В практиці експлуатації електровозів керування тягових агрегатів серії ПЕ2У досить часто, особливо в останні десятиріччя, виникає необхідність в різних видах ремонту і відновлення вже досить зношеного парку цих машин. При цьому змінюється важливіший показник в роботі машини – розподіл мас, і відбувається розбалансування машини, яке може досягати 30 %. Подальша експлуатація такого електровозу призводить до зниження його тяги на 40–100 кН, скорочення строку служби ходової частини в середньому на 8–10 років, а також необхідності зниження швидкості машини під час експлуатації на 10–15 км/год.

Завдяки відсутності належної нормативної бази та рекомендацій фахової літератури подібні балансувальні роботи виконуються фактично ітераційним шляхом з довільним розміщенням елементів баласту, що нерідко затягує строки робіт і призводить до їх неякісного виконання.

Одним з можливих шляхів розв'язання подібної проблеми є розробка і впровадження спеціального теоретичного методу, який дозволяє аналітично обґрунтувати запропоновані конструктивно-технологічні рішення щодо розташування баласту електровозу керування тягового агрегату ПЕ2У. При цьому баласт формується із окремих малорозмірних елементів, які укладаються рядами в наявні конструктивні полості несучої рами. В результаті складається так звана індивідуальна баластна карта для кожної машини.

Підхід, що пропонується, включає два етапи розрахунків і дозволяє не тільки отримувати практично прийняті схеми розташування баласту, але й також суттєво скоротити кількість зважувань машини, необхідних для цього. Підхід був апробований на низці машин електровозів керування тягових агрегатів серії ПЕ2У в 2010–2012 рр. і може бути офіційно використаний в спеціалізованій нормативній документації. Його практична погрішність не перевищую 3 % і обумовлена головним чином технологічними чинниками

Ключові слова: локомотив, електровоз, тяговий агрегат ПЕ2У, балансування машини, баластна карта

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ANALYTICAL METHOD FOR COMPILING AND APPLYING A BALLAST MAP FOR THE TRACTION UNIT PE2U

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1. Introduction

Electric locomotive direct current traction units of series PE2U are designed for use at different sections of mine workings, quarries, mines, and industrial railroad tracks (Fig. 1). Quite often, especially in recent decades, there is a need for various kinds of repair and restoration of the fleet of these machines that are rather worn-out.

In most cases, repairs are performed at specialized enterprises or plants that manufacture these machines, such as the Dnipro electric locomotive factory (DEVZ), Ukraine, the main manufacturer of traction units of series PE2. One should also mention the Novocherkassk electric locomotive plant (NEVZ) in Russia, which, in contrast to DEVZ, specializes on the production of AC traction units of OP and NP series. However, starting from around 2010, NEVZ has been also involved in the maintenance and repair of DC traction units. The renowned German factory Lokomotivbau Elektrotechnische Werke (LEW) produced over the period of 1957–1967 several semi-experimental traction units based on the electric locomotives of series EL, with a diesel drive, which implied a different layout of the machine. Since 1999, they have been partially modernized in Germany, due to their transition to electrical control system.

Fig. 1. Operation of electric locomotive traction unit of series PE2U

Such a repair can include repairing or replacing the worn-out or damaged elements from both the bearing structure of an electric locomotive body and from the components of its equipment. That changes the most important indicator in the machine operation – the distribution of masses with the resulting imbalance of the machine. According to data provided by the manufacturer DEVZ, pressure on the wheelsets of front and rear axles can differ by 15–20 %, while the onboard imbalance could amount to 30 % in some cases. Further operation of such a locomotive results in significant torsional efforts in the elements of a machine body, leading to a decrease in traction by 40–100 kN, as well as the enhanced wear of its running gear, whose service life reduces by 8–10 years on average. This in turn leads to the need to reduce the speed of a machine during operation by 10–15 km/h in some cases, to maintain the upper track structure. We also note that this situation is typical for modern conditions not only in Ukraine, but also in a number of CIS countries, such as Russia or Kazakhstan, which operate traction units of series PE2U, manufactured in the 1960s–80s.

Given the fact there are no, up to now, any alternative machines produced in Ukraine, it is necessary, in order to maintain the operability of traction units themselves, as well as railroad tracks, to balance control electric locomotives after repairs. That explains the relevance of research in this area, which could theoretically extend the duration and quality of operation of the series PE2U machines.

2. Literature review and problem statement

The main and perhaps the only solution under current circumstances is to balance the machine by adding a special ballast. In this case, there is an issue related to the arrangement of the ballast inside a body of the machine in such a way as to ensure primarily the maximum symmetrical mass distribution of the machine. In addition, the mass of such a ballast should be minimally required in order to not make the machine any heavier. Resolving this task is especially complicated if there is a constraint on the maximum permissible load on rails at any sections of railroads.

At present, Ukraine lacks regulatory framework regarding the design, implementation, and operation of locomotives in general, electric locomotives in particular. Most often, when one needs to clarify any issues related to the estimation of the bearing capacity of machines, obsolete rules are applied [1], valid for locomotives manufactured in the 20th century. That is why the manufacturer of the machine (DEVZ) compiled its own standard [2], which makes it possible to further regulate these issues.

However, both normative documents do not contain any recommendations concerning a possibility to balance electric locomotives or traction units after running repair-restoration works not only using a ballast, but by any other method. The acting rules in Russia [3], where most of the fleet of the PE2U series traction units are operated, completely disregard this aspect. This issue has been paid almost no attention to by the current periodical scientific literature (for example, [4]).

