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Microcontroller Carrying Capacity Limiter of the Electric Crane

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ABSTRACT

The opportunity of realization of the carrying capacity limiter for cranes of bridge type with use of an indirect method of measurement of cargo weight is provided. The informative parameter is evaluated and experimentally confirmed. The mathematical model of the hoisting mechanism of the electric crane and the carrying capacity limiter is developed. Rotational speed of the driving IM was determined with respect to stator reference frame with Sensorless techniques and was experimentally checked, allowing to determine with sufficient accuracy rotation frequency of the motor and to calculate weight of a lifted cargo.

Keywords: Bridge Crane, Hoisting Mechanism, Electric Drive, Induction Motor, Carrying Capacity Limiter, Mathematical Model, Simulation

Introduction

Reliability and safety of load-lifting bridge cranes which has especially fulfilled normative service life are substantially defined by a level of their equipment devices and devices of safety, major of which are carrying capacity limiters and parameters registrars of work of the crane.

Industry produces at present carrying capacity limiters for bridge cranes in which it is used methods of direct measurement of the mechanical pressure arising from action of the moved cargo (direct methods). Using such equipments demands modification in metal ware of the crane that raises cost of equipment, and external force sensor essentially reduces reliability of the limiters.

To identify informative parameters that may determine the weight of a lifted cargo, it is necessary to study process of lifting and lowering of a cargo by mathematical model of the electric drive of the hoisting mechanism.

The mathematical model of the IM is considered with the assumptions as of the idealized electromechanical systems, for simulation of IM, the reference frame directly connected to stator windings has been chosen. Such simplification allows avoid the effect of the inductances variation. The system of the differential equations describing the IM in three-phase reference frame is submitted and resulted in the matrix form. The matrix equations in normal form Koshii will look as follows.

$$\frac{d[i]}{dt} = [L_1]^{-1} \cdot \left\{ [U] - \left([R] + [L_2] \cdot \frac{\omega}{\sqrt{3}} \right) \cdot [i] \right\} \tag{1}$$

where $[i]$ – a matrix-vector, consisting of 6 unknown currents: i_A, i_B, i_C – currents in stator phases; i_a, i_b, i_c – currents in rotor phases; $[U]$ – a matrix of supply phase voltages; $[R]$, $[L_1]$, $[L_2]$ – matrixes of resistances and inductances (matrixes of constant factors). The decisions of system (1) are currents in all stator and rotor phases. By the currents it is possible to define the electromagnetic moment of motor M:

$$M = p_n \frac{\sqrt{3}}{2} L_m \left[(i_A i_c + i_B i_a + i_C i_b) - (i_A i_b + i_B i_c + i_C i_a) \right], \tag{2}$$

where p_n – number of pole pairs, L_m – the maximal mutual inductance between stator and rotor phases.

For simulation hoisting electric crane, the most simple two-mass settlement model is used (fig. 1). At rather simple mathematical calculations it gives the accuracy which is meeting the requirements of a delivered problem.

On Fig. 1.a): m_1 – the sum of weights of the crane bridge and the carriage, m_2 – the sum of weights of a cargo and the hook assembly, c_1 – rigidity of the bridge crane (depends on position of the carriage), c_2 – rigidity of an elevating rope, x_1 – coordinate of movement of the crane bridge with the carriage, x_2 – coordinate of movement of a cargo.

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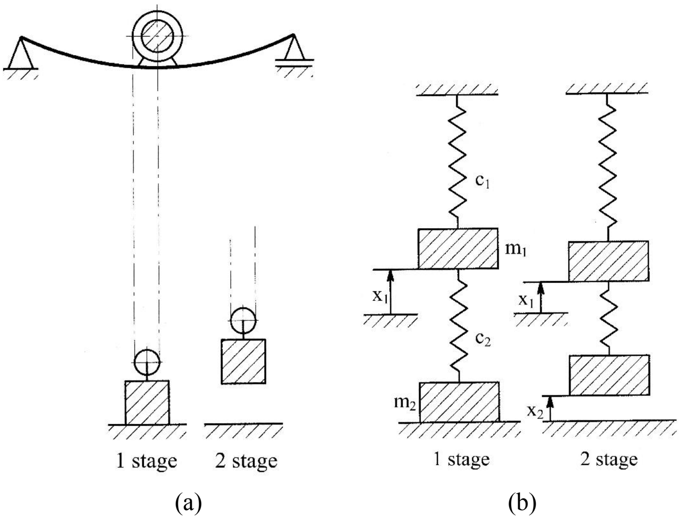

Fig. 1: a) settlement model of the bridge crane, b) the kinematic scheme of the bridge crane

Process of cargo lifting can be divided into two stages (Fig. 2.b). The first stage begins from the moment of start-up of the motor and comes to an end at the moment of time t_1 when the effort in tackle begins to satisfy to expression:

$$F_2 = m_2 g\ . \tag{3}$$

The differential equation of the first stage will be written down as:

$$m_1 \frac{d^2 x_1}{dt^2} + (c_1 + c_2)x_1 = -c_2 \upsilon t\ , \tag{4}$$

where υ – linear speed of winding of a rope on a drum.

