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Increasing the Dynamic Characteristics of the Locomotive by Changing the Position of the End Coils of the Springs of the Body Spring Suspension

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ABSTRACT

The article presents the results of a study of the influence of the position of the end coils of the springs of the locomotive body spring suspension on their static deflection and on the parameters of the elastic transverse connection of the bogie with the body, which depends on angular movement of the end coils when a locomotive negotiates curves of different directions, to improve the dynamic qualities of the electric locomotive.

Consideration of various options for installing body springs with the method of mathematical modelling using a computer-aided design software package has resulted in the rationale and description of the optimal version of the position of the end coils of the springs allowing to improve dynamic qualities of the locomotive thanks to the least resistance to bogie rotation, to the symmetry of the restoring torque and to favourable curve negotiation by locomotive thus reducing the wear rate of the flanges of the wheel tires.

It has been established that if the position of end coils is optimal, the direction of coiling of body springs does not have a significant effect on the symmetry of the restoring torque when the bogie negotiates the curves of different directions.

Keywords: *railway transport, body suspension, transverse connection, body spring, end coil, static deflection, restoring torque, lateral force, dynamic characteristics of the locomotive, flange wear.*

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INTRODUCTION

The underframe is part of the design of the locomotive, ensuring its movement along a rail track, and is a carriage with wheelsets on which the necessary power and auxiliary equipment is located. The underframe is the main body structure of the locomotive directly ensuring its movement.

The underframe is subject to a number of mandatory design requirements and maintenance conditions during operation, which include the ability:

• To move on straight and curved sections of the track without causing overloads in structural elements.

• To maintain the strength of components and parts throughout their service life.

• To protect equipment against harmful effects of vibrations and the external environment.

The bogies perceive traction and braking forces, lateral, horizontal and vertical forces when the locomotive passes uneven tracks and transmit them through spring supports to the body frame. The transverse connection of the bogie frame with the body is carried out due to the transverse compliance of the body springs and the stiffness of the springs of stop pins, which also provide the ability to rotate the bogie in curved sections of the track and dampen various forms of vibration of the body [1].

The spring suspension should have the necessary flexibility and the ability to absorb (dampen) vertical and lateral vibrations that occur during movement of an electric locomotive and evenly distribute the loads between the wheelsets and wheels [2].

The so-called dynamic characteristic or qualities of an electric locomotive depend on the design features of the spring suspension and its parameters, as well as on how the oscillating masses of the body and bogie are distributed [2; 3].

The vertical stiffness of the primary suspension (on the wheel) is determined by the total stiffness of the springs and the stiffness of the vertical locking plate sets connected parallel to them. The presence of a parallel connected flexible element (locking plates sets) with significant stiffness does not allow make the primary spring suspension sufficiently soft. Thus, reducing the stiffness of the springs by half leads to a decrease in the total stiffness by only 30 %. To simultaneously ensure the necessary strength of the springs, their overall dimensions would have to be significantly increased, which is impossible. To reduce the dynamic impact of forces acting on the locomotive from the track and to increase the efficiency of damping vertical vibrations of its underframe, the spring suspension of the locomotive is carried out as two-stage suspension. The secondary suspension consists of flexible side supports, through which the weight of the body is transferred to the bogie frames. The location of the side supports, and the stiffness of the secondary suspension are determined by the conditions for the rational use of the adhesion weight (weight on the driving wheels) of the locomotive when applying tractive force [4], the selection of the optimal damping torque that dampens the horizontal vibrations of the locomotive, and the rational perception of the body weight by the bogie frame.

The objective of the study, the results of which are presented in this article, was to determine the optimal option for installing the end coils of springs of the flexicoil type for a body spring suspension from the point of view of increasing the dynamic characteristics of an electric locomotive.

The work was carried out using the mathematical modelling method including the application of the universal MathCAD software, the Siemens NX10 software package based on the finite element method and using the linear static analysis.

