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TOWER CRANE DYNAMICS STUDY

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ABSTRACT

The emergence and development of new highly complex technical products generate numerous problems in designing technological systems. For these products design and manufacturing traditional models are no longer sufficient for two reasons: during lengthy design and high costs for implementing these methods.
The new methodological superiority, wich does not necessarily involve an increase in study complexity, is based on importance of the whole assembly related to its components.

KEYWORDS: lifting weight, lifting mechanism

1. INTRODUCTION

The lifting and lowering movements of the load are the most frequent working movements of the lifting machines. Dynamic phenomena occur during starting and braking of these movements. There are two cases to be considered separately when it comes to lifting:

- The first corresponds to lifting the suspended load - the charge is at rest at a certain height;
- The second case corresponds to lifting the load placed on the supporting surface.

The dynamic effects are usually greater in the second case and are even more pronounced as the load is suddenly removed.

2. THE PHYSICAL MODEL

The simplified dynamic model is studied to highlight the conditions and parameters that determine the dynamic effects. The model is a result of the real life behavior of the crane.

The elements of the lifting mechanism kinematic chain are at least one order of magnitude stiffer than the steel construction crane so that the transmission mechanism: motor-cable reel, can be considered rigid.

Maximum dynamic effects occur during the first, or at least the first two periods of oscillation of the crane structure, while still damping effect is still negligible; study is therefore dynamic models without damping.

It neglects the effect of varying stiffness elastic hoist for lifting due to variations in the length of his raise or lower the load because on the one hand speed lift-descent is usually low (several meters per minute), and on the another, lasting so small oscillations of the first hoist amendment is insignificant.

The dynamic lifting mechanism takes the form of a physical model (see Figure 1) and a reduced dynamic model (see Figure 2).

The physical model consists of: 1-drive motor, 2-clutch, 3-reducer, 4-reel, 5-hoist, 6- load high.

Inertial mass elements are: $J_1, J_2, J_3, J_4, J_6, J_7, m_8$, and the elastic elements are: k_1, k_2, k_3, k_4, k_5.

The calculation equivalent scheme can be done in several the ways in view of the properties of inertia, and elastic elements dominant components. In the physical model of the mechanism the mass and elastic parameters of the system.

Thus, there are known moments of inertia of engine rotor, coupling parts, gears, drum, as well as the lifting weight task.

The kj (j = 1.5) - stiffness coefficients of the intermediate elements (shaft and the lifting cable).

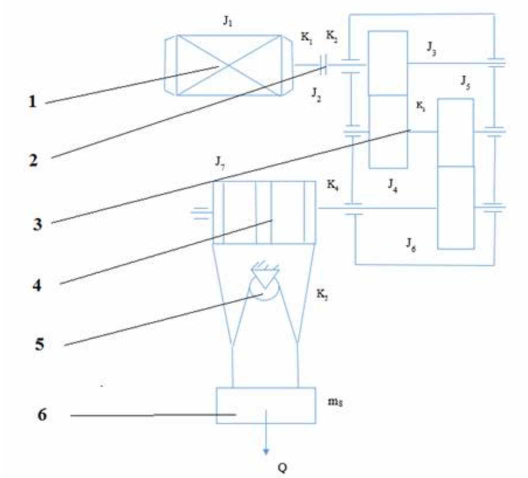

Fig. 1- The physical model of tower crane hoisting mechanism (Scheme kinematics) 1 - Motor drive, 2 - Coupling, 3 - Reductor, 4 - Reel, 5 -Tackle, 6 - Lifting weight

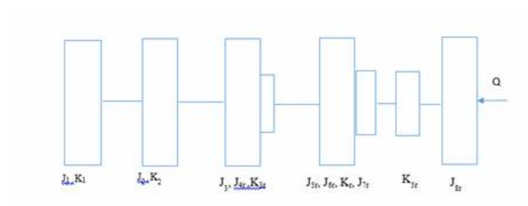

Fig. 2 - Equivalent circuit model of Figure 1.

Considering only the motor shaft the space-time model can be obtained; Figure 2. The dynamic deformation of each elastic element and the state of their dynamic loading can be determined using this model.

The dynamic modeling will consist of the following steps:

- Develop physical model
- Develop the model with low space-time features
- Determining the set of differential equations of motion
- Composition of inertia matrix [M], the stiffness [K], and the disturbing forces vector {f}
- Determination and graphic representation, in real time, of the motion laws and own pulsation according to concrete data and initial conditions
- The system of differential equations that determine the motion of the mechanical system in Figure 2 has the form:

$$[M]\{\ddot{\varphi}\}+[K]\{\varphi\}=\{f\} \qquad (1.1.)$$

3. EQUIVALENCE OF INERTIAL ELEMENTS

The equivalence of inertial system dynamic elements can be seen in figure 3.. The dynamic model is a system with three degrees of freedom.