The second stage begins from the moment of a cargo is becoming airborne. At this stage the cargo and the crane make fluctuations like a system with two degrees of freedom. The system of the differential equations describing the moment of the system are:

$$\begin{cases} m_1 \frac{d^2 x_1}{dt^2} + (c_1 + c_2)x_1 - c_2 x_2 = -c_2 \upsilon t \\ m_2 \frac{d^2 x_2}{dt^2} - c_2 x_1 + c_2 x_2 = c_2 \upsilon t - m_2 g \end{cases} \tag{5}$$

From the equations of the first and second stages (4), (5) it is possible to calculate displacements of the crane and a cargo x_1 and x_2 accordingly. For the given displacements it is possible to find effort in bridge flight of crane F_1, and effort in tackle F_2 for each stage of time. Force F_2 creates on the shaft of the electric motor the drag torque:

$$T_L = \frac{F_2 D}{2\alpha \eta_t i_{mech} \eta_{mech}}, \tag{6}$$

where D_d – diameter of a cargo drum; α – repetition factor of tackle; η_t – efficiency of tackle; i_{mech} – transfer number of the mechanism; η_{mech} – efficiency of the mechanism.

The resulting moment T_L (6) is the loading torque of a resistance from the hoisting mechanism for the induction motor. The equation of motion of the crane electric drive in this case can be written in the following form:

$$\frac{J_\Sigma}{p_n} \cdot \frac{d\omega}{dt} = T - T_L - T_{IN} - T_{BR}, \tag{7}$$

where J_Σ – the total moment of inertia of the rotating weights resulted to the shaft of the motor; p_n – number of pairs poles; T_{BR} – the braking torque developed by the brake device (an electromagnet or a hydropusher), T_{IN} – the inertia torque of rotating weights of the mechanism, consisting of the moments from inertia forces of weights of the shaft and weights of other shaft resulted to the motor shaft.

The simulation of all equations (1)-(7) is realized in program package Delphi. The system of the differential equations is solved by numerical method Runge-Kutta of 4-th order. For research the electric drive of the bridge crane the motor MTF 311-6 has been chosen. For check of this work microcontroller (MC) with carrying capacity limiter with the hoisting mechanism was taken into consideration in the model with the informative characteristic $n=f(m_2)$ which is resulted by raising empty hook assembly and one cargo of known weight. Transient characteristics at start-up of the crane on lifting of load with weight 10 ton are submitted on Fig.2.

It is shown in Fig. 2 that the initial stage of time occurs disinhibition of brake (hydropusher) and acceleration of the motor till the speed close to idling $n \approx 960$ rev/min. Thus modelling of the hoisting mechanism is carried out at the first stage (3). The cargo is in rest: $x_2(t)=0$, and the crane bridge caves in, x_1 decreases in the negative side, rotation frequency n falls linearly, efforts in bridge crane F_1 and in the rope F_2 grow.

