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MODELLING OF THE LIFT CRANE VIBRATION CAUSED BY THE LIFTING LOADS

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Abstract

At designing of the supporting iron of the bridge cranes it is necessary among other loadings to consider the dynamic forces caused by the lifting loads. At the strength analysis of the bearing structures the static loads are usually considered with the subsequent correction in view of dynamic coefficient. In the presented work the vibrations of the bridge crane were modelled with the use of the finite element method and the entry conditions were set in the form of the kinematic excitation. The functional dependency on the time for kinematic excitation of the vibrations was found by means of the simplified dynamic model of the system with two or four degrees of freedom.

1. Introduction

The forecasting of the dynamic properties of the bearing structures of a bridge cranes at the stage of their designing is now possible with use of the finite element method. Thus there can be a problem with the correct estimation of the value of the damping parameters for the vibration analysis of the considered model. The complications arise, for example, at modeling of the vibrations caused by the moving carriage or the lifting of loads. If it is necessary to consider the complex movements of the rigid bodies, the modelling with use of the FEM becomes insufficient.

On the other hand, the use for the description of bridge crane dynamics the models with a rigid mass elements and concentrated elastic and damping elements (MBS) at restriction up to several degrees of freedom does not give the full information on vibrations of a design as a whole. In the case of the complex designs of the bridge labour intensive process is also definition of parameters of model, such as the reduced mass, stiffness and damping parameters.

2. The modelling of the lifting by means of the FEM

The example of the finite element model which can be used for an estimation of the vibrations caused by the lift of loads is presented on fig. 1. Two mass elements simulating the carriage and the load are used in this model besides finite element modelling of the bridge structure. The nonlinear rod element replaces a rope; next rod element replaces the elastic foundation. The contact element of the node - node type models the contact between the load and the foundation. Originally the load lays on the foundation and the contact element is "closed". In offered model the elastic foundation moves down with the speed of the lifting of loads that leads to dynamic effect similar to the action caused by the shortening of a reeled up rope.

The performance of calculations demands use of the FEM software which allow transferring the results of calculations from one step of calculations to another, and also updating the loadings and the boundary conditions. The solving algorithm consists of two stages:

1. It is necessary to determine static deflections of the system caused by own weight of the bridge and carriage, and also by the weight of a lifted load. The rod simulating the elastic foundation is compressed. The node „N4" (fig.1) remains motionless at the given stage.

2. Further it will be necessary to set the constant speed for the node „N4", thus, the foundation will move down from a considered load.