RESULTS

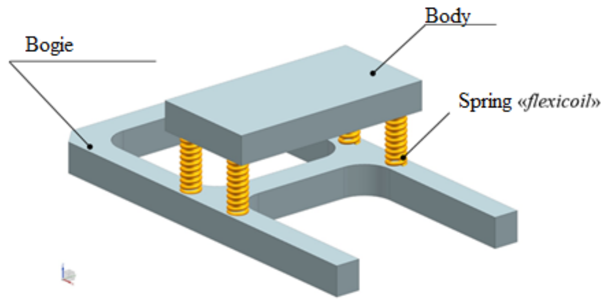
Assessment of the Influence of the Position of the End Coils of Body Springs on the Dynamic Characteristics of the Locomotive

The modern options for spring suspension for traction rolling stock comprise technical solutions, the use of which is associated with operation of springs regarding transverse (shear) loads [5]. An example is the body suspension used on electric locomotives of the 2ES6 series, made through four flexicoil springs on each bogie (two on each side). The connections between the body and the bogie frame are designed to transmit all types of forces between the body frame and the bogie. Rotation of the bogie relative to the body in curved sections of the track causes transverse deformation of the end coils of the springs, while the bogie is subject to a restoring

Table 1

Properties of the flexicoil spring [performed by the authors]

Designation	Name	Value
Steel	60C2XA	
G	Shear modulus	78 kN/ mm²
E	Modulus of normal elasticity	196 kN / mm²
d	Spring rod diameter	46 mm
D	Average spring diameter	197 mm
n	Number of operating coils	9
n_1	Total number of coils	11
h_0	Free height of spring	650 mm
F_1	Calculated vertical static load on spring	66,2 kN
s_1	Calculated static spring deflection under load F_1	105 mm
C	Longitudinal spring stiffness	640 N/ mm
C_Q	Lateral spring stiffness	123 N/ mm
h_1	Spring height under calculated static load F_1	549 mm
m	Spring mass	79 kg



Pic. 1. 3D model of the design of the body spring suspension of the 2ES6 electric locomotive [performed by the authors].

torque as described in GOST [Russian state standard] 34628–2019 [1] and 2ES6.00.000.00 RE5 [2] operating manual. The position of the end coils of the springs affects the restoring torque caused by transverse deformation of the springs acting on the bogie, on the parameters of the flexible transverse connection of the body with the bogie when the locomotive negotiates curved sections of the track, and can lead to misalignment of the body relative to the bogie frame and uneven distribution of vertical loads along the axes of the wheelsets [2; 6].

Modern computer-aided design software systems, due to the ability to analyse many options for the relative arrangement of structures, components and parts, make it possible to achieve an optimal design solution [3] [7; 8]. When implementing this approach, it is possible to qualitatively and quantitatively assess the influence of the design features of the units and their relative position on the performance of the entire structure [9; 10].

This principle was used to find the optimal option for installing flexicoil type springs in the body spring suspension of electric locomotives of the 2ES6 series. During the design process, three options for the position of the end coils of the body springs in relation to the sides of the bogie frame were studied, including the option recommended in the operating manual for the 2ES6 electric locomotive, with the end coils oriented outside the bogie.

The study allowed assessing of the influence of the position of the end coils of body springs on their static deflection, revealing a relationship

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[2] 2ES6 DC cargo electric locomotive with commutator traction motors. Operating manual. Part 6. Mechanical part. 2ES6.00.000.00 RE5. Yekaterinburg: Publishing house of Ural Locomotives LLC, 2011, 97 p.

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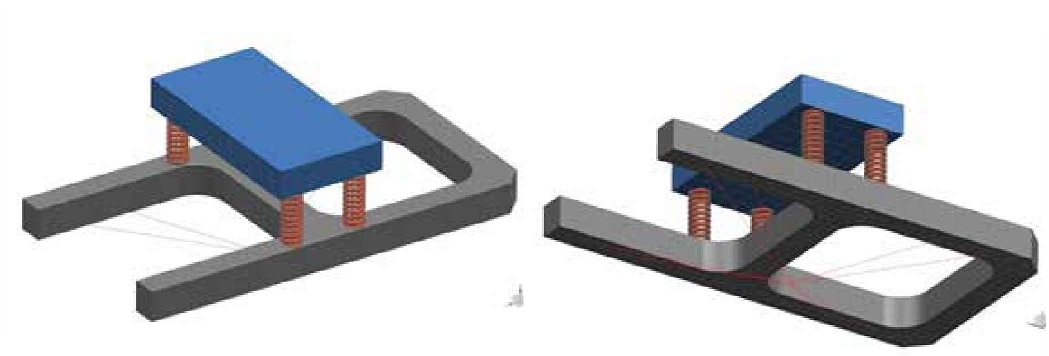