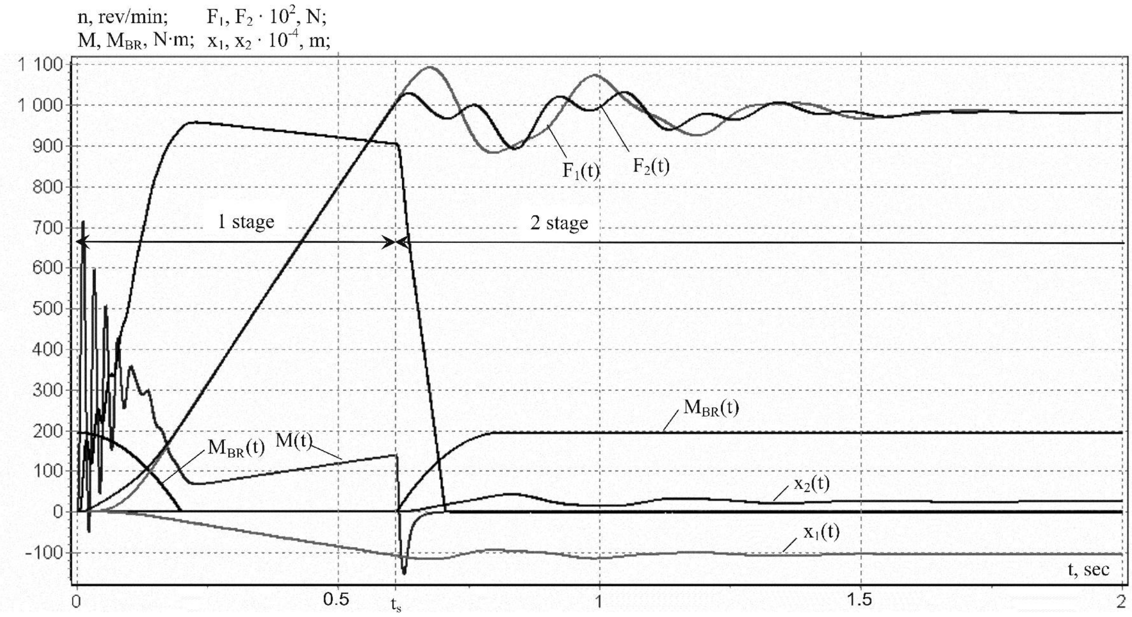

Fig. 2: Transient characteristics at start-up of the crane and operation of the carrying capacity limiter (lifting a load of 10 ton weight)

At achievement of effort in the rope F_2 of value m_2g (2) the second stage of work of the hoisting mechanism (4) in which the crane bridge, having caved in, oscillates and fading remains in rest $x_1(t)$=const, the cargo there comes off the basis and rises upwards. During the coming off cargo moment rotation frequency n falls up to 904 rev/min that corresponds to inadmissible value of weight of a cargo (≈10 ton). The carrying capacity limiter snaps into action at time t_s and de-energize a power line. The motor stops by brake, thus occurs stop way of rotating weights in braking time, and a cargo remains in the air. In view of the accepted assumptions and instant operation of the carrying capacity limiter the cargo will come off the basis approximately on 5mm, and the bridge of the crane will cave in approximately on 1 cm. At the further perfection of the carrying capacity limiter there is a necessity of reduction stop way of rotating weights. One of ways of such perfection can be a restriction of lifting speed at approach of loads to loading rating value.

For check of adequacy of mathematical model and confirm the possibility of determining the weight of the lifted cargo by an indirect method experimental dependences of rotation frequency of lifted cargo weight have been taken off. Experimental researches were carried out on a natural sample of bridge crane MK-10.

Apparently, the experimental characteristic of rotation frequency of cargo weight $n=f(m_2)$ (Fig. 3) has linear chars. The error of definition of cargo weight by means of dependence $n=f(m_2)$, constructed on two points (idling and the maximal cargo – 9 ton), makes no more than 5 % that simplifies input the informative characteristic in MC memory in a mode of «training» of carrying capacity limiter .

Thus, in MC memory dependence of rotation frequency of the lifted cargo mass m_2 is entered. This dependence is linear or consists of linear functions pieces, than process of «training» MC of the carrying capacity limiter is provided. In addition input of the characteristic directly on the crane allows to take into account its specific features, such as transfer number of the mechanism, frequency rate of tackle, efficiency of the mechanism, and also technological disorder of parameters of the electric motor and a degree of deterioration of the hoisting mechanism at work in the mode of «measurement» of a lifted cargo.

The new approach of rotation frequency definition of a motor by the spectral analysis (Fourier transformation) vibrations of a stator frame of the motor is offered. With the help of the frequency analysis in the carrying capacity limiter it is possible to determine continuously rotation frequency of the crane motor, using accelerometer which is fastened on a stator frame of the induction motor or on a basic plate. The signal from an accelerometer is submitted to the spectral analysis from which peak value of amplitude of the signal is found out, corresponding to the rotation frequency of the motor.

Accelerometer installation on a motionless part of the electric crane – on a basic plate, or on a stator frame of the motor allows determining rotation frequency that facilitates installation and raises reliability of the carrying capacity limiter.