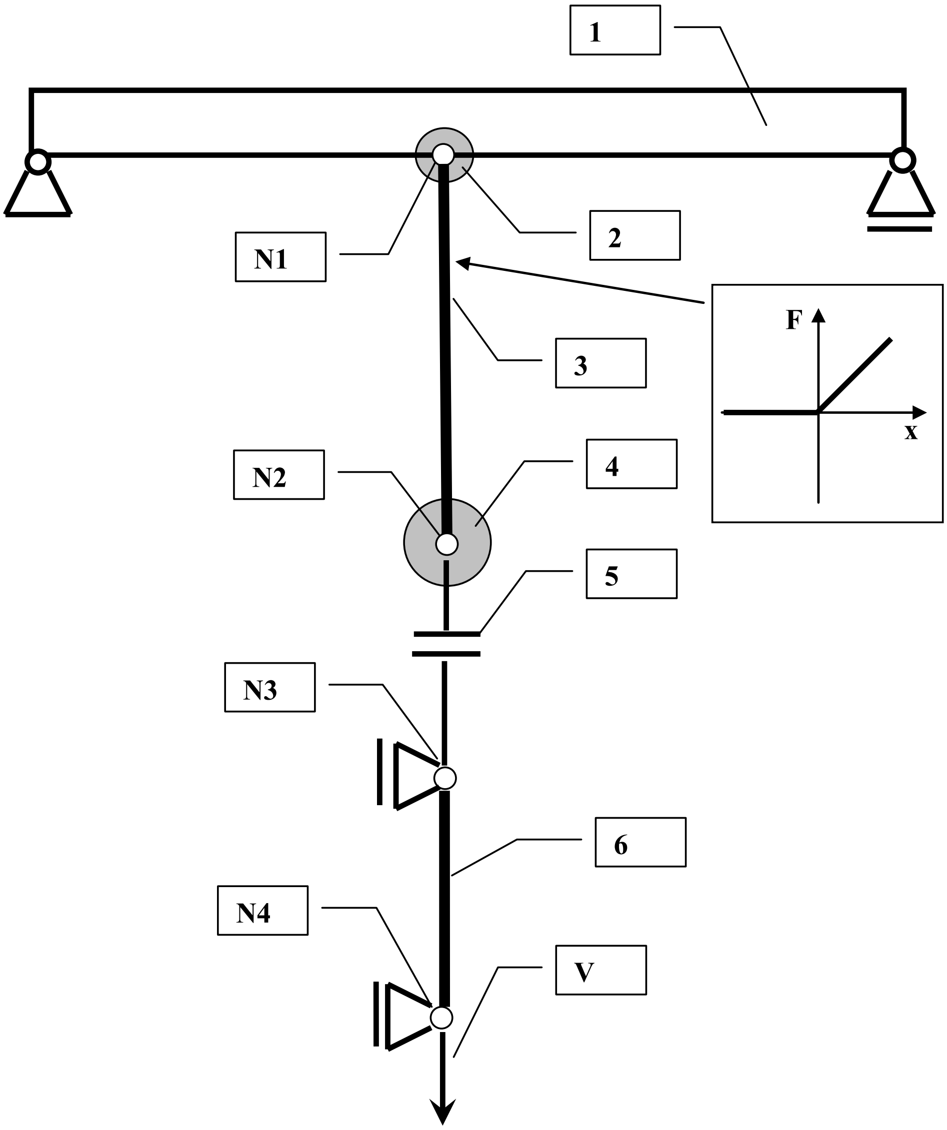


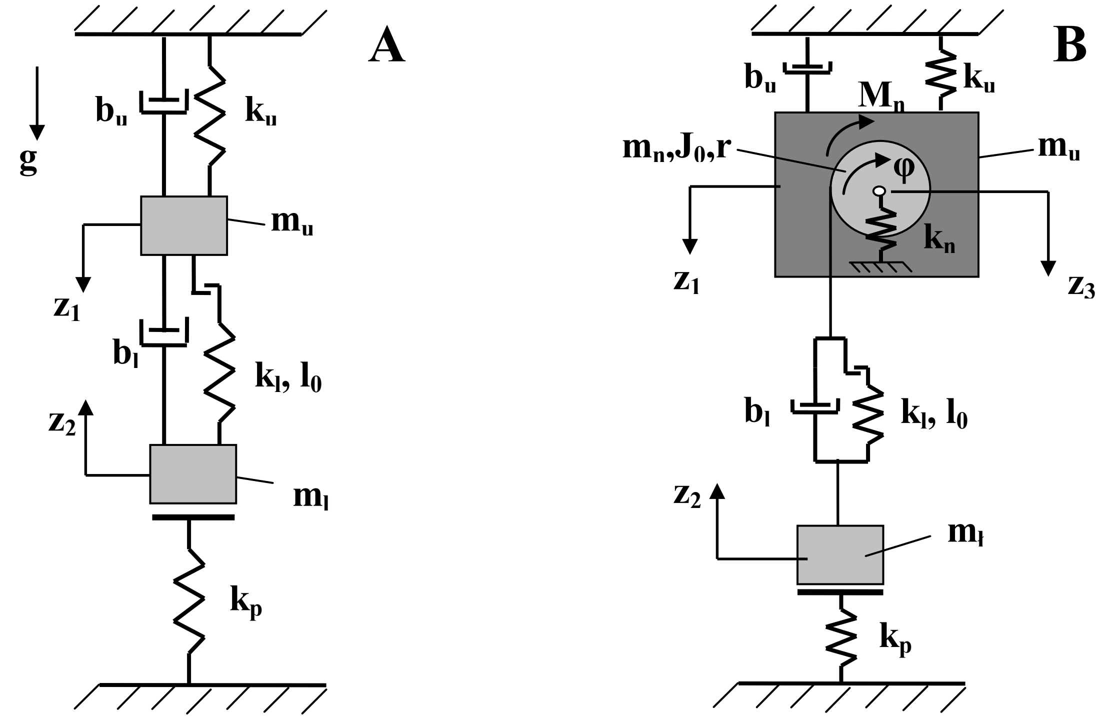
Fig. 1. Finite element model of lifting process