Pic. 2. FEM of the body spring suspension of the 2ES6 electric locomotive [performed by the authors].

between their location and the magnitude of the angular movement of the end coil, which in turn has a significant impact on the resulting transverse deformation of the springs and on the parameters of the flexible transverse connection of the bogie with the body when the locomotive negotiates curved sections of the track [11].

The peculiarity of the design of flexicoil springs is their transverse stiffness, which is five times less than the longitudinal one. This design solution does not prevent the bogie from rotating in curves, and the restoring torque from the transverse deformation of the springs with the correct orientation of the end turns depends on the angle of rotation of the bogie and is equal to 11.75 kN•m/deg^2. Table 1 shows the parameters of the flexicoil body spring.

Study of the influence of the position of the end turns on the parameters of the flexible transverse connection of the locomotive body suspension was carried out using the Siemens NX10 software package [7].

The calculated 3D model of the design of the body spring suspension of the electric locomotive of the 2ES6 series is shown in Pic. 1.

The bogie is represented by a dimensional model, and the body of the electric locomotive is represented as a volumetric mass element with characteristic points for installing body springs. The springs are modelled in full accordance with the design documentation.

To perform the calculation, six finite element models (FEM) were created [12], one of which is shown in Pic. 2.

The other models differ only in orientation of the end coils of the springs relative to the longitudinal axis of the bogie and the direction (depending on the direction of the negotiated curve) of the force Q_m acting on the spring set and tending to rotate the bogie through an angle φ.

The structural elements are modelled with 3D *CTETRA(10)* and *CHEXA(20)* elements.

The installation of the bogie on the axle-box springs was modelled by 1D *RBE2* elements, the dependent nodes of which are connected to the places where the axle-box spring supports are installed on the bogie. The independent unit is located on the axis of rotation of the safety king pin of the electric locomotive and is fixed according to five degrees of freedom (movements along three *XYZ* axes are limited and rotations relative to the *X* and *Y* axis are limited).

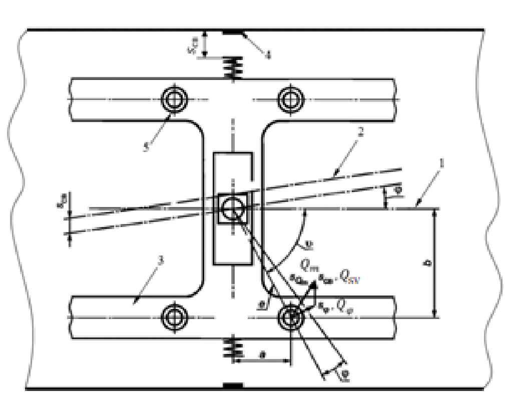
The bogie body simulator is limited along its vertical edges by two degrees of freedom (movements along *X* and *Y* axes are limited).

The contact points of the body springs with the bogie and the body simulator are modelled with a Face Gluing type connection, which is a rigid connection between structural elements that eliminates transverse movements of the end coils of the body springs in the lower guide cups of the bogie frame and in the upper cups of the body frame.