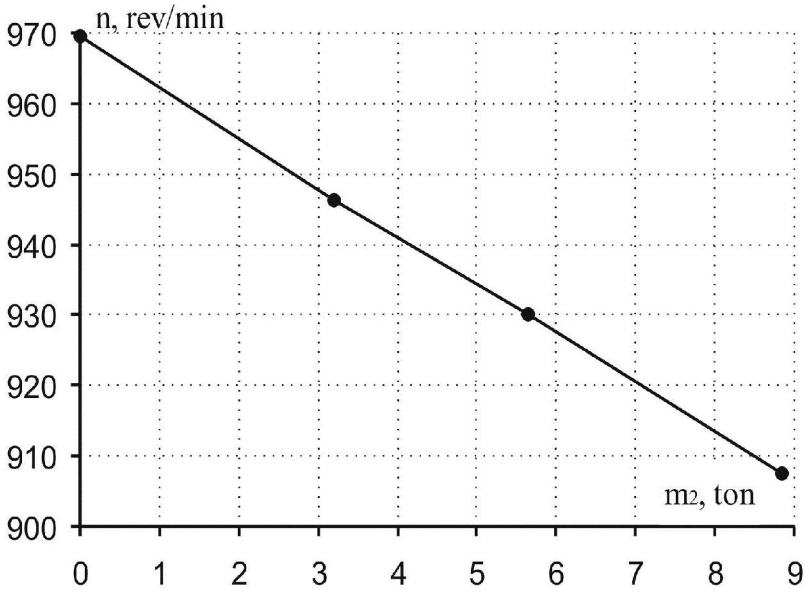

Fig. 3: Experimental dependence $n=f(m_2)$ of crane electric drive

For check the efficiency of the suggested way experiment with use of the dc motor with built in tacho-generator PIVT 6-25/3 has been carried out. On the motor frame has been fixed accelerometer (the integrated sensor of acceleration) Analog devices Inc. ADXL202. Then at work of the motor at the maximal speed 17 rev/sec and at speed 9 rev/sec the signal, taking from accelerometer, on a computer has been kept. After the spectral analysis in software package WinPOS dependences of amplitudes values A_n of vibrations harmonics of the motor (normalized within the limits of 0..1) from vibration frequency of the motor f (Hz) which are submitted on Fig. 4. a) and Fig. 5. a). It is visible from figures, that frequency corresponding the peak of vibrations amplitude of motor A_n, is 17 Hz for Fig. 4.a) and 9 Hz for Fig. 5. a), that will correspond to rotation frequency of the motor n=17 rev/sec and n=9 rev/sec. It has been confirmed with indications by built in tacho-generator. Dependences of rotation frequency of the motor (a tacho-generator signal) n_{TG} from time are submitted on Fig. 4. b) and Fig. 5. b), whence follows, that n_{TG}=17 rev/sec and n_{TG}=9 rev/sec accordingly.

Since the given experiment was carried out on well balanced motor of low power with high-quality bearings it is possible that rotation frequency of the motor, revealed from a signal of vibration diagram, which corresponds to value of the indication tacho-generator, therefore the given method, can be used in the carrying capacity limiter of the electric crane.

Conclusions: The opportunity of realization of the carrying capacity limiter for cranes of bridge type with use of an indirect method of definition of cargo weight is proved. As informative parameter for indirect definition of lifted cargo weight a rotation frequency of crane motor n is offered. The mathematical model of the hoisting mechanism of the electric crane is developed and researches of the carrying capacity limiter work on the crane were carried out. The way of definition of rotation frequency of the motor by vibration diagrams of motor stator frame without the speed sensor is offered and checked experimentally up, allowing to determine with sufficient accuracy rotation frequency of the motor and to calculate weight of a lifted cargo.

