# Research of Cargo Delivery Errors by Conveyance using Lifting Mechanism

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**Abstract.** The mechanical properties of the rope - stiffness and internal friction changes during the movement of cargo. For this reason, under the influence of gravity and inertial forces in the rope having varying tension. Thus, the lift mechanism further exposed to dynamic loads. The highest value of this load is obtained at the beginning of lifting and lowering in place. The mathematical model of the lift mechanism was investigated using the original software package and found dynamic load. In modern control system used cranes lifting mechanism, taking into account the deviation from the vertical rope. Dynamic load on the rope can distort the signals. Results are used to improve the control system of the lifting mechanism.

## 1. Introduction

Manufacture of large constructions involves some responsible operations, e.g. delivery of separate components to an assembly site. Overhead cranes are used for transport of the same parts. The said cranes just as gantry cranes are used for loading works in ports and railway stations. In order to cut the duration of the said operations, transport speed is increased, thereby adding to momentum in the start and end of transport. This in turn causes additional dynamic loads and poses threat to the service personnel and other objects in the vicinity. The purpose of the following paper was to provide analysis for trajectory of cargo movement and dynamic phenomena arising in the process. Study was conducted by way of modelling involving special software and computer models in MATLAB/SIMULINK media. As a result of the modelling session, dependencies of cargo swinging were received in course of its movement and depending on oscillation of longitudinal load of the rope.

## 2. Mathematical model and the program for its computing

In Fig. 1, a dynamic model of a cargo lifting mechanism using overhead crane is provided. Rope with a hook, where cargo of mass $M$ is suspended, is fixed to a rope pulley in point $O$. Rope pulley can move under impact of gear on crane rails on $X_0$ coordinate. Crane with a rope pulley can move under impact of gear on $Y_0$ coordinate using support rails. Gears are used to set, by using e.g. controllers, given speed on the axes. The same goes for the length of rope. Diagrams on speeds set during modelling are provided in Fig. 3. We shall assume that the performance mechanisms use high precision in working out given movement, which allows for application of cinematic agitation on $X_0$, $Y_0$ and $L_0$ coordinates. Length of rope $L$ can change under control, force of gravity and dynamic loads.

The following expressions for kinetic and potential energy and dissipative function were established. Having differentiated Lagrange equations, equations were received for generic $\theta_x$, $\theta_y$ and $\delta_L$ coordinates. General solution can be presented as follows:

$$\ddot{\vartheta}_x + \frac{H_2}{M{L_0}^2}\dot{\vartheta}_x + \frac{g}{L_0}\vartheta_x = \frac{\ddot{X}_0}{L_0}, \tag{1}$$

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$$\ddot{\vartheta}_y + \frac{H_2}{ML_0^2}\dot{\vartheta}_y + \frac{g}{L_0}\vartheta_y = \frac{\ddot{Y}_0}{L_0}, \quad (2)$$

$$M\ddot{\delta}_L + H_1\dot{\delta}_L + \frac{C_1}{L_0}\delta_L = Mg - M\vartheta_x(\ddot{X}_0 - \ddot{L}_0\vartheta_x) - M\vartheta_y(\ddot{Y}_0 - \ddot{L}_0\vartheta_y) - M\ddot{L}_0. \quad (3)$$

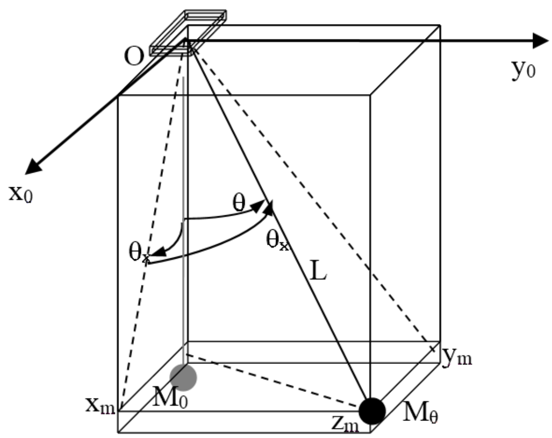



**Figure 1.** The dynamic model.

**Table 1.** The parameters of the model.

| | | | |
|---|---|---|---|
| G | 9.81 | m/s$^2$ | Free fall (gravitational) acceleration |
| $L_0$ | 10 | m | Initial length of the rope |
| M | 950 | kg | Mass of cargo |
| H1 | 225 | N s/m | Damping in the rope |
| H2 | 1050 | Nm s/rad | Damping in the cargo suspension point |
| C1 | 716000 | N/m | Initial tensile stiffness of the rope |