Description: N1,N2,N3,N4 - additional nodes; V - speed of lifting; 1 - FE model of the bridge; 2 - mass element (weight of the carriage); 3 - rod element for modeling rope (nonlinear); 4 - mass element (weight of the load); 5 - contact element (node-node); 6 - rod element for modeling elastic foundation

The imperfection of the presented solution is the assumption of the constant speed of the lifting loads. It is not possible to consider also the change of a stiffness of the rope owing to its shortening. Solving process demands direct integration of the equations of movement and is usually very long.

3. Modelling of the process of lifting by means of the rigid mass elements

The model with the rigid mass elements having 2 degrees of freedom is shown on fig. 2a. Here the constant speed of lifting of loads is set. Fig. 2b represents the model based on work [1] which has 4 degrees of freedom. The given model is added with the rope drum on which the constant rotating moment is set.



Rys. 2. The models with the rigid mass elements

Description: model A: m_u – mass of the bearing structure and the carriage with the rope drum; m_l – mass of the load; k_u,b_u – stiffness and damping of the construction; k_l,b_l – stiffness and damping of the rope; l_0 – length of the rope; k_p – stiffness of the foundation; z_1 – vibrating movement of the bridge; z_2 – movement of the load;

model B: m_u – mass of the bearing structure; m_n, J_0, r – parameters of the carriage and the rope drum; M_n – rotating moment of a drum; z_3 – vibration of an axis of a drum; φ – rotating angle of a drum

The equations of the movement of the model B can be written in the next form:

$$\begin{aligned} m_u \ddot{z}_1 &= m_u g + k_n\left(z_3 - z_1\right) - b_u \dot{z}_1 - k_u z_1 \\ m_n \ddot{z}_3 &= m_n g + F_{dyn} + R_{dyn} - k_n\left(z_3 - z_1\right) \\ m_l \ddot{z}_2 &= F_{dyn} + R_{dyn} - m_l g + N \\ J_0 \ddot{\varphi} &= M_n - \left(F_{dyn} + R_{dyn}\right) r \end{aligned} \qquad (1)$$

where F_{dyn} i R_{dyn} – the forces of elasticity and damping in the rope; N – the force of a reaction of the elastic foundation. The coordinate z_1 shows the displacement of a bearing structure relatively of its position in the not deformed condition. The coordinate z_2 describes the moving of the load, and z_3 is the moving of the drum relatively of the bridge.

The force of the elasticity of a rope depends on its length, and also depends on the presence or absence of the loading. It can be described by means of formulas:

$$F_{dyn} = \begin{cases} 0 & \Delta(t) \le l(t) \\ \dfrac{EA}{l(t)}\left[\Delta(t) - l(t)\right] & \Delta(t) > l(t) \end{cases} \quad (2)$$

$$\begin{aligned} l(t) &= l_0 - r\varphi(t) \\ \Delta(t) &= l_0 + z_{10} + z_{30} - z_{20} - z_1(t) - z_2(t) - z_3(t) \end{aligned} \quad (3)$$

where: *l(t)* – current length of a rope; *Δ(t)* – distance between the load and the middle of the rope drum; z_{10} – initial deflection of the bearing structure; z_{20} – initial deflection of the foundation under action of the load weight; z_{30} – initial deflection of the bearings of the rope drum axis; *EA* – rope stiffness on a tension.

