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MOTION OF CRANES OF BRIDGE TYPE SIMULATION IN THE MS EXCEL ENVIRONMENT

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Abstract: The idle times of the crane caused by need of replacement of wheels, can have critical value for functioning of a logistic chain. In article the task about the movement of the crane with a skew with the accounting of several mutually influencing processes having various nature is considered. The solution of this task has important applied value for increase in a resource of wheels. For the crane designs, more varied, a known problem is representation of results in a suitable form for engineering calculations, as a compromise between simplicity and quality of the results. Possible solution is modelling in the environment of MS Excel. This approach allows the best way to provide the necessary engineering calculations for simplicity, clarity and reliability of the submission and processing of a large number of heterogeneous data. As an example, modelling of an elastic skeleton of the crane in dynamics that represents complexity in view of lack of specialized mathematical apparatus is considered.

Keywords: crane skew, bridge type cranes, running qualities, mathematical model, MS Excel

1. Problem statement

Cranes are an integral part of infrastructure of transport and warehouse logistics. High-quality functioning of a logistic chain assumes minimization of repair operations. It is especially actual in case of operation of several cranes on one ways as idle time of one crane limits operational space of other cranes. Most often elements of running gears fail. In this article the aspects of modelling of the crane in the movement which are of interest from the point of view of minimization of transport idle times, and also economy of energy are considered.

Movement of the crane is accompanied by turns and steel construction deformations in the horizontal plane. The most widespread and well-studied type of deformations – a skew (outrunning of supports), however others are known also, for example, shift sideways. Thus the steel structure is exposed to additional loads, there are elevated levels of energy consumption, wear and fatigue damage to the wheels, rails and other expensive items. Replacement of the failed component can take some days. All this contradicts main objectives of logistics (increase in quality, reduction of time, decrease in expenses).

Skewing forces acting on the structure, it is assumed to be directed along the rails. A pair of lateral forces applied to the zones of contact of wheels with the track rails, are reactions to the skewing forces. Lateral force is commonly used as a basic characteristic running qualities and stress-strain state of the crane. The general idea of the nature of loads acting at moving, give graphs of lateral loads (R1, 2, 3, 4), acting on the gantry crane wheel shown in Figure 1.

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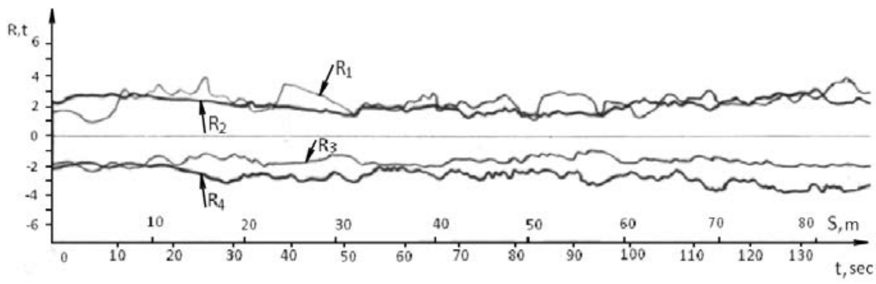

Figure1. The oscillogram of the lateral loadings operating on wheels at movement of the KS 50-42 crane of Zmiyevsky power station [1]

Similar results are received by many researchers. Variability of loadings attracts attention; existence of the expressed peaks corresponding, allegedly, to changes of a condition of system the rail-wheel-crane. The strongest pushes can arise at coupling failures, entries into contact of flanges (also at interruption of this contact), moving of joints of rails, etc. These loads are largely dependent on geometry of the crane, characteristics of engines, features of a power supply system and control of the drive, the accuracy of installation of wheels, straightforwardness of rails, a condition of their surface, movement speed.

The major factors constraining studying of the crane in movement, are a variety of designs, a wide range of parameters, as well as the presence of the mutual influence of individual processes. The phenomena accompanying movement of cranes, draws attention of several generations of experts. The considerable volume of information is accumulated. These are experimental, theoretical and normative data. Actual task is establishment of correct and rational compliance between these 3 information areas.