The rapid development of computer technology in the early 21st century gave rise to the emergence of qualitatively new approaches to designing machine-building structures in general, and specifically locomotives. Thus, one of the numerical methods in construction mechanics – a finite element method (FEM) – has been very widely applied [5], especially owing to the possibility of its implementation in the form of specialized software packages. In foreign practice, there have been developed generic software packages, such as ANSYS, which has had 4 practical realizations up to now [6]. An equally powerful software product is SolidWorks [7], which enables analysis of work, primarily, of moving mechanisms and systems. A simplified version of a given product is another software – CosmosWorks [8], which does not imply the use of rod elements that often complicates the process of structure simulation. Another software, well known and common in design practice, is the programming complex NASTRAN [9].

All the above software products focus, first of all, on the estimation of the static bearing capacity of a structure in a linear or non-linear statement [10]. They also make it possible to conduct a dynamic analysis of work of a structure, which is especially relevant for machine-building field [11]. In this case, there is a possibility to evaluate the destruction processes of structural materials [12]. However, these complexes cannot deal with tasks on the static balancing of machines. The most powerful and popular software products such as SCAD for Windows or Lira for Windows also lack the functional for solving the problems on estimating the spatial stability of structures. Overall, these software packages are largely intended for construction engineering, which significantly complicates their application in machine building [13].

Under such circumstances, in practical operation and maintenance of locomotives, electric locomotives, and other rolling stock units, the work required for balancing the machines after repairs is actually performed under a «blind» mode. They use improvised tools by applying which balancing is carried out based on experience, without proper theoretical justification. In this case, the ballast typically used is composed of available pieces of rolled steel, with a random mass and different geometrical dimensions. Such «elements» of the ballast are randomly arranged, usually chaotically, in the plane of the bearing frame of an electric locomotive for better balancing of the machine. Such operations are repeated many times, actually using an iterative technique, and require, accordingly, repeated weighing of an electric locomotive, which is often hardly feasible.

The result often means delays in balancing operations themselves, as well as their explicitly superficial and poor execution. This, in turn, adversely affects the timing and quality of subsequent post-repair operation of machines. In practice, there are cases of occurrence of not only technical difficulties at that, but emergencies as well, associated with the derailing of machines or their clashes with other rolling stock units [14]. This not only leads to substantial material damage, but often kills people as well [15].

3. The aim and objectives of the study

The aim of this study is to devise and implement a specialized theoretical approach that would make it possible to analytically substantiate the proposed structural-technological solutions on the arrangement of ballast at the electric locomotive traction unit PE2U. That implies compiling a so-called individual ballast map for each machine.

To accomplish the aim, the following tasks have been set:

– to design a technological structure of the ballast for a control electric locomotive that would enable its compact and simple installation and, if necessary, its operational replacement;

– to describe theoretically the procedure to determine the required amount and weight of the ballast, as well as its spatial arrangement in the machine;

– to test practically the devised theoretical approach using actual machines of series PE2U.

4. Materials and research methods for compiling a ballast map

4. 1. Ballast design

We propose to use a ballast in the form of a special system of small-sized loads of equal size. Structurally, they may represent rolled profiles, cut in small pieces, that are available at industrial sites. The size of such elements of the ballast, and thus their weight, are fairly similar, making it easier to work with them in the future. Out of such ballast elements, stacked in rows into the structural cavities in the bearing frame of a locomotive, we form two ballast parts, oriented along the boards of the machine. That produces the structural layout of ballast arrangement, shown in Fig. 2.

A special analytical calculation is performed for determining the geometrical dimensions and layout of each part of such a ballast relative to the elements of an electric locomotive. Such a calculation implies only a one-time initial weighing of the machine, the result being its established actual imbalance. The calculation itself makes it possible to acquire a so-called ballast map according to which it becomes possible to quickly and accurately enough to lay the ballast and, in doing so, to balance the electric locomotive.

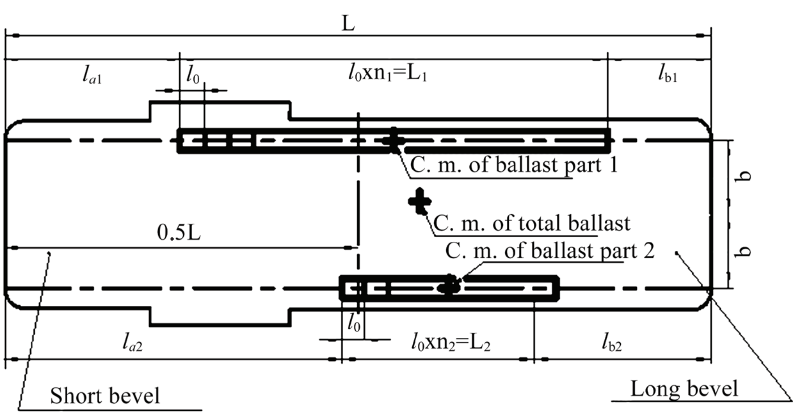

Fig. 2. Schematic of ballast arrangement

4. 2. Denotation system

To perform calculation, we shall use the right-hand Cartesian coordinate system xOy, originating (point O) from the geometric center of a body frame (Fig. 3, 4). In this case, the longitudinal Ox axis is oriented in parallel to the longitudinal axis of the electric locomotive, the transverse Oy axis is perpendicular to the longitudinal axis of the locomotive. The Oz axis is oriented vertically relative to the horizontal plane of the bearing frame of electric locomotive. The geometrical center of the locomotive's body frame (point O) is assumed to be positioned along the same vertical axis of the geometric center of its wheelbase.