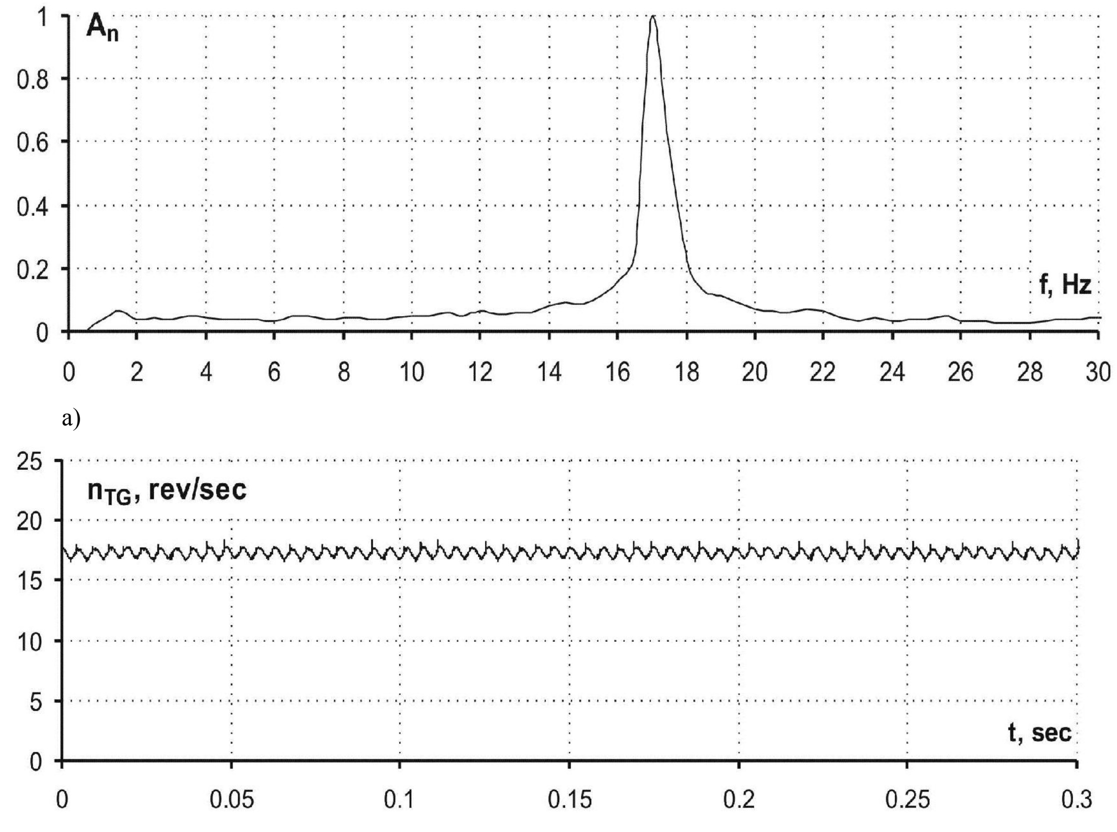

Fig. 4: Vibration diagram of the accelerometer signal A_n (a) and the diagram of a tacho-generator signal n_{TG} (b) at speed of rotation of the motor 17 rev/sec.

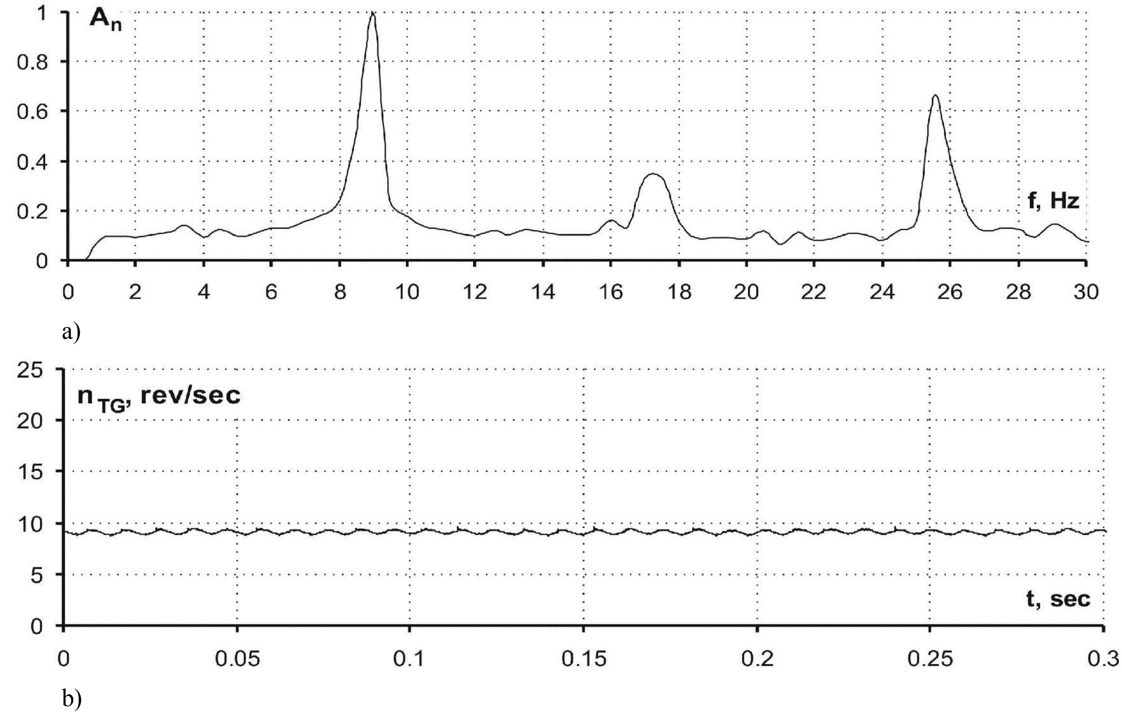

Fig. 5: Vibration diagram of the accelerometer signal A_n (a) and the diagram of a tacho-generator signal n_{TG} (b) at speed of rotation of the motor 9 rev/sec.

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