The rope damping can be described as follows:

$$R_{dyn} = b_l(-\dot{z}_1 - \dot{z}_2 - \dot{z}_3 + r\dot{\varphi}). \quad (4)$$

The reaction force of the elastic foundation is equal:

$$N = \begin{cases} -k_p z_2 & z_2 < 0 \\ 0 & z_2 \ge 0 \end{cases} . \quad (5)$$

It is similarly possible to write the equations of the movement of the model A. They are simpler, as the model has less degree of freedom.

The scheme presented on fig. 3 shows a method of the modelling of the equations of movement (1) in the program Simulink of the package MatLab.

4. Typical results

Test calculations are lead for the bridge presented on fig. 4. By means of the FEM the reduced stiffness of a design has been defined, its mass has been certain also.

Modelling for both models A and B is lead for identical parameters. The rotating moment necessary for model B has been picked up so that to receive experimentally the speed of the lifting specified in model A.

The analysis of figures has shown (fig. 5, 6), that the vibrations of a bridge of the crane are closer to reality in the case of the model B. They decay during sufficient short time, have pulse character typical for the lifting of loads. The vibration of the model A despite of identical conditions of damping decay gradually. It is represented, that the model with two mass elements does not allow with sufficient accuracy to analyze the mechanical phenomena occurring at lifting of loads. The same results concerns to FE model (rys.1) which is ideologically close to the model A.

The amplitudes of the vibration in the model B can be reduced at the modification considering the fact of the use in the lifting mechanism of the polyspast, which essentially reduces the size of the rotating moment [2].