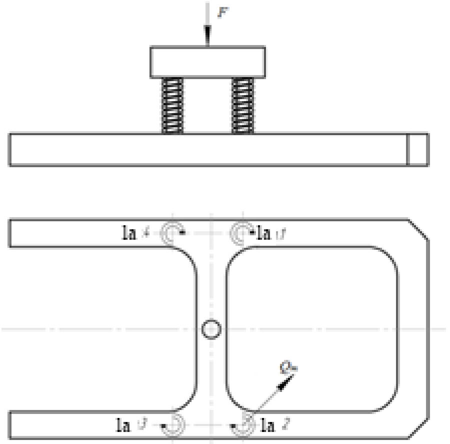
Calculations of the angle of rotation of the bogie relative to the body were carried out using the Siemens NX10 software package, based on the finite element method, and using a nonlinear static analysis.

When an electric locomotive negotiates a curve, the forces $Q_φ$ from the rotation and the forces Q_{sv} from the sideslipping of the bogie act on the set of body flexicoil springs in the transverse direction. These two forces result in the force Q_m, which tends to rotate the bogie through an angle $φ$ (Pic. 3). The reaction to the force Q_m will be the moment of resistance to rotation (restoring torque), tending to return the bogie to its original position.

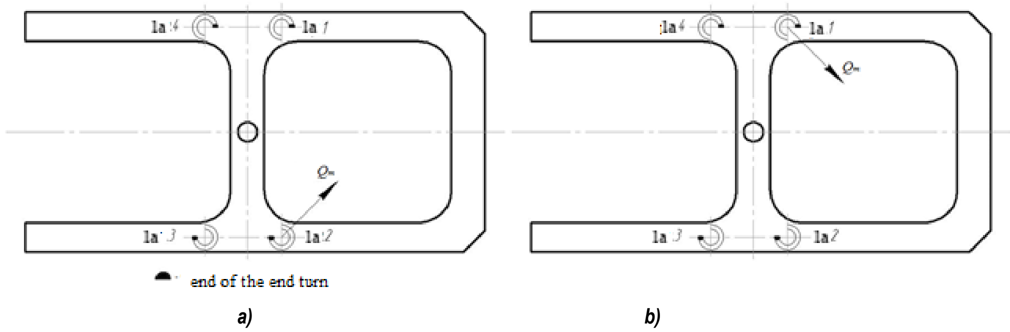
When calculating, we accepted that the vertical static force from the mass of the electric locomotive per spring set of one bogie, $F = 270$



Pic. 3. Calculation diagram of transverse deformations of body springs when the locomotive moves in a curve: 1 – longitudinal axis of the body; 2 – bogie axis during rotation and swaying; 3 – bogie frame; 4 – body bolster; 5 – body spring [performed by the authors].



Pic. 4. Directions of action of design forces [performed by the authors].

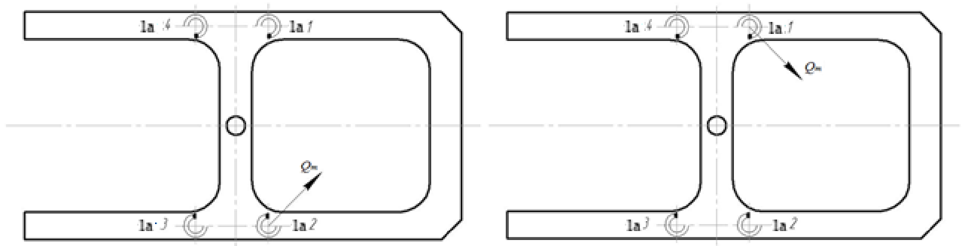


Pic. 5. Design diagram No. 1: a) – movement of the locomotive in the left curve; b) – movement of the locomotive in the right curve [performed by the authors].

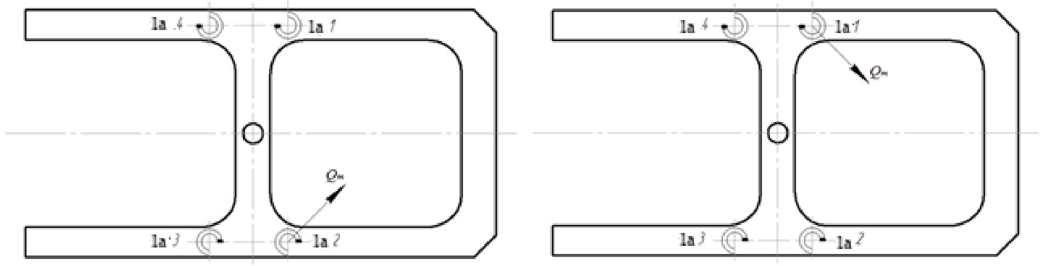
kN, and the transverse force oriented to the longitudinal axis of the bogie at an angle of 315° or 45° depending on the direction of the curve, Q_m = 30 kN (Pic. 4).