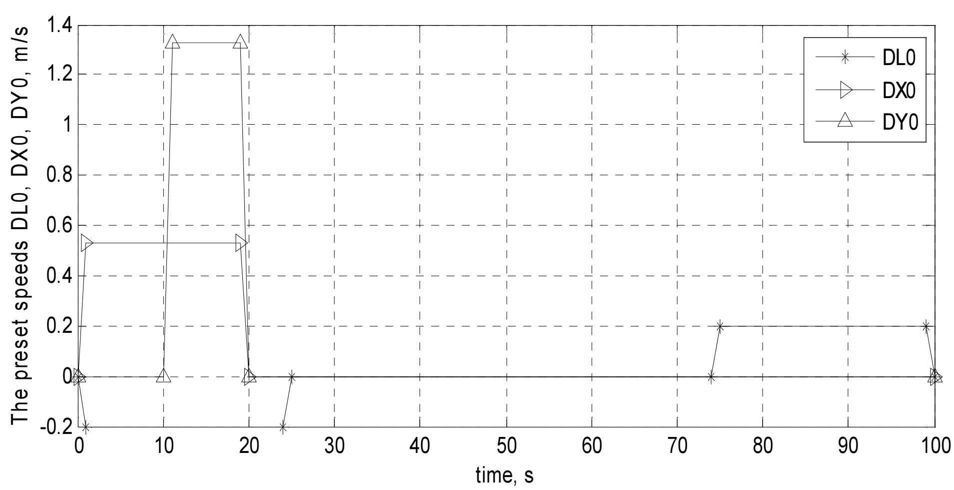



**Figure 2.** Diagrams of change in pre-set speeds of lifting mechanism (DL0), rope pulley (DX0) and crane (DY0).

## 3. Terms of simulation

Values of parameters in the model appear in Table 1, while the values of agitation signals appear in Fig. 2. Damping data corresponds to [1].

## 4. The results of the investigation

Processing of modelling results employs the following correlations between key and auxiliary coordinates:

1. Projections of distances from suspension point on rope pulley to cargo centre of gravity:

$$X_m = \vartheta_x L, \tag{4}$$

$$Y_m = \vartheta_y L. \tag{5}$$

2. Distance from starting point of movement to cargo center of gravity and height of hook over ground level:

$$X_M = X_0 + X_m, \tag{6}$$

$$Y_M = Y_0 + Y_m, \tag{7}$$

$$h_{kr} = h_k - L, \tag{8}$$

$h_k$ – starting height of hook position, $h_{kr}$ – current height of hook.

In case of horizontal movement of cargo suspended on hook, swing occurs. Swinging can materially distort trajectory of movement of cargo, which in turn can have severe consequences. Amplitude of swinging changes in course of movement of freight and depends, e.g. on scope and nature of horizontal acceleration at cargo suspension point, length of rope and other factors.

Fig. 3 displays nature of cargo swinging at the end of movement cycle, when engines of horizontal movement are switched off, and the winch of rope pulley brings down the cargo.

