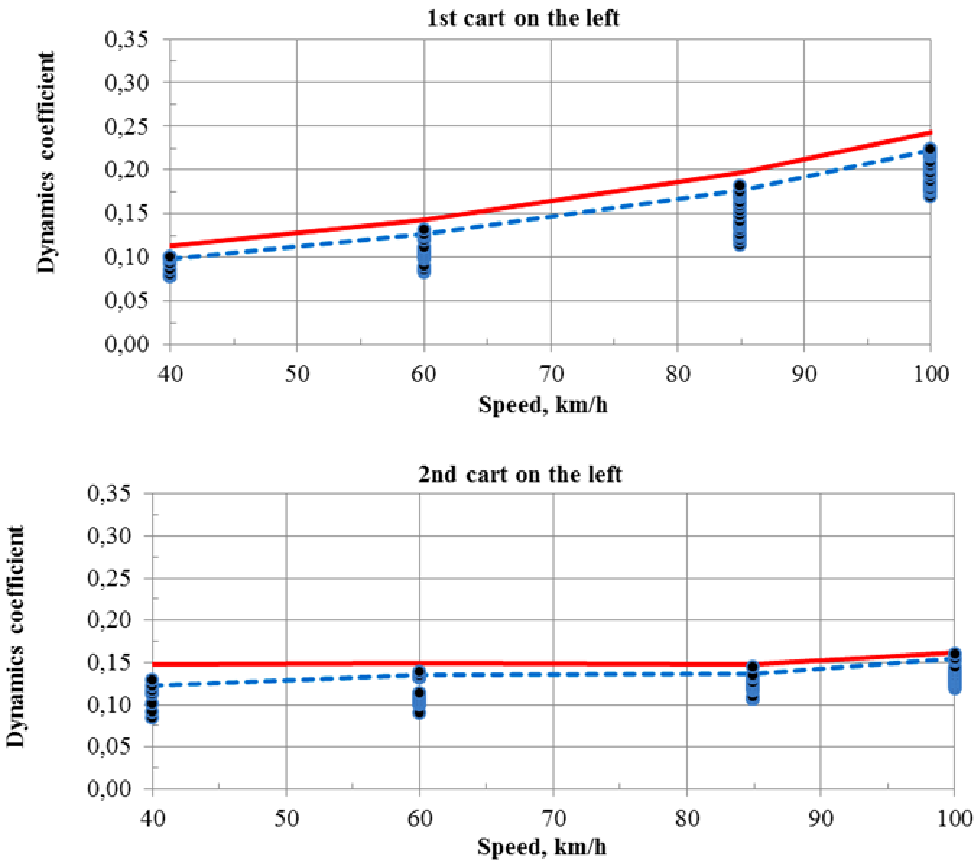

Fig. 5. The coefficient of vertical dynamics of the second suspension stage during the movement of the locomotive TE-33A along a curve with a radius of 600 m.

Frame forces and coefficients of vertical dynamics of the first and second stages of suspension of the locomotive in a curve of radius 600 m in the studied speed range meet the requirements of permissible norms [12, 16]. It is noteworthy that the level of the vertical dynamics coefficient of the second stage differs significantly in different directions of movement. With forward running at a speed of 100 km/h, the vertical dynamics coefficient of the second stage almost reaches the upper limit of permissible values (0.24), and with reverse running does not exceed 0.16.

The coefficient of stability margin against wheel derailment in a curve with a radius of 600 m was determined by the same method as for a straight section of track [17, 18]. The obtained dependence of the coefficient of stability margin against wheel derailment on the speed of movement is shown in Fig. 6.

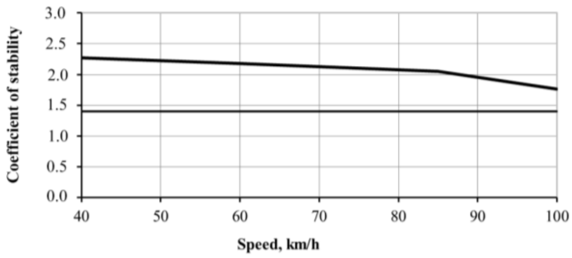

Fig. 6. Coefficient of stability against wheel derailment in a curve with a radius of 600 m.