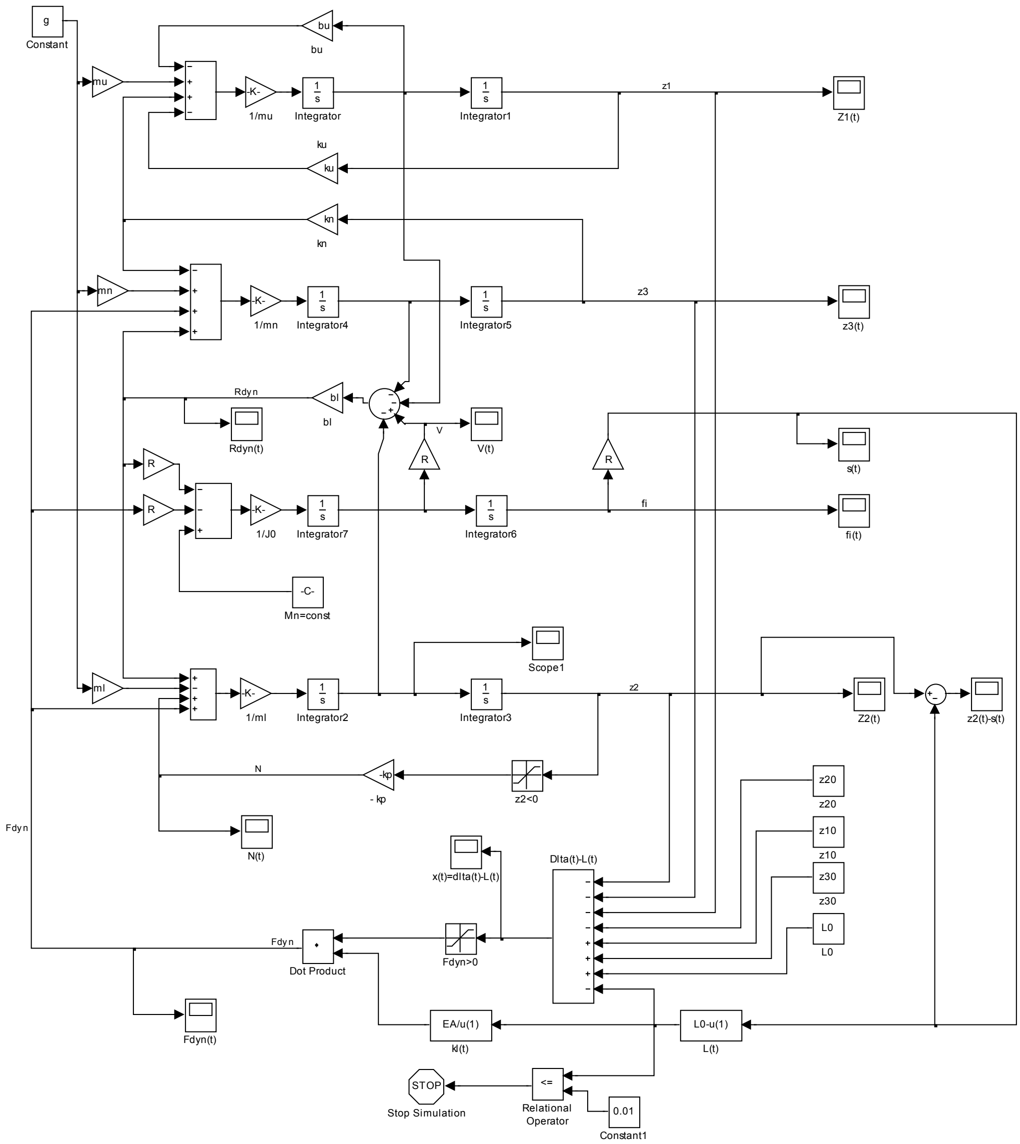


Fig. 3. Modelling of the equations of the movement (1) in software package Matlab