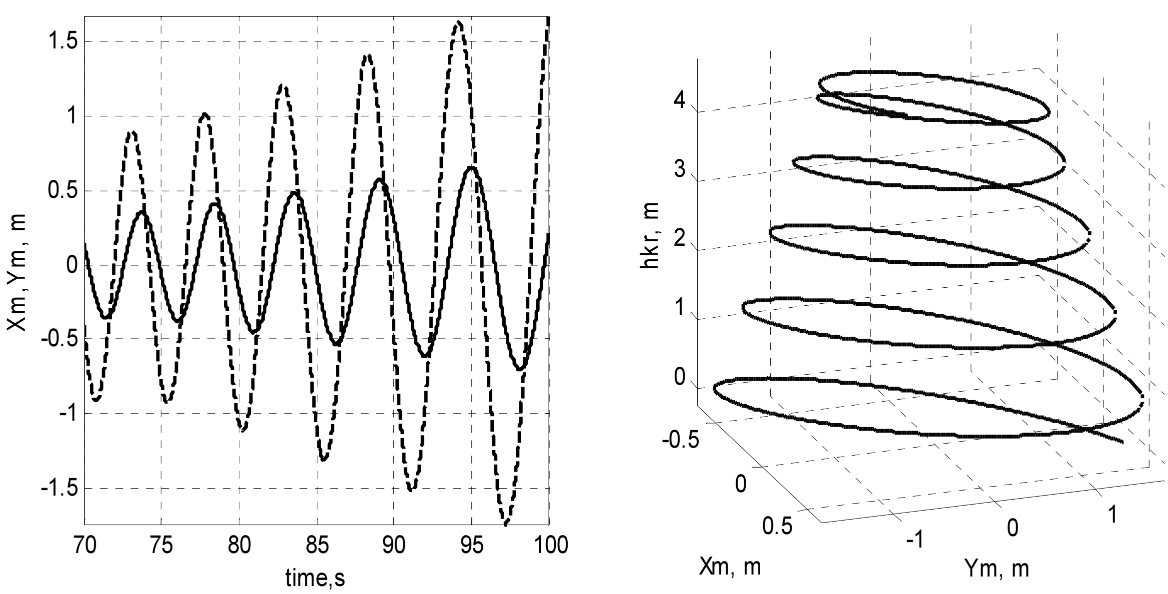
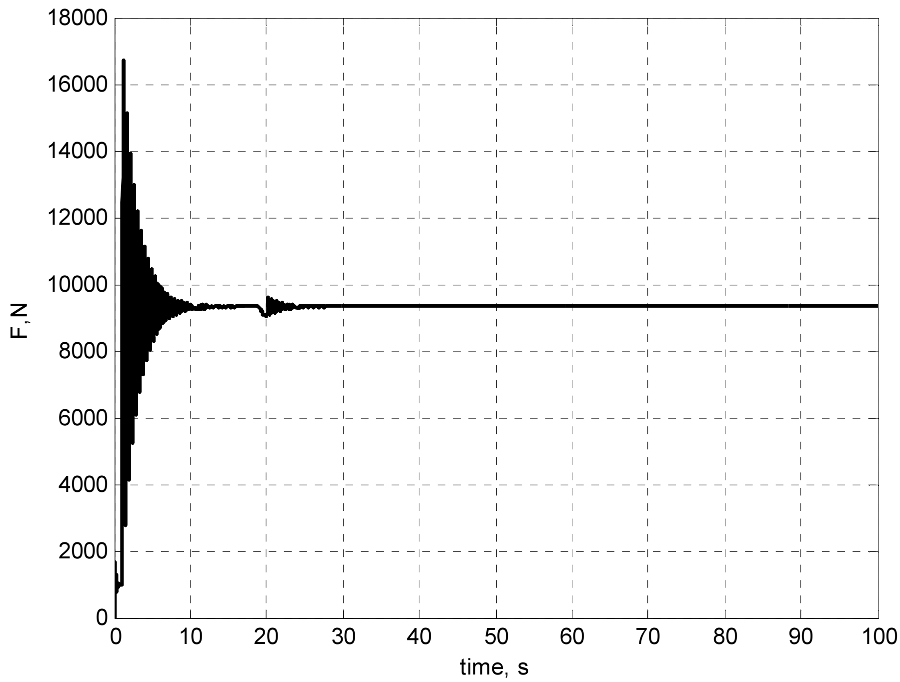