2. Recent research analysis

In the works performed till 1980, the established movement of cranes without external disturbances was considered, mathematical models were exclusively analytical. Originally, the crane was considered as a rigid body with possibility of lateral shift and turn in the horizontal plane. Further numerous specifying experimental and theoretical works were performed. Today the fullest mathematical model of movement for four-wheel bridge cranes of the average loading capacity, confirmed with natural tests, is offered by N. A. Lobov [2]. Were considered: adjusting misalignment of wheels; inequality of traction efforts of drives and forces of resistance of the opposite sides of the crane; influence on lateral loadings of shocks when passing joints of rails.

First motion was consistently considered taking periodic disturbances into account. Own frequencies and damping parameters are determined, characteristics of loadings and power losses are offered.

On the basis of experimental and theoretical studies designed engineering calculation method, adopted as industry norms and standards [3, 4].

3. Unsolved aspects of the general problem

Existing theories have high degree of continuity. Traditionally, theoretical works of the previous generation become a basis of engineering settlement techniques of the following generation which finally are accepted as standards. Specifications extend, mainly, on empirical coefficients that provides laconicism and accurate physical sense of the expressions describing the most important effects that is approach advantage. Thus, most often, statistical processing of empirical data is required. However loss of part of information, and narrowing of a scope of a technique is an inevitable consequence. For example, it is impossible to consider the scheme of deviations from straightforwardness of a railway line. Therefore for the solution of a wide range of the tasks connected with optimization of service conditions of operating cranes, the new approaches directed on association of research and engineering calculation are required; first of all, programming. An attempt of removal of noted restrictions is made in annexes to PTM 24.090.07-85 "Norms of calculation of steel designs of bridge cranes of the item over 50 t" where systems of the equations of movement of the crane are given. However the algorithm of the decision is absent.

The mathematical model of the crane in movement has to meet additional requirements of completeness and presentation of the data, the developed interface, ease of a task of geometry of a frame of the crane and parameters of mechanisms etc.

The model has to provide the following opportunities:

- the accounting of the scheme of deviations of rails from straightforwardness; schemes of deviations of arrangements of wheels, changes of the parameters characterizing coupling of wheels with a rail, speed-torque characteristics of engines and other parameters relating to the studied crane (optional, must be possible to use the averaged values),
- calculations of the loadings operating on the crane and crane-rails of the increased accuracy; optimization at a design stage,
- consideration of consequences of emergency situations, for example, movement on one drive in a repair zone at failure of the second drive, unilateral blow in the buffer, etc.,
- optimization of stocks of power when replacing drives on new (the insufficient stock of power, as well as an excessive stock, cause additional loadings),
- research of efficiency of use of systems of restriction of skews, for example, synchronization of movement of opposite support or use of sensors of distance of an element of a design from a lateral surface of a rail,
- the solution of the problems connected with operation of the particular crane taking its design features, schemes of the railway line, the measured deviations of wheels, the most probable arrangement of the trolley at movement, etc. into account. Program application at inspections of cranes for the purpose of an assessment of its state.

As the objective of the article the aspects of mathematical modelling of the moving crane are considered. Expediency of a choice of the MS Excel environment and possibility of such approach from the point of view of gap overcoming between theoretical works and engineering calculation techniques.

4. Research results

Using programs for engineering calculations is possible under certain requirements, largely traditional. First of all, simplicity and presentation of calculations has to be provided, an open source programming language prevalence, low cost is important also. The most complex challenge is achievement of a compromise with research opportunities which also have to be considerable.

When modelling crane in motion the accounting of the processes having various nature, in their interaction is required. The model has to include the parameters characterizing geometry and the kinematic scheme of the drive. Tasks such (creation of parameterized models taking characteristics of separate drives, dynamics, elastic properties of a design and the contact phenomena into account) are the priority direction of development of applied program environments. However development of such model differs the increased labor input [5], and the corresponding appendices (CosmosWorks, Ansys, Abaqus, Nastran, etc. in the most expensive versions) have high cost and are intended for work on high-performance computers.