Determining the Optimal Option for Installing the End Coils of Springs of the Flexicoil Type for Body Spring Suspension

To find the optimal position of the end coils of the spring set, at which the restoring torque of the bogie will be symmetrical, and the influence of the torsional moments arising in the working coils of the springs under the influence of a vertical static load on the parameters of the transverse elastic connection of the bogie with the body will be minimal [13], three position options were studied while six design cases were accepted depending on the direction of the curve negotiated by locomotive. Design cases and diagrams of the position of the end coils of the springs are shown in Pics. 5–7.



Pic. 6. Design diagram No. 2 [performed by the authors].

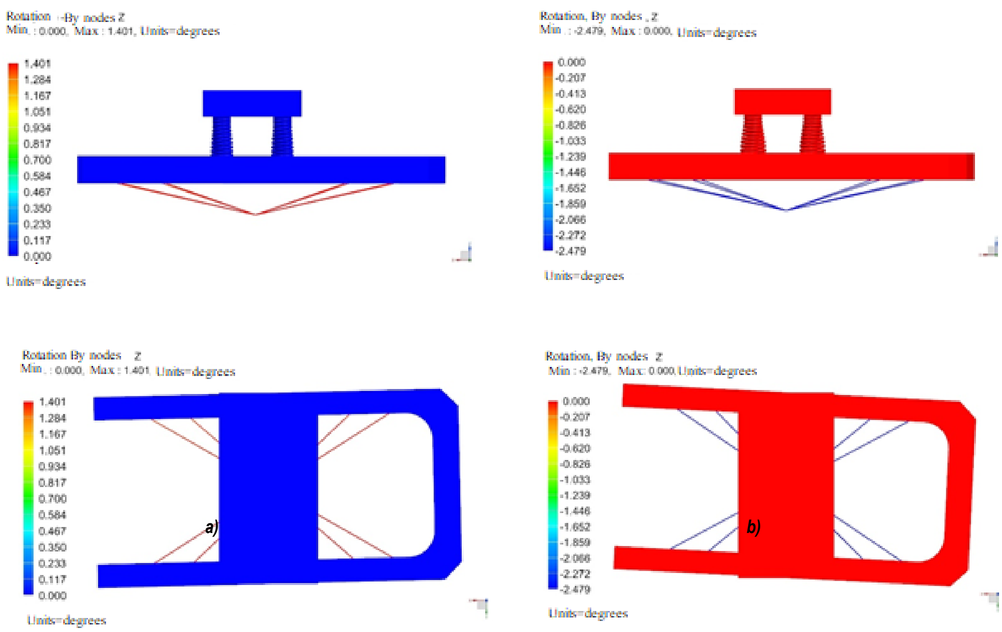


Pic. 7. Design diagram No. 3 [performed by the authors].

Table 2

The value of angles for design diagrams [performed by the authors]

Design diagram	Spring 1	Spring 2	Spring 3	Spring 4
1	0°	180°	180°	0°
2	90°	270°	270°	90°
3	180°	0°	0°	180°



Pic. 8. Fragment of calculating the angle of rotation of the bogie in the Siemens NX10 software package (design diagram No. 1): a) – movement of the locomotive in the left curve; b) – movement of the locomotive in the right curve.

The angles between the longitudinal axis of the bogie and the end of the end coil of the spring are shown in Table 2.

The results of calculating the angle of rotation of the bogie relative to the body of the electric locomotive for all design diagrams and cases are given in Table 3.

The «–» sign is used when the bogie is rotating clockwise, i.e., the locomotive negotiates the right curve.