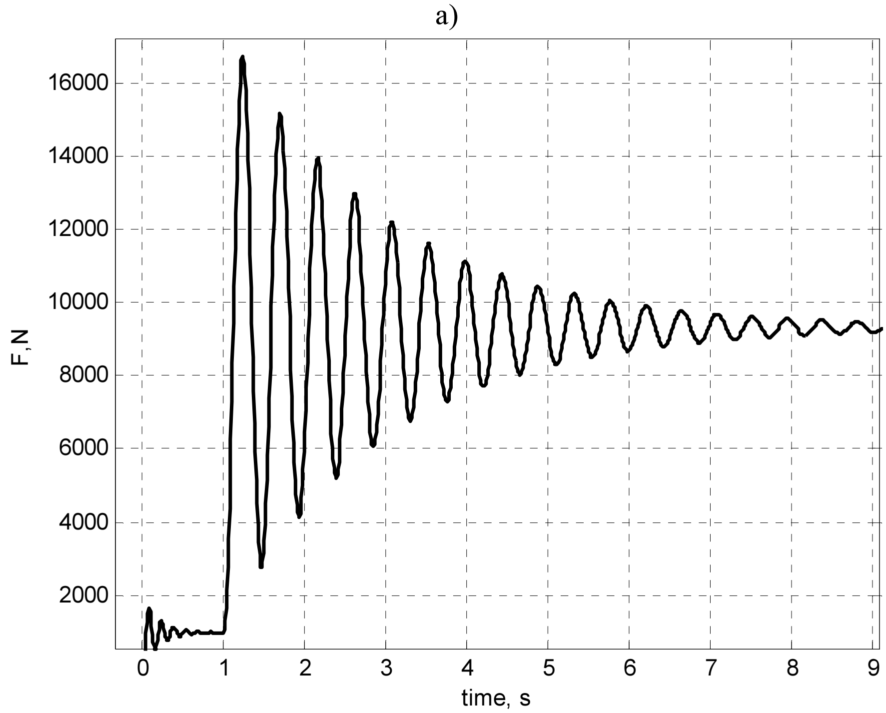

**Figure 3.** Nature of swinging of cargo, when winch of rope pulley operates on lowering only.

Notably the amplitude of swinging in case of lowering cargo (Fig. 3) increases. In the meantime however one must stabilize position of cargo before placing the same on the foundation. In order to stabilize the position one must weight for a certain time or take special means to tackle swinging. Amplitude of swinging can be reduced by making use of special laws [1] of smooth acceleration and breaking of horizontal movement as well as by applying other laws on optimum movement, e.g. by using soft logic [2] and return correlation on deviation of cargo rope from vertical position.

Different events, e.g. picks slack rope (sudden selection of ease), turning on and off controllers of horizontal movement, swinging of cargo; all cause change in longitudinal force, which affects the rope and frequencies of oscillations [4, 5]. The model has demonstrated increase in frequency at 1.38 times while the length of rope was reduced by 1.9 times. This can be explained by the fact that longitudinal stiffness of rope (for stretching) decreases as the length increases.




a)




b)

**Figure 4.** Oscillations of stretching effort on rope: a – general picture; b – selection of ease of rope.

It is established that stiffness of rope increases depending on increase in load. Experimental data were provided to support nominal load of rope and stiffness under nominal load. The dependency obtained of relative stiffness of rope from relative value of load is can be approximated using polynomial.

As a result of modelling session trajectories of key coordinates were obtained in cycle of movement of cargo. Analysis of dependences obtained allows for stating that inertia forces in the start and end of transportation make delivery of cargo more difficult given strict requirements on precision positioning. This must be taken into account when designing mechatronic control software.

## 5. Conclusions

1. In the beginning of the lifting process, additional dynamic loads appear. The value of the dynamic load factor achieves up to 1.7. The duration of the impact – up to 10s.

2. On cargo swinging, dynamic loads appear in the rope. The value of the dynamic load factor depends on the amplitude of swinging. On appearance of swinging, the frequency of the dynamic loads is not bound with the frequency of swinging. Later, the frequency of the dynamic loads becomes equal to the frequency of swinging and they act within the whole period of swinging.

3. On cargo descending, the amplitude of cargo swinging increases: the precizity of cargo delivery increases as well.

4. For reduction of cargo swinging, mechatronic systems controlling the torque formed in a lifting mechanism are applied. In order to ensure a reliable operation of such a system, the dynamic loads that appear in the said mechanism should be assessed.

5. With horizontal movement of the suspended load may be rocking, which can significantly distort the path of the load, reduce turnover and cause dangerous consequences.

6. The amplitude of the swing depends on the nature and horizontal accelerations of the suspension point load rope length and other factors. The amplitude of the swing can be reduced by smooth acceleration and deceleration of horizontal displacement, and the application of other laws optimal control.

7. Various events, such as sudden weakness sample, switching controllers, the horizontal displacement, load swing, cause changes in the longitudinal force acting in the rope and the frequency of oscillation.

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