Hereafter, we shall use a series of special alphanumeric designations whose decoding and explanations are listed below. For the sake of convenience, the denotations are combined into three groups: geometric symbols, coordinate notations, and mass designations.

1) Geometric symbols:

b – lateral distance from the longitudinal plane of symmetry of the body frame to the centers of masses of the first and second parts of the ballast;

l_0 – the length of one load in a ballast;

l_{a1} – the longitudinal distance from the edge of a short bevel of electric locomotive to the beginning of the first part of the ballast;

l_{b1} – the longitudinal distance from the end of the first part of the ballast to the long bevel of electric locomotive;

l_{a2} – the longitudinal distance from the edge of the short bevel of electric locomotive to the beginning of the second part of the ballast;

l_{b2} – the longitudinal distance from the end of the second part of the ballast to the long bevel of electric locomotive;

n_1 – the number of loads that make up the first part of the ballast;

n_2 – the number of loads that make up the second part of the ballast;

n_Σ – the total number of loads that make up the ballast of a locomotive;

L – the length of the body frame of electric locomotive;

L_1 – the total length of the first part of the ballast;

L_2 – the total length of the second part of the ballast.

2) Coordinate notations:

p. O – the geometric center of the electric locomotive;

p. B – the center of masses of the ballast;

p. K – the center of masses of the locomotive, weighted with uninstalled parts and without ballast;

p. U – the center of masses of the locomotive parts, not installed when weighing it;

p. U_k – the center of masses of the k-th part of the locomotive, not installed when weighing it;

p. KU – the center of masses of the completely equipped electric locomotive without a ballast;

p. C – the center of masses of the completely equipped electric locomotive with a ballast;

pp. $K_{i;j}$ – the points of contact between wheels and rails, where i=1; 2 – the dumb index of an electric locomotive's side (1 – side above the Ox axis; 2 – side below the Ox axis), j=1; 2; 3; 4 – the number of a wheel set axle (adopted from left to right);

pp. B_i – the center of masses of the i-th part of the ballast, installed along the i-th side (accepted names of ballast parts: i=1 – first, i=2 – second);

x_K, $x_{Ki;j}$, x_U, x_{Uk}, x_{KU}, x_B, x_{B1}, x_{B2} – coordinates of x corresponding points described above (when $y_{B1}=-y_{B2}=b$);

y_K, $y_{Ki;j}$, y_U, y_{Uk}, y_{KU}, y_B, y_{B1}, y_{B2} – coordinates of y corresponding points described above (when $y_{B1}=-y_{B2}=b$);

Δx_{B1}, Δx_{B2} – shifts along the Ox axis of points B_1, B_2 relative point B (Δx_{B1}, $\Delta x_{B2}>0$ when they coincide in direction with the Ox axis; Δx_{B1}, $\Delta x_{B2}<0$ when they are in opposite directions).

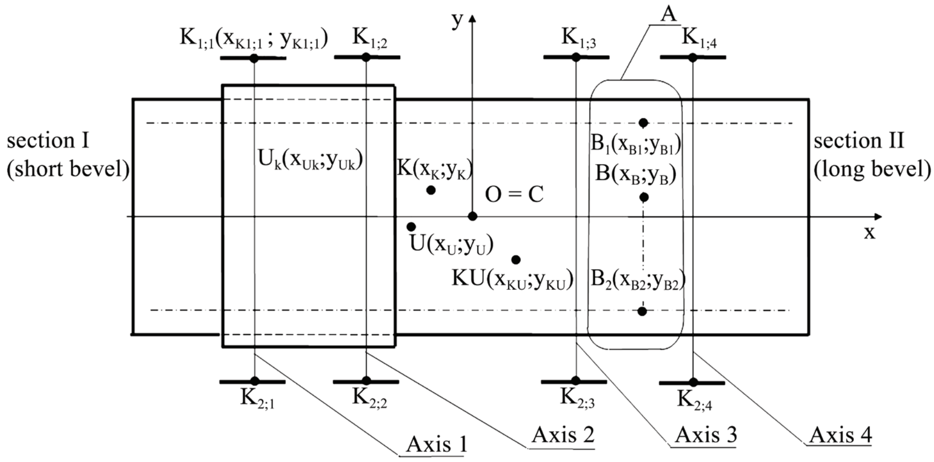

Fig. 3. Basic coordinate notation

3) Mass designations:

M_K – the total mass of a wheel-per-wheel weighing of electric locomotive;

M_U – the total mass of uninstalled parts of electric locomotive;

M – the mass of completely equipped electric locomotive with a ballast;

$m_{Ki;j}$ – the masses of loads per each wheel;

m_Σ – the mass of the ballast;

m_0 – the averaged mass of a separate load for a set of ballast;

m_1 – masses of the first part of the ballast;

m_2 – masses of the second part of the ballast.