Using of cheaper programs, for example, "the Universal Mechanism" is possible. This program is intended for calculations of objects of railway transport. Such approach is represented natural, as application for cranes of the fundamental results received in railway branch – long-term tradition. However a negative side of such approach is ignoring of specifics of cranes (significantly smaller speed of movement, heavy loads on wheels, wider track, etc.). If initial researches were based on related branch, then later characterized by a high degree of independence, which is a consequence of gradual refinement of methods.

Also hybrid modelling is possible, with use of multiple applications (CosmosWorks, Ansys, Abaqus, Nastran in less expensive modifications, the Universal Mechanism, MathCad, etc.), however it is rejected in view of the known problems connected with the organization of interaction of various environments at program level.

The above approaches do not satisfy the basic requirement of availability to the end user. Alternative is the using of MS Excel environment. In this case low level of cost, clear presentation of data, possibility of programming in the built-in VBA language (the major feature – code debugging in an operating mode) is provided. These qualities are especially valuable to the solution of the task having the complex nature. Successful experience of use of Excel for the solution of complex challenges of CAD connected with storage, data processing and their transfer in a graphic application, for example Autocad [6] was one of motives of a choice of the environment.

The main disadvantage of this approach is lack of built-in models of the physical phenomena which should be developed "from scratch".

The sequence of the solution of a task is presented in Figure 2. where it is designated: $X_{ij}, Z_{ij}, V_{sj}, a_{ij}$ – coordinates, speed and acceleration of the points corresponding to axes of running wheels at time t_j.

We will consider one of the most difficult moments – modelling of an elastic design of a skeleton of the bridge crane. At the moment we finalized the module that takes into account the behaviour of the elastic steel structure having the degree of redundancy - six. The example of an elastic metal construction of the crane with the indication of its splitting into elements and points is given in Figure 3. In this drawing the equivalent system for six times of statically indefinable metal construction of the bridge crane where excess unknown efforts are replaced with single forces is shown.

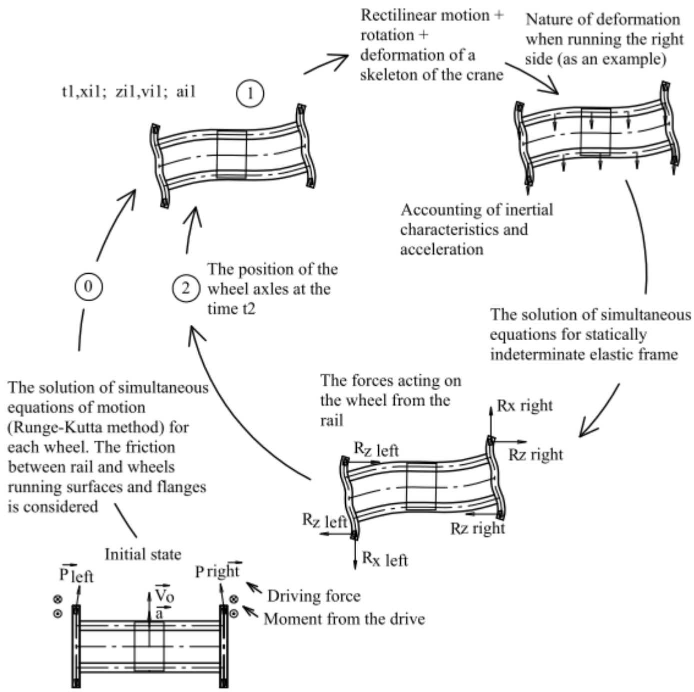

Figure 2. Sequence of the Decision of System of the Equation of Movement of the Crane

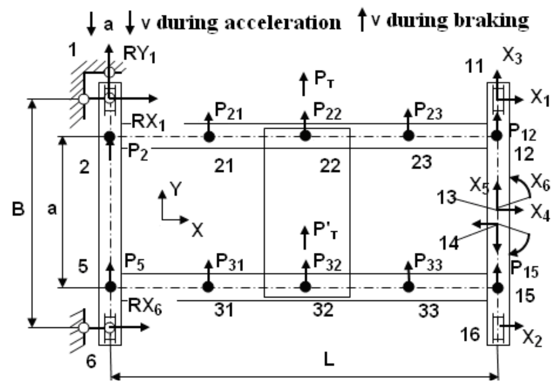

Figure 3. Submodel of an Elastic Metal Construction of the Crane and its splitting into elements and points

For simplicity, the external forces are applied to the system point- that allows us to calculate the Mora integral for moving (see the system of canonical equations in Figure 4., the sample solution is shown in Figure 5.) by the method Vereshchagin.