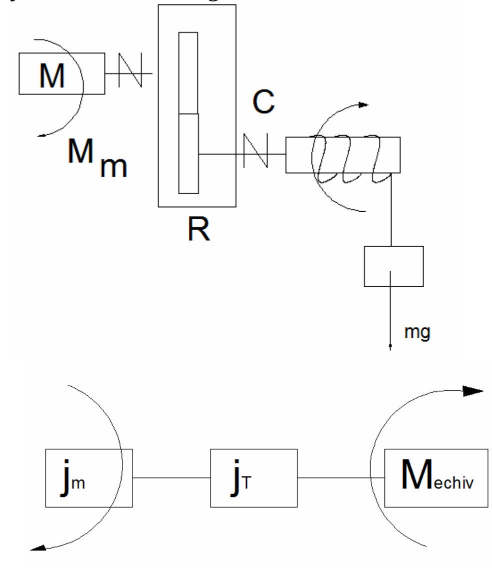

Fig. 3 - Scheme to reduce inertial elements

The principle of equivalence of inertia for essential elements is the kinetic energy of equivalence relation (1.2.).

$$E = E_{echiv} \qquad (1.2.)$$

For the motor shaft, the real moment of inertia is equal to the equivalent moment of inertia.

$$J_{motor} = J_{echiv} \qquad (1.3.)$$

Applying the principle of kinetic energy equivalence for the gear:

$$E_2 = E_{2echi} \Rightarrow \frac{1}{2}J_2\omega_2^2 = \frac{1}{2}J_{2echiv}\omega_1^2 \Rightarrow$$
$$J_{2echiv} = J_2\left(\frac{\omega_2}{\omega_1}\right)^2 = J_2 i_{21}^2 \qquad (1.4.)$$

The inertial element for the reel has the formula:

$$\frac{1}{2}J_{tambur}\cdot\omega_2^2 = \frac{1}{2}J_{tambur\_echiv}\cdot\omega_1^2 \Rightarrow$$
$$J_{tambur\_echiv} = J_{tambur}\cdot(i_{21})^2 \qquad (1.5.)$$

We substitute values and obtain equivalent moments of inertia for equivalent dynamic system in Figure 3.

The following initial data is considered for the lifting equipment: Lifting load,Q=12.5 tf, the motor’s inertia moment Jm= 0.0547daNms^2, the moment of coupling inertia Jc= 0.0471 daNms^2, the gear ratio i_R=101.88, the gear ratio of the hoist i_p=4, the average diameter of the drum D_{tm} = 0.4174 m, the efficiency of the mechanism η=0.85

Considering the values of initial data:

The moment of equivalent inertia for the gear:

$$J_{2echiv} = J_1 \cdot i_{21}^2 \cdot \eta = 0.0471 \cdot 101.88^2 \cdot 0.85$$
$$= 482.59 daN \cdot m \cdot s^2$$

The equivalent inertia moment for the reel:

$$J_{3echiv} = J_2 \cdot i_p^2 \cdot \eta = 428.59 \cdot 4^2 \cdot 0.85 = 6563.224 daN \cdot m \cdot s$$

The value of the inertia matrix of the system:

$$M = \begin{bmatrix} J_1 & 0 & 0 \\ 0 & J_2 & 0 \\ 0 & 0 & J_3 \end{bmatrix} = \begin{bmatrix} 0.0471 & 0 & 0 \\ 0 & 482.59 & 0 \\ 0 & 0 & 6563.224 \end{bmatrix}$$

Differential equations of the motion:

$$\begin{cases} k_2(x_2 - x_1) - F_{sol} + m_1 g = m_1 \ddot{x}_1 \\ F - k_2(x_2 - x_1) + m_2 g = m_2 \ddot{x}_2 \\ -F + m_3 g = m_3 \ddot{x}_3 \end{cases}$$

Results for movements, speeds and accelerations can be achieved by solving movement equations using Simulink Matlab software

The solving scheme of differential equations is illustrated in Figure 4.