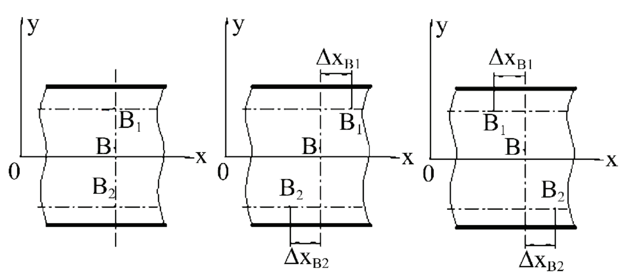

Fig. 4. Position of the centers of masses of ballast's parts

4. 3. Original parameters

In order to acquire initial data to substantiate a ballast arrangement diagram, one must preliminary weigh the electric locomotive to establish the weight loading per each wheel (hereafter – a load per each wheel). Additional original parameters, when necessary, could include information about the masses and coordinates of the centers of masses (points of location) of a locomotive's structural elements that are not installed at the time of weighing. It includes all existing actual deviations in the location and mass of the locomotive's structural elements valid for a particular machine. The resulting information is conveniently presented in a tabular form.

In line with technical documentation for the locomotive, a body frame length is taken as L, the lateral distance from the longitudinal plane of symmetry of the frame body to the centers of masses of the first and second parts of ballast is taken as b. Based on design considerations (for example, to ensure reliable fixing of ballast's parts relative to the body frame, etc.), one defines the required minimum distance from the edge of a ballast to the end of body frame $l_{\min}$. One should also perform special weighing of loads needed for a ballast set of the electric locomotive. Based on the result, one determines the average value for a single load mass m_0 (arithmetic mean). Separately, one must perform special measurements of the loads needed for a ballast set of the electric locomotive. Based on the result, one determines the average value for a single load length l_0 (arithmetic mean).

5. Results of research on the development of an analytical method for compiling a ballast map

All the parameters for the ballast should be defined for a completely equipped locomotive so that condition (1) is satisfied:

$$M^n_{c\min w} \le M \le M^n_{c\max w}. \quad (1)$$

In this case, the ballast must provide for the static balancing of an electric locomotive, which is matched by the alignment of points O and C (Fig. 3). This is the prerequisite for the calculation.

The calculation of the ballast itself is performed in two stages. The main objective of the first stage is to determine the required mass of a ballast and its individual parts to balance the electric locomotive. At this state, the following parameters are determined:

– the mass of the first part of the ballast m_1;

– the mass of the second part of the ballast m_2;

– the required quantity of loads n_1 for a set of the first part of the ballast;

– the required quantity of loads n_2 for a set of the second part of the ballast.

The main objective of the second stage is to design structural diagrams for arranging the ballast and its separate parts at the frame of the locomotive. At this stage, the following parameters are determined:

– the total length L_1 of the first part of the ballast;

– the total length L_2 of the second part of the ballast;

– longitudinal dimensions that define the location of the first part of the ballast l_{a1} and l_{b1};

– longitudinal dimensions that define the location of the second part of the ballast l_{a2} and l_{b2}.

We also note also that each stage of the calculation is performed three times. In this case, three cases are considered – for the nominal mass of an electric locomotive, for the maximally permissible mass of a locomotive, and for the minimally permissible mass of a locomotive.

5. 1. Stage I

The calculation of parameters for the ballast of an electric locomotive should start with determining the required total mass of a ballast according to expression (2), where the mass M^n is taken to be the normative values for masses of an electric locomotive:

$$m_\Sigma = M^n - M_K - M_U. \tag{2}$$

Masses M_K and M_U are taken based on the preliminary weighing of an electric locomotive, as described in the previous chapter.

Next, one determines the static moments for the masses of loads per each wheel and for the masses of uninstalled parts. They are calculated according to expressions (3) and (4), respectively:

$$S_{xKi;j} = x_{Ki;j} \cdot m_{i;j};\ S_{yKi;j} = y_{Ki;j} \cdot m_{i;j}, \tag{3}$$

$$S_{xU} = x_k \cdot m_k;\ S_{yU} = y_k \cdot m_k. \tag{4}$$

Next, one determines the required masses for the first and second parts of the ballast according to expressions (5) and (6), respectively:

$$m_1 = 0.5[m_\Sigma - (S_{yK} + S_{yU})/b], \tag{5}$$

$$m_2 = 0.5[m_\Sigma + (S_{yK} + S_{yU})/b]. \tag{6}$$

The required quantity of loads for a set of the necessary mass of both parts of the ballast is calculated according to the expressions (7), (8), respectively:

$$n_1 = m_1/m_0, \tag{7}$$

$$n_2 = m_2/m_0. \tag{8}$$

The required quantity of loads, thus obtained, is rounded up to integer values according to the following rules:

– for the minimally permissible mass of a locomotive, rounding is performed to the nearest larger integer value;

– for the nominal mass of an electric locomotive, rounding is performed according to mathematical rules (depending on the value of the digit in decimal place);

– for the maximally permissible mass of a locomotive, rounding is performed to the nearest smaller integer value.

Next, one refines masses for the first and second parts of the ballast according to expressions (9), (10), respectively:

$$m_1 = n_1 \cdot m_0, \tag{9}$$

$$m_2 = n_2 \cdot m_0. \tag{10}$$

In this case, the magnitudes n_1 and n_2 used in these expressions are the rounded values.

The mass of the ballast of a locomotive is refined according to expression (11), and the mass of a completely equipped ballasted electric locomotive is refined according to expression (12):

$$m_\Sigma = m_1 + m_2, \tag{11}$$

$$M = M_K + M_U + m_\Sigma. \tag{12}$$

The refined mass of a completely equipped ballasted electric locomotive is checked according to expression (1) for two extreme cases – for the maximally permissible mass of a locomotive and for the minimally permissible mass of a locomotive.