Taking the example of the design diagram No. 1 (Pic. 5), a fragment of calculating the angle

Table 3

Values of rotation angles of the bogie relative to the electric locomotive body [performed by the authors]

Design diagram	φ, °	Curve direction
1	1,401	left
	–2,479	right
2	2,099	left
	–1,971	right
3	2,215	left
	–1,121	right

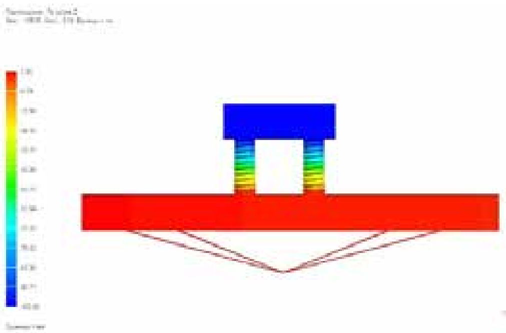


Рис. 9. Фрагмент расчета статического прогиба кузовного пружинного комплекта от действия вертикальной статической силы F в программном комплексе Siemens NX10.

of rotation of the bogie in the Siemens NX10 software package is shown in Pic. 8.

To assess the influence of the position of the end coils of the body springs on their static deflection, as well as to assess the movements of the bogie (angle of rotation) due to unbalanced torsional moments arising in the working coils of the springs from the influence of a vertical static load, the force Q_m was excluded from the FEM and design diagrams. This condition can be interpreted as movement of the locomotive along an ideal straight section of track [14] and used when assembling the mechanical part during the repair process to comply with the regulated parameters of the flexible transverse connection of the bogie with the body and preserve them in operation [6].

The calculation results are shown in Table 4.

One of the fragments of calculating static deflection in the Siemens NX10 software package is shown as an illustration in Pic. 9.

Fragments of calculations of the angles of rotation of the bogie are similar to those presented in Pic. 8.

Taking into account the requirements for the dynamic qualities of the locomotive and with the vertical dynamics coefficient of the second stage of the spring suspension equal to 0,25 (GOST R 55513–2013 [4]), which corresponds to real operating conditions, the longitudinal deformation of the springs increases by 26 mm, the difference in the angles of rotation of the bogie to the left and right along the direction of the curve relative to the electric locomotive body, taking into account the action of the force Q_m, increases by 1,6°, and the angle of rotation of the bogie relative

Table 4

Static deflection values for a set of body springs and the angle of rotation of the bogie under the action of force *F* alone

Design diagram (only force *F*)	Static deflection, mm	φ, °
1	105,50	–0,567
2	105,10	0,1
3	105,58	0,578

to the electric locomotive body under the action of a vertical force *F* alone increases by 0,24°, which has a significant negative impact on the characteristics of the transverse flexible connection of the bogie with the body and contributes to the skewing of the bogie in a curve.

CONCLUSIONS

Thus, the conducted research has resulted in identification of the optimal layout of the end coils of body springs in which, the angular movement of the end coils under the influence of the vertical force from the mass of the body per bogie will be minimal (0,1°), and the restoring torque from the lateral deformation the springs will be symmetrical and the same in value regardless of the direction of the curve of the rail track (Pic. 6).

This orientation of the end coils of the body flexicoil springs contributes to the symmetry of the parameters of the transverse flexible connection of the bogie with the body when the locomotive negotiates the curves of different directions, ensuring a uniform effect on the ridges of the tires of the wheelsets, and does not affect the static deflection of the springs. The same coiling (right) of all four body springs when installed in accordance with design diagram No. 2 (Pic. 6) does not have a significant effect on the bogie's resistance to negotiating the curves of different directions.

The rational installation of the end coils of the body suspension springs alone can reduce the lateral force acting on the tire flange, thereby creating more favourable conditions for the bogie to negotiate the curved sections of the track, which will help reduce the wear rate of the wheelset tire flanges [15–17].

The proposed algorithm for selecting the position of the end coils of body springs can be used for traction rolling stock of all series, which use the similar design solutions for body spring suspension as those used for the 2ES6 electric locomotive.

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