System of equations

δ11*X1 + δ12*X2 + δ13*X3 + δ14*X4 + δ15*X5 + δ16*X6 = Δ1 - ∑δ1*Pj
δ21*X1 + δ22*X2 + δ23*X3 + δ24*X4 + δ25*X5 + δ26*X6 = Δ2 - ∑δ2*Pj
δ31*X1 + δ32*X2 + δ33*X3 + δ34*X4 + δ35*X5 + δ36*X6 = Δ3 - ∑δ3*Pj
δ41*X1 + δ42*X2 + δ43*X3 + δ44*X4 + δ45*X5 + δ46*X6 = Δ4 - ∑δ4*Pj
δ51*X1 + δ52*X2 + δ53*X3 + δ54*X4 + δ55*X5 + δ56*X6 = Δ5 - ∑δ5*Pj
δ61*X1 + δ62*X2 + δ63*X3 + δ64*X4 + δ65*X5 + δ66*X6 = Δ6 - ∑δ6*Pj

Simultaneous equations solving

0,03*X1	+ 0,00*X2	- 0,33*X3	- 0,08*X4	- 0,32*X5	- 0,03*X6	= 0,00	+ 0,16*Pj	= 1,61E-01
0,00*X1	**+ 0,03*X2**	+ 0,01*X3	+ 0,08*X4	- 0,32*X5	- 0,03*X6	= 0,00	+ 0,16*Pj	= 1,61E-01
-0,33*X1	+ 0,01*X2	**+ 7,18*X3**	+ 1,05*X4	+ 8,48*X5	+ 0,54*X6	= 0,00	- 6,52*Pj	= -6,52E+00
-0,08*X1	+ 0,08*X2	+ 1,05*X3	**+ 0,53*X4**	+ 0,00*X5	- 0,00*X6	= 0,00	+ 0,00*Pj	= 2,78E-17
-0,32*X1	- 0,32*X2	+ 8,48*X3	+ 0,00*X4	**+ 16,96*X5**	+ 1,07*X6	= 0,00	- 13,03*Pj	= -1,30E+01
-0,03*X1	- 0,03*X2	+ 0,54*X3	- 0,00*X4	+ 1,07*X5	**+ 0,10*X6**	= 0,00	- 0,70*Pj	= -7,01E-01

Inverse matrix

84,04	-12,35	1,80	10,27	-0,90	21,58
-12,35	84,04	-1,80	-10,27	0,90	21,58
1,80	-1,80	1,18	-1,80	-0,59	0,00
10,27	-10,27	-1,80	8,33	0,90	0,00
-0,90	0,90	-0,59	0,90	0,46	-1,71
21,58	21,58	0,00	0,00	-1,71	40,14

Figure 4. System of the Initial Equations of a Method of Forces and the return matrix for its coefficients

Prescribed displacements

Δ1 =	0,00	м
Δ2 =	0,00	м
Δ3 =	0,00	м
Δ4 =	0,00	м
Δ5 =	0,00	м
Δ6 =	0,00	м

Solving			**Solution check** Δi - ∑j δi*Pj
X1 =	**-3,563E+00**	кН	-5,8E-16
X2 =	**-3,558E+00**	кН	3,1E-16
X3 =	-1,664E-03	кН	0,0E+00
X4 =	2,530E-03	кН	2,2E-16
X5 =	-9,785E-01	кН	0,0E+00
X6 =	1,191E+00	кН	0,0E+00

Figure 5. Example of the Decision of System of the Initial Equations at basic data of P_{22} = 2 kN; P_{32} =-2 kN

Data are set and processed in the following sequence. At first automatically is formed, and then the system of the initial equations of a method of forces (see fig. 4), with use of special language of the description of model decides. The geometry of the bridge is defined by means of the points connected in elements.