5. 2. Stage II

One calculates the longitudinal coordinate of the position of the center of ballast x_B according to expression (13):

$$x_B = -(S_{xK} + S_{xU})/m_\Sigma. \tag{13}$$

In this expression, one uses the refined mass of the ballast, determined at the first stage of the calculation.

One then needs to calculate the total lengths of the first and second parts of the ballast (Fig. 3) according to expressions (14), (15):

$$L_1 = l_0 \cdot n_1, \tag{14}$$

$$L_2 = l_0 \cdot n_2. \tag{15}$$

The actual arrangement of both parts of the ballast in the longitudinal direction of a locomotive relative to the derived center of gravity of the ballast (coordinate x_B) can be implemented in an infinite number of variants. The main variant that should be considered in this case is the variant when the centers of masses of both parts of the ballast are along the same transverse line that passes through the center of masses of the ballast ($\Delta x_{B1} = \Delta x_{B2} = 0$ – Fig. 4). Determining the required longitudinal coordinating sizes in this case is carried out as follows.

One calculates the dimensions that determine the location of the first part of the ballast along the length of the body frame from expressions (16), (17):

$$l_{a1} = 0.5 \cdot L + x_B - 0.5 \cdot L_1, \tag{16}$$

$$l_{b1} = L - L_1 - l_{a1}. \tag{17}$$

One calculates dimensions that determine the location of the second part of the ballast along the length of the body frame from expressions (18), (19):

$$l_{a2} = 0.5 \cdot L + x_B - 0.5 \cdot L_2, \tag{18}$$

$$l_{b2} = L - L_2 - l_{a2}. \tag{19}$$

All the values for dimensions l_{a1}, l_{b1}, l_{a2} and l_{b2}, thus obtained, are compared with the minimal distance, accepted in initial data, from the edge of the ballast to the edge of a body frame $l_{\min}$. If any of these dimensions is less than dimension $l_{\min}$, this variant for the accepted normative value for the mass of a locomotive cannot be implemented structurally (there is not enough space for arranging a ballast in the frame of the body).

In this case, one must perform a reverse recalculation of all parameters related to the arrangement of a ballast of an electric locomotive, having derived another value for the mass of a completely equipped electric locomotive with a ballast.

Additional variants considered for the arrangement of a ballast at a locomotive are the cases when each part of the ballast is maximally shifted to the edge of a body frame. In this case, it is necessary to note two cases on which the adopted variants for the arrangement of a ballast depend:

1) If the coordinate for the center of masses of a ballast, derived earlier, is positive ($x_B>0$), then the parts of the ballast are arranged in line with the following two variants:

– additional variant No. 1 – the center of masses of the first part of a ballast is maximally shifted to the right, and that of the second part of the ballast is maximally shifted to the left of a transverse line passing through the center of masses of the ballast ($\Delta x_{B1}>0$ and $\Delta x_{B2}<0$);

– additional variant No. 2 – the center of gravity of the second part of a ballast is maximally shifted to the right and that of the first part of the ballast is maximally shifted to the left of a transverse line passing through the center of gravity of the ballast ($\Delta x_{B2}>0$ and $\Delta x_{B1}<0$).

2) If the coordinate of the center of masses of a ballast, derived earlier, is negative ($x_B<0$), then the parts of the ballast are arranged in line with the following two variants:

– additional variant No. 3 – the center of masses of the first part of a ballast is maximally shifted to the left, and that of the second part of the ballast is maximally shifted to the right of a transverse line passing through the center of masses of the ballast ($\Delta x_{B1}<0$ and $\Delta x_{B2}>0$);

– additional variant No. 4 – the center of gravity of the second part of a ballast is maximally shifted to the left, and that of the first part of the ballast is maximally shifted to the right of a transverse line passing through the center of gravity of the ballast ($\Delta x_{B2}<0$ and $\Delta x_{B1}>0$).

Each of these variants is calculated for three standard cases – for the nominal mass of an electric locomotive, for the maximally permissible mass of a locomotive, and for the minimally permissible mass of a locomotive. Given this, there may occur a situation when calculation for different cases should be performed based on different variants, according to expressions given in Table 1.

The resulting values for the dimensions that determine the arrangement of part of the ballast along the length of the body frame are compared with the the minimum distance, accepted in initial data, from the edge of a ballast to the edge of a body frame ballast $l_{\min}$. If any of these dimensions is less than dimension $l_{\min}$, this variant for the accepted normative value of the mass of a locomotive cannot be implemented structurally (there is not enough space for the arrangement of a ballast at the body frame).

In this case, one must perform a reverse recalculation of all parameters related to the arrangement of a ballast at an electric locomotive, having derived another value for the mass of a completely equipped electric locomotive with a ballast.

The total number of loads that make up the ballast of a locomotive is additionally calculated from expression (20):

$$n_\Sigma=n_1+n_2. \quad (20)$$

The resulting quantity of ballast elements is sent to the production site, where repair and balancing operations are performed. It also is entered in the ballast map of the machine and is stored until the next periodic maintenance or repair of the machine.

6. Discussion of results of devising an analytical method for compiling a ballast map

We shall illustrate the practical use of the above-described analytical method for compiling a ballast map of the electric locomotive traction control unit PE2U by calculations performed for the machine with serial number 119, repaired at DEVZ in 2011.

Results from weighing each wheel of the electric locomotive are given in Table 2; data on uninstalled parts of the electric locomotive at the time of weighing are given in Table 3.

In Tables 2, 3, the total amount is taken only for the last column, the coordinates are not summed up. This is the way these tables are filled in the practice of machine repairs.