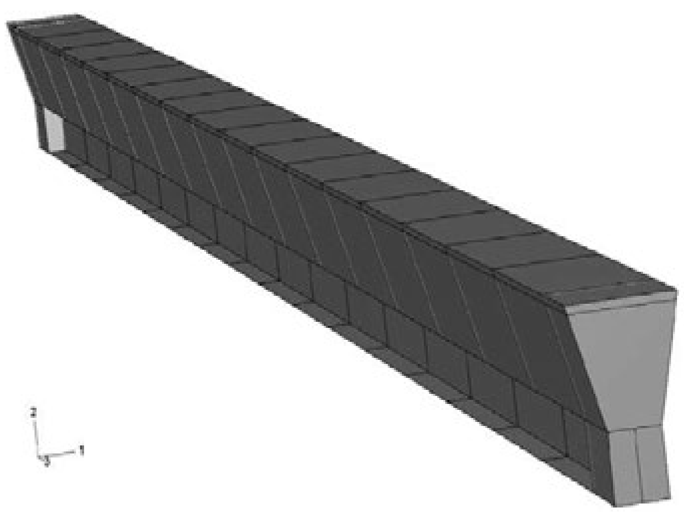


Fig. 4. Geometrical model of the considered bridge

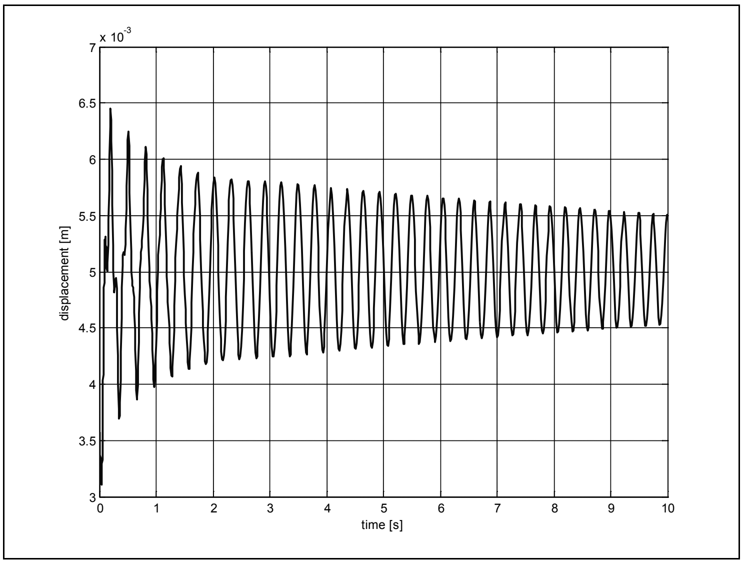


Fig. 5. Vibration of the bearing structure - model A

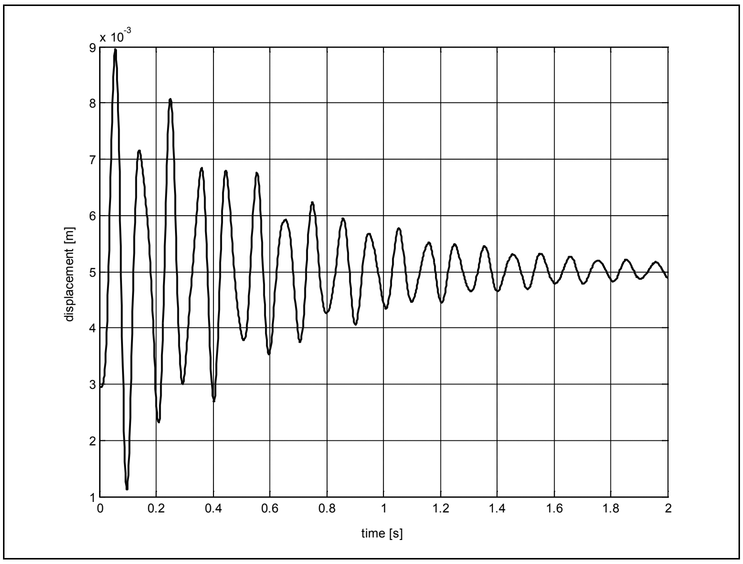


Fig. 6. Vibration of the bearing structure - model B

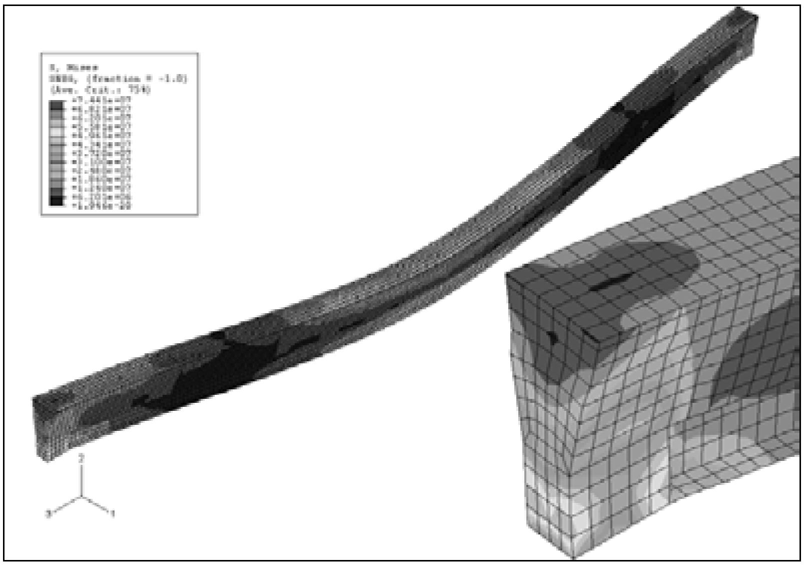


Fig. 7. Von Mises stress caused by the lifting of loads

The force impulse defined by means of model B in the further has been used as kinematic excitation at the analysis with use of the FEM of distribution of vibrations in the whole design. Results of researches are presented on fig. 7,8 and 9. During the first second the static deflection of a design under action of the own weight is considered. Kinematic excitation operates from the beginning of the second second up to the end of the third second of the analysis.