Then on the basis of original data on a work sheet calculation tables are automatically formed, links of settlement formulas are generated. Thus, first of all, anchor points are distinguished and the corresponding reactions calculated. Further, for each point the moments of forces operating on it, and also longitudinal and cross forces are defined. Pre-compiled schema influences which are fixed on the sheet in the form of special formulas containing references to affect segments. Is "the way of load transfer " to a point on the left (see Figure 6). The program gives preference to shorter way. In the same way the moments in all points are defined. Then for all elements formed connected pairs of points constructed diagrams of moments (for each force separately).

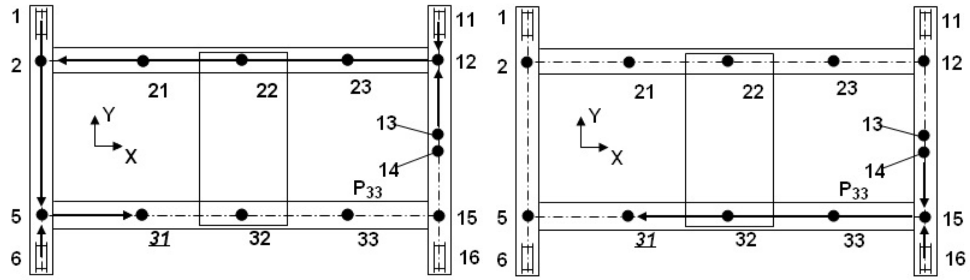

Figure 6. Power streams to a point No. 31 from forces applied in other points of model

Proposed rule of signs, convenient from the standpoint of making the algorithm for constructing diagrams. Accounted for the enumeration sequence points of the elements in their job and the direction of the power flow diagrams to the point under consideration. As an example, Figure 6 shows two variants of power flows to one of the points of the model (point number 31).

Diagrams are multiplied by Vereshchagin (trapezoid rule) and summed. The obtained values are the coefficients of the linear equation system (see Figure 5):

$$\Delta_{iP} = \sum\left[\int_S \frac{\overline{M}_i \cdot M_P ds}{EJ_y} + \int_S \frac{\overline{N}_i \cdot N_P ds}{EF} + \int_S k \cdot \frac{\overline{Q}_i \cdot Q_p ds}{GF}\right] \quad (1)$$

$$\delta_{ik} = \sum\left[\int_S \frac{\overline{M}_i \cdot \overline{M}_K ds}{EJ_y} + \int_S \frac{\overline{N}_i \cdot \overline{N}_K ds}{EF} + \int_S k \cdot \frac{\overline{Q}_i \cdot \overline{Q}_K ds}{GF}\right] \quad (2)$$

where:

M_p – is the moment caused by a system of external forces (∑P) [$kN\cdot m$],
N_p, Q_p, – is the forces caused by a system of external forces (∑P) [kN],
$\overline{M}_i$, $\overline{M}_k$ – is the moments caused by single forces ($\overline{X_i}$) [$kN\cdot m$],
$\overline{N}_i$, $\overline{N}_k$, $\overline{Q}_i$, $\overline{Q}_k$, – is the forces caused by single forces ($\overline{X}_i$) [kN],
K – is the coefficient depending on the shape of the section,
G – is the shear modulus [kPa],
E – is the modulus of elasticity [kPa],
F – is the cross-sectional area [m^2],
J_y – is the moment of inertia about the vertical axis of the cross-sections of the bridge structure [m^4],
s – is the variable of integration (along the structural element) [m].

It may be noted that there is no fundamental difference between the traditional method of solving the problem and the method of elastic beam finite elements [7]. Waiver of making complex matrices and partial transfer actions in the logic of generating the design scheme can greatly simplify the resulting matrix that is essential to improve the performance in the calculation step.

5. Conclusions

The program intended for modelling of process of movement of cranes of bridge type is developed. The program has to be applicable equally for researches, and also for calculations of cranes again developed and being in operation taking features of a design, the scheme of a way and an arrangement of wheels into account. It has to provide the increased quality of resultant data, and also expand possibilities of the analysis of the emergency situations arising in practice.

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