Table 1

Calculation sequence for additional variants of ballast arrangement

Calculation operation	Calculation expression for additional variant			
	No. 1	No. 2	No. 3	No. 4
Dimensions that determine the arrangement of part of the ballast along the length of the body frame	$l_{b1}=l_{\min}$, $l_{a1}=L-L_1-l_{b1}$	$l_{b2}=l_{\min}$, $l_{a2}=L-L_2-l_{b2}$	$l_{a1}=l_{\min}$, $l_{b1}=L-L_1-l_{a1}$	$l_{a2}=l_{\min}$, $l_{b2}=L-L_2-l_{a2}$
Coordinate of the center of masses of part of the ballast	$x_B=0.5\cdot L-l_{b1}-0.5\cdot L_1$	$x_{B2}=0.5\cdot L-l_{b2}-0.5\cdot L_2$	$x_{B1}=0.5\cdot L-l_{a1}-0.5\cdot L_1$	$x_{B2}=0.5\cdot L-l_{a2}-0.5\cdot L_2$
Longitudinal shifts of the center of gravity of parts of the ballast relative to the center of masses of electric locomotive	$\Delta x_{B1}=x_{B1}-x_B$, $\Delta x_{B2}=-\Delta x_{B1}\cdot m_1/m_2$	$\Delta x_{B2}=x_{B2}-x_B$, $\Delta x_{B1}=-\Delta x_{B2}\cdot m_2/m_1$	$\Delta x_{B1}=x_{B1}-x_B$, $\Delta x_{B2}=-\Delta x_{B1}\cdot m_1/m_2$	$\Delta x_{B2}=x_{B2}-x_B$, $\Delta x_{B1}=-\Delta x_{B2}\cdot m_2/m_1$
Coordinate of the center of masses of part of the ballast	$x_{B2}=x_B+\Delta x_{B2}$	$x_{B1}=x_B+\Delta x_{B1}$	$x_{B2}=x_B+\Delta x_{B2}$	$x_{B1}=x_B+\Delta x_{B1}$
Dimensions that determine the arrangement of part of the ballast along the length of the body frame	$l_{b2}=0.5\cdot L-x_{B2}-0.5\cdot L_2$, $l_{a2}=L-L_2-l_{b2}$	$l_{b1}=0.5\cdot L-x_{B1}-0.5\cdot L_1$, $l_{a1}=L-L_1-l_{b1}$	$l_{a2}=0.5\cdot L-x_{B2}-0.5\cdot L_2$, $l_{b2}=L-L_2-l_{a2}$	$l_{a1}=0.5\cdot L-x_{B1}-0.5\cdot L_1$, $l_{b1}=L-L_1-l_{a1}$

Table 2

Results from weighing wheel-per-wheel

Points of load application (Fig. 2)	Coordinates, m		Loads, t
	$x_{i;j}$	$y_{i;j}$	$m_{i;j}$
$K_{1;1}$	–6.565	0.76	12.98
$K_{1;2}$	–3.815	0.76	13.04
$K_{1;3}$	3.815	0.76	12.00
$K_{1;4}$	6.565	0.76	12.52
$K_{2;1}$	–6.565	–0.76	13.16
$K_{2;2}$	–3.815	–0.76	12.83
$K_{2;3}$	3.815	–0.76	11.93
$K_{2;4}$	6.565	–0.76	12.99
Total	–	–	M_K=101.45

Table 3

Data on uninstalled parts

Uninstalled parts	Coordinates, m		Loads, t
	x_k	y_k	m_k
Sand	0	0	0.448
SPA	0	0	0.92
Armchair 1 with a machine driver	–2.500	1.35	0.15
Armchair 2 with a machine driver	–2.770	–1.35	0.15
Generator	–7.9	0.97	0.302
Total	–	–	M_U=1.97

The length of the locomotive's body frame, in line with technical documentation, is taken to be L=179.68 mm. The lateral distance from the longitudinal plane of symmetry of the body frame to the centers of masses of the first and second parts of the ballast, in line with technical documentation on the electric locomotive, is taken to be b=1.365 m.

The required minimal distance from the edge of the ballast to the edge of a body frame is taken equal to $l_{\min}$=200 mm.

The average value for the mass of a single load that the ballast is composed of, determined form the results of special weighing, equals m_0=0.18 t. The average value for the length of a single load that the ballast is composed of, determined from the results of special measurement, equals l_0=300 mm.

The ultimate results from the calculations at the first stage are given in Table 4, at the second stage – in Table 5. We give data for each of the considered variants in rows that correspond to the nominal mass of an electric locomotive, to the maximally permissible mass of an electric locomotive, and to the minimally permissible mass of an electric locomotive. Additional variants No. 3, 4 for arranging a ballast cannot be implemented in a given case.

Table 4

Results from calculations at the first stage

Mass, t				Number of loads, pcs.		
M	m_Σ	m_1	m_2	n_Σ	n_1	n_2
116.74	13.32	6.66	6.66	74	37	37
119.98	16.56	8.28	8.28	92	46	46
123.58	20.16	10.08	10.08	112	56	56

Table 5

Results from calculations at the second stage

Mass, t	Dimensions, mm					
	L_1	L_2	l_{a1}	l_{a2}	l_{b1}	l_{b2}
Basic variant						
116.74	11.100	11.000	4.539	4.539	2.329	2.329
119.98	13.800	13.800	2.972	2.972	1.196	1.196
123.58	16.800	16.800	–	–	–	–
Additional variant No. 1						
116.74	11.100	11.000	6.668	2.410	200	4.458
119.98	13.800	13.800	3.968	1.976	200	2.192
123.58	16.800	16.800	–	–	–	–
Additional variant No. 2						
116.74	11.100	11.000	2.410	6.668	4.458	200
119.98	13.800	13.800	1.976	3.968	2.192	200
123.58	16.800	16.800	–	–	–	–

Fig. 5 also shows a plot of dependence of the total required ballast mass, as well as its individual parts, on the mass of a completely equipped electric locomotive.