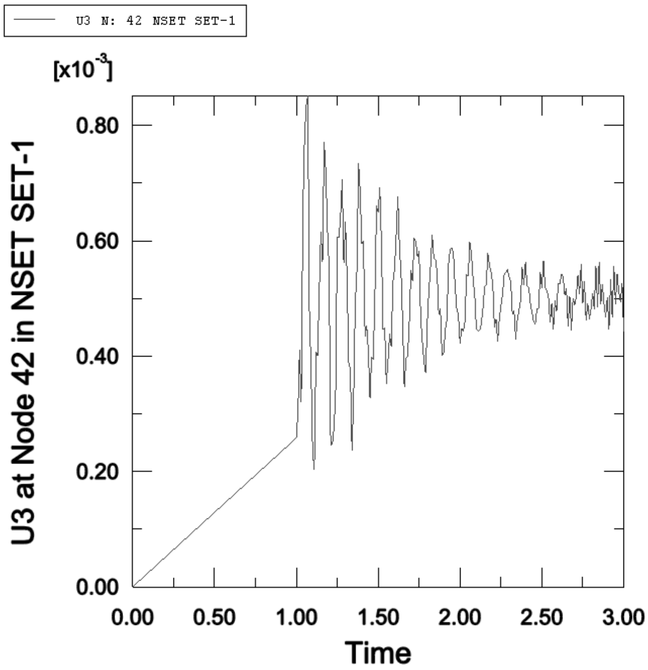


Fig. 8. Nodal displacements of the top bar relative to a direction of an axis of a bridge in a zone of a motionless support

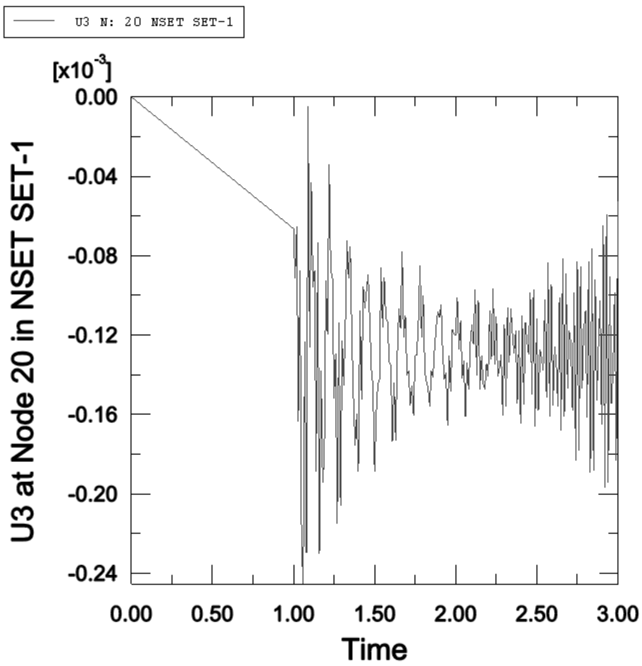


Fig. 9. Nodal displacements of the top bar relative to a direction of an axis of a bridge in a zone of a mobile support

5. Conclusion

The research of the bearing structures exclusively in the points of view of the static strengthening calculation with additional loadings [3] or the research of frequencies and eigenvibrations on occasions is insufficient. Sometimes it is necessary to carry out the analysis of the influence of the complex dynamic phenomena on a considered design.

The models offered in work and the methods of calculation of vibrations of bearing structures of bridge cranes caused by the lifting of loads can be used for an estimation of a design at the stage of its virtual modelling (conceptual). Final modification of the model is in need of the further researches. The numerical testing and also the verification of results by means of measurements on the operative objects are planned.

6. Literature

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[2] Borkowski W., Konopka S., Prochowski L.: Dynamika maszyn roboczych. WNT, Warszawa 1996.

[3] EN 13001-1÷3.1:2005. Cranes. General Design.