As can be seen from Fig. 6, the minimum value of the coefficient of stability against wheel derailment in a curve with a radius of 600 m is 1.8 at a speed of 100 km/h [19, 20]. Fig. 7 shows the location of the sensors along a curve with a radius of 600 m.

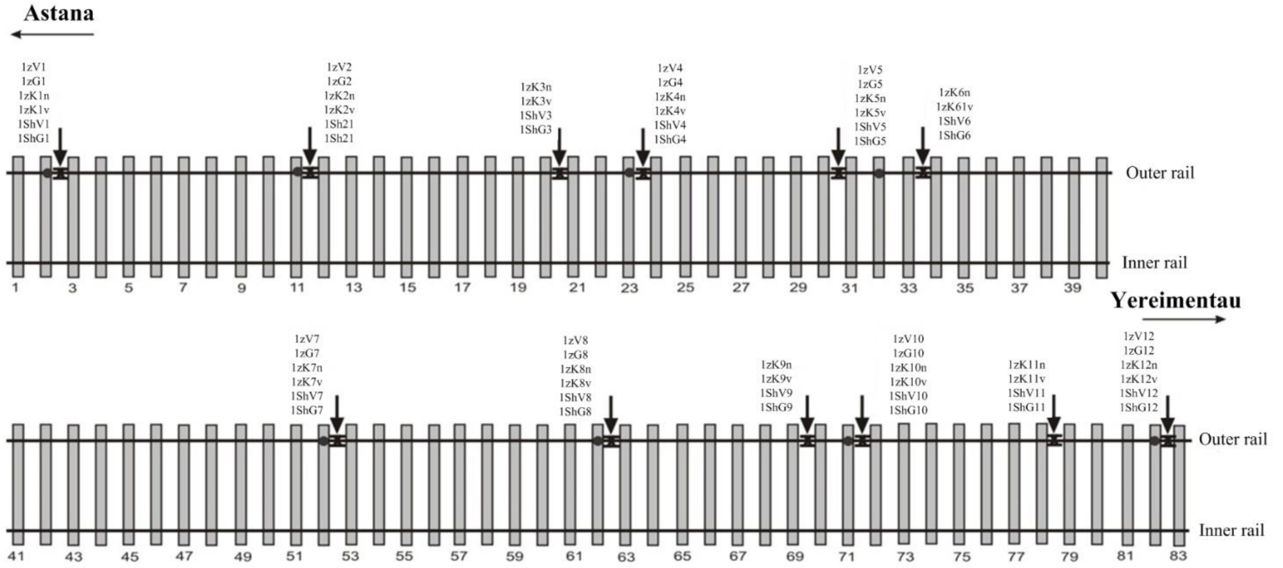

Fig. 7. The layout of the sensors in a curve with a radius of 600 m.

V. Conclusion

When running in a curve with a radius of 600 m, the frame forces and the coefficients of vertical dynamics therefore meet the requirements of the permissible standards over the entire range of test speeds.

Taking into account the weight data of the TE-33A series locomotive, parameters such as the speed and acceleration of this locomotive were determined using experimental and mathematical methods.

Using an experimental method, at speeds of 40, 60, 85 and 100 km/h, the indicators of frame forces and the coefficients of vertical dynamics of the first stage of the suspension were determined when travelling through a curve with a radius of 600 m.

It was found that the indicators of frame forces and dynamic indicators of the first stage of the suspension of the TE-33A locomotive meet all the requirements of the permissible standards.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

SA organization and management of research, writing of the manuscript; GB experimental work, computer processing and correction of the manuscript, communication with the editorial board of the journal; AK assistance with computer processing of the manuscript; NS literature review and analysis of methods; NT-K analysis of methods and execution of calculations; all authors had approved the final version.

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