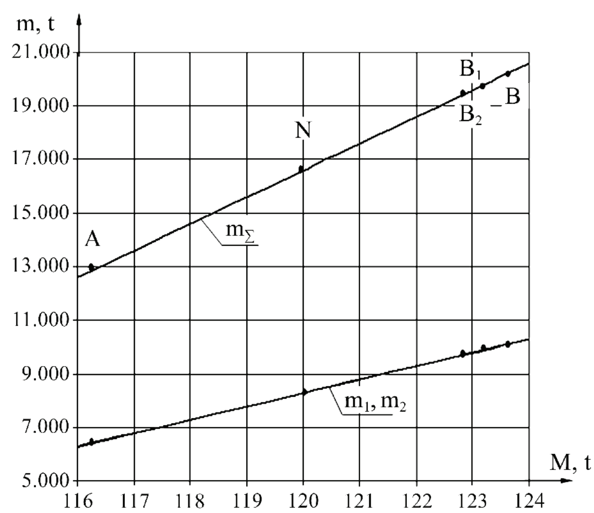

Fig. 5. Dependence of ballast mass on the mass of electric locomotive

The plot shown in Fig. 5 makes it possible to calculate the required values for the masses of a ballast's parts for different intermediate cases that may occur in practice.

Based on the results of the performed calculations, as well as the ballast map, compiled based on it, for the considered electric locomotive traction control unit PE2U, we carried out its practical balancing. In this case, the total mass of the ballast was 13.32 tons, distributed almost evenly along two boards. As a result, based on data from final weighing, pressure on the wheelsets at the front and rear axles differed by 1.3 %, while the board imbalance was 0.7 %, which is a rather good indicator.

Thus, the devised and proposed analytical approach for compiling a ballast map for electric locomotives of the PE2U control type has made it possible to obtain an almost perfect balancing of the machine with a minimally required ballast mass and at a minimum number of weighings at that. The observed small deviations are related to a bias, inevitable during calculations when rounding the required number of loads that form the ballast to integers. A certain contribution is also introduced by technological errors that arise in practice when installing the ballast elements themselves and a deviation in their masses from nominal.

It should be noted that the scope of application of the described analytical approach focuses directly on the design of electric locomotive traction control unit of series PE2, whose bearing frame has prefabricated special cavities. For electric locomotives of traction units from other series, the proposed structural-technological solution requires additional consideration in terms of adjusting it to the design of machines themselves. In this case, the analytical approach can be applied without any fundamental adjustments. The only limitation is a possibility to weigh each wheel of machines themselves, which is not always feasible under actual service conditions.

7. Conclusions

1. We have proposed to apply, as a structural-technological solution for arranging a ballast for the locomotive traction control unit PE2U, a special system of small-sized loads of equal size, forming the sets of elements that make up a ballast of the machine. Such ballast elements, stacked in rows into the structural cavities, available in the bearing frame of a locomotive, form two ballast parts, oriented along the boards of the machine.

2. The reported algorithm for theoretical calculation of the required number and mass of the ballast is given in a practically applicable form as a set of formulae for specific practical cases. The result of the calculation is a compiled individual ballast map of the machine, containing information about the arrangement and structure of the ballast.

3. The proposed approach has been tested on several machines at electric locomotive traction units of series PE2U over 2010–2012, during planned and unscheduled maintenance over that period at the Dnipro electric locomotive factory (DEVZ), Ukraine. As a result, that made it possible to significantly simplify and speed up the process of machine balancing.

The devised structural-technological solutions for arranging a ballast of the locomotive traction control unit PE2U, as well as the theoretical approach underlying its justification, could be officially used in specialized regulatory documentation.