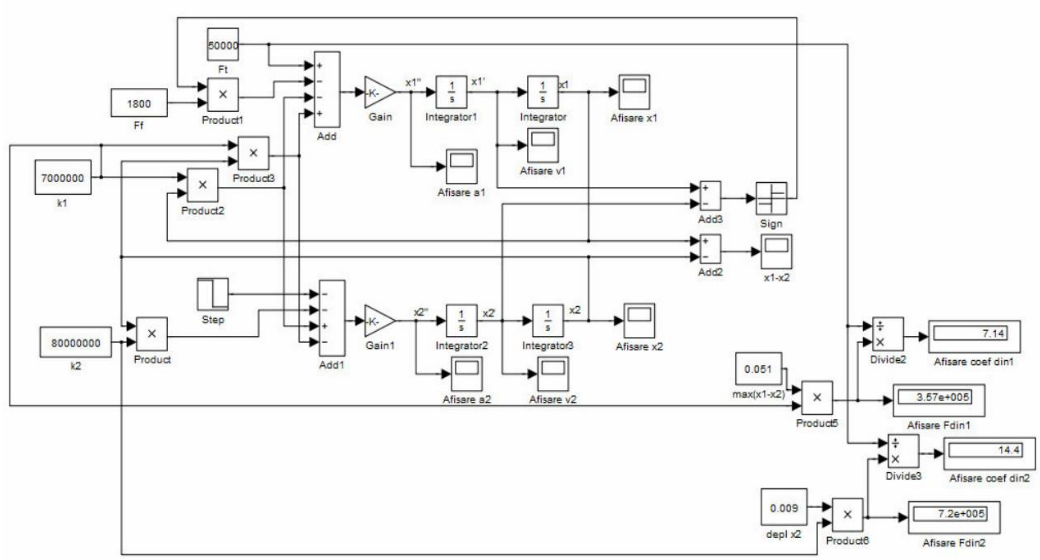

Fig. 4. Logical scheme of differential equations solving

4. RESULTS

Following the numerical simulation of a lifting system, the following results were obtained:

As seen in the chart, the maximum dynamic load movement is 10 mm. So, the cord extends 10 mm during the lifting system operation.

Figure 6 shows the diagram of velocity variation of vertical displacement of the load.

The speed varies from 0 to 12 m / s as green marks in the chart show.

The transitional arrangements of vertical movement of the load can be seen in the chart: acceleration, deceleration and braking.

There is an increase in speed due to gravitational acceleration within the 5....6 seconds range.

We know that vertical speed depends on the gravitational acceleration.

Figure 7 shows the variation of acceleration. As it can be seen in the chart, maximum acceleration is in the 5 ... 6 seconds range.

The load moving variation diagram is illustrated in Figure 5.

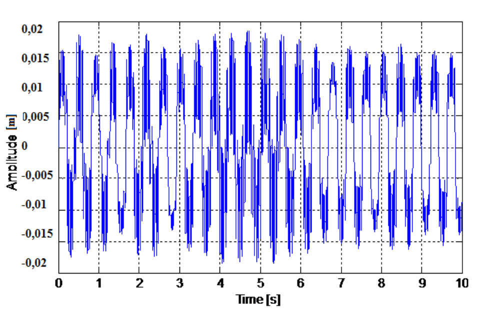

Fig. 5 - Movement variation

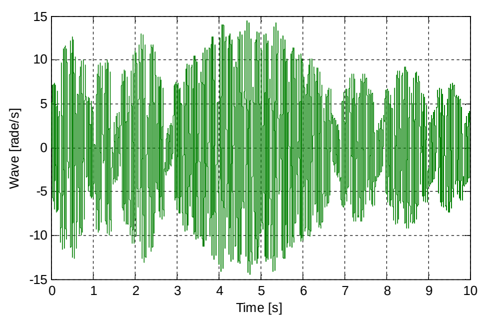

Fig. 6 - Speed variation

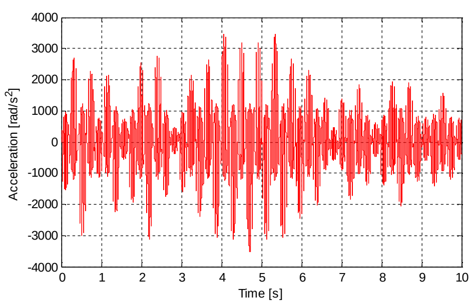

Fig. 7- Acceleration variation

5. CONCLUSIONS

Designing a lifting and transportation installation is a system of complex problems whose solution involves imagination and expertise of consumption of technical and financial resources that should be used efficiently.

In these circumstances, the most rational way to proceed is to approach the study of lifting and transportation installations as dynamic systems.

Fundamental advantages arising from the hierarchical structure of these systems as dynamic systems involving the use of specific methods and procedures, and general systems theory using a powerful mathematical apparatus that facilitates appropriate processing of data obtained through various experiments.

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