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References

1. Normy dlya rascheta i ocenki prochnosti nesushchih elementov, dinamicheskih kachestv i vozdeystviya na put' ekipazhnoy chasti lokomotivov zheleznyh dorog MPS RF kolei 1520 mm. Moscow: VNIIZHT, 1998. 145 p.
2. TU U 35.2-32495626-010-20. Agregaty tyagovye. Tekhnicheskie usloviya. Dnepopetrovsk: DEVZ, 2003. 48 p.
3. GOST R 55513-2013. Lokomotivy. Trebovaniya k prochnosti i dinamicheskim kachestvam. Moscow: Standartinform, 2014. 45 p.
4. Datsun Y. M. Conformance rating for locomotive repair productions // Science and Transport Progress. Bulletin of Dnipropetrovsk National University of Railway Transport. 2017. Issue 3 (69). P. 23–31. doi: https://doi.org/10.15802/stp2017/103937
5. Liu G. R., Quek S. S. The Finite Element Method. Elsevier, 2014. 464 p. doi: https://doi.org/10.1016/c2012-0-00779-x
6. Wang B., Zhang Y., Chen R. J. Several Realizations of the Finite Element Software ANSYS Structural Analysis // Applied Mechanics and Materials. 2013. Vol. 442. P. 507–510. doi: https://doi.org/10.4028/www.scientific.net/amm.442.507
7. Toreh E. H., Shahmohammadi M., Khamseh N. Kinematic and Kinetic Study of Rescue Robot by SolidWorks Software // Research Journal of Applied Sciences, Engineering and Technology. 2013. Vol. 5, Issue 21. P. 5070–5076. doi: https://doi.org/10.19026/rjaset.5.4399
8. Modeling and Static Analysis of an Areogenerator Savonius Cracked by Using SolidWorks/CosmosWorks Software / Khelifi C., Ouali M., Ferroudji F., Adjilout L. // Applied Mechanics and Materials. 2013. Vol. 446-447. P. 744–750. doi: https://doi.org/10.4028/www.scientific.net/amm.446-447.744
9. Gao H. F. The Development and Application of Parallel Computation for Structural Analysis Based on Nastran Software // Applied Mechanics and Materials. 2015. Vol. 778. P. 41–45. doi: https://doi.org/10.4028/www.scientific.net/amm.778.41
10. Kathrotiya M. Construction Stage Analysis of Flat Slab Structure with respect to Non Linear Time History Analysis using Software Aid // International Journal for Research in Applied Science and Engineering Technology. 2018. Vol. 6, Issue 4. P. 4833–4839. doi: https://doi.org/10.22214/ijraset.2018.4791
11. Vysoký R. Current Capabilities of Modal Analysis of Aircraft Propeller in ANSYS Mechanical Environment // Advances in Military Technology. 2017. Vol. 12, Issue 1. P. 33–47. doi: https://doi.org/10.3849/aimt.01160
12. Li W. M., Yan Y. Y., Xing Y. The Numerical Simulation of Punching and the Fatigue Analysis of Punch Based on ANSYS/LS-DYNA and ANSYS-Fatigue Tool // Advanced Materials Research. 2014. Vol. 904. P. 469–473. doi: https://doi.org/10.4028/www.scientific.net/amr.904.469
13. Bannikov D. O. Usage of construction-oriented software scad for analysis of work of machine-building structures // Science and Transport Progress. Bulletin of Dnipropetrovsk National University of Railway Transport. 2018. Issue 1 (73). P. 98–111. doi: https://doi.org/10.15802/stp2018/123406

14. Transport accidents distribution at ukrainian railways according to categories depending on severity of consequences / Ohar O. M., Rozsocha O. V., Shapoval G. V., Smachylo Y. V. // Science and Transport Progress. Bulletin of Dnipropetrovsk National University of Railway Transport. 2018. Issue 3 (75). P. 7–19. doi: https://doi.org/10.15802/stp2018/124466
15. Vyrkov S. A. Classification of railway accidents by the criterion of material damage // Proceedings of Petersburg Transport University. 2015. Issue 1. P. 12–19.

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INTENSIFICATION OF THE PROCESS OF DOSING BULK CONCENTRATED FEEDS BY SIEVE HOPPER

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Дослідження присвячено розробці та обґрунтуванню параметрів дозуючого пристрою, який встановлюється у технологічному процесі виробництва сипких концентрованих кормів. Проведено аналіз конструкцій дозаторів, способів підвищення продуктивності та якості їх роботи, визначено перспективи розвитку даного напрямку. Підвищення ефективності дозування досягнуто шляхом модернізації решітного дозатора з розрідженою видачею дозованого матеріалу за рахунок використання отворів у вигляді пятипелюсткової епіциклоїди.

Для визначення раціональних конструктивно-технологічних параметрів модернізованого решітного дозатора проведено математичне моделювання руху сипкого середовища, обрані умови процесу, встановлені кінцеві математичні вирази. Окрім параметрів решітного дозатора у виразах та експериментах враховано властивості сипких кормів. Визначені діапазони варіювання розмірів отворів нижнього та верхнього решіт, амплітуда та частота їх коливань, що є значущими параметрами процесу дозування сипких кормів на запропонованому дозаторі.

Результати моделювання підтверджено проведеними експериментальними дослідженнями. Експериментально встановлені залежності продуктивності решітного дозатора його від конструктивно-кінематичних параметрів, у базовому та модернізованому варіантах. Використавши данні залежності, за умови максимальної ефективності дозування, визначені діапазони варіювання продуктивності модернізованого дозатора, які склали 0,75...2,6 т/год. Встановлено, що використання решіт з активаторами підвищують продуктивність дозатора на 15...44,4 %. Адекватність розробленого математичного моделювання підтверджена допустимою розбіжністю результатів з експериментами, яка не перевищила 5 %.

В результаті дослідження отримана методика досліджень дозаторів решетного типу, яка передбачає можливості дослідження впливу форм та розмірів отворів на ефективність дозування сипких кормів

Ключові слова: дозатор, концентрований корм, віброрешето, рівномірність дозування, активатори просіювання, діаметр отвору, амплітуда коливань

1. Introduction

Livestock production is a priority for the economies of many European countries and demands the improvement of its profitability by increasing the volumes with a parallel reduction in cost.

Modern livestock maintains the positive dynamics of its growth. Thus, milk yields of cows reach up to 12 thousand kg of milk per lactation, live weight of chickens reaches up to 3 kg for 40 days, the growth of pigs is up to 1 kg per day etc. [1]. A similar intensity is explained to a great extent by breeding new breeds, lines, crosses, that is, genetic research. The growth of efficiency requires adequate nutrition, which is determined by the energy, amino acid, protein, mineral and vitamin directions, and ultimately contributes to the implementation of genetic potential of animals. For example,