TRANSPORT PROBLEMS 2010
PROBLEMY TRANSPORTU Volume 5 Issue 1

Cranes, automation, drive and control

**Jerzy TOMCZYK**
Technical University of Lodz, Department of Working Machines Drives and Control
1/15 Stefanowskiego Str., 90-924 Łódź, Poland
*Corresponding author*. E-mail: jerzy.tomczyk@p.lodz.pl

# IDENTIFICATION OF THE SUSPENDED ON THE ROPE LOAD PHYSICAL MODEL

**Summary.** The problems connected with the modelling of the suspended on the ropes load are presented in the paper. The possible simple model of the flexible suspended load should be used for automatic control with using of state observer. Complicated rope systems have to be substituted by single string with suspended element in form of particle.

# IDENTYFIKACJA PARAMETRÓW MODELU FIZYCZNEGO ZAWIESZONEGO NA LINACH ŁADUNKU

**Streszczenie.** W referacie przedstawiono problemy związane z modelowaniem zawieszonego na linach ładunku. Do automatycznego sterowania numerycznego ruchu maszyn dźwigowych z wykorzystaniem obserwatora stanu potrzebny jest możliwie prosty model dynamiczny wiotko podwieszonego ładunku. Złożone układy linowe muszą być zastąpione jedynym cięgnem z podwieszonym elementem o masie skupionej.

## 1. INTRODUCTION

The research work [1] connected with quality of crane mechanisms control in the condition of wind disturbance whit using of state observer has been made in the department of Working Machines Drives and Control. The subject of works where equipped with automatic elements crane machines, working in open air in condition of wind disturbance acting on the suspended on the ropes load. The main aims of researches where control quality increase of flexibly suspended load trajectory and positioning accuracy by introduction into the control system state observer when the accuracy determination of forces coming from the wind and acting on the load is impossible.

Researched system contains the real object and simultaneously working in real time mathematical model called of the state observer. The same control signal is acting on the real object and on the state observer. The real object is acted by disturbances and state observer is working without of disturbances. The wind disturbances changes of the real object behaviour and its output variables running are different into comparing with output variables running of the state observer. The deviation as different between real and state observer output variables is given into the regulator which workout correction for real object control in time the deviation takes the zero or minimal value.

Working in real time crane model should be as simple as possible. Especially it is connected with model of suspended on the ropes load. Real systems of the load suspending have mostly sophisticated structure. For numerical control this structure should be replaced by load in form of particle suspended on one string with length depended on motion plane. The method of real suspended on the ropes load identification enabling of simple load model using for automation numerical control with state observer has been presented in the paper.

## 2. REAL SYSTEMS AND THAIR MODELLING

The example of laboratory overhead crane load suspending schema is presented in fig. 1. It can be observed the different distances between load and pulley block centre and points of ropes suspending. The replacing lengths of the load suspending model strings should be assumed for motion plates of the crane bridge and end carriage. It is necessary for calculation of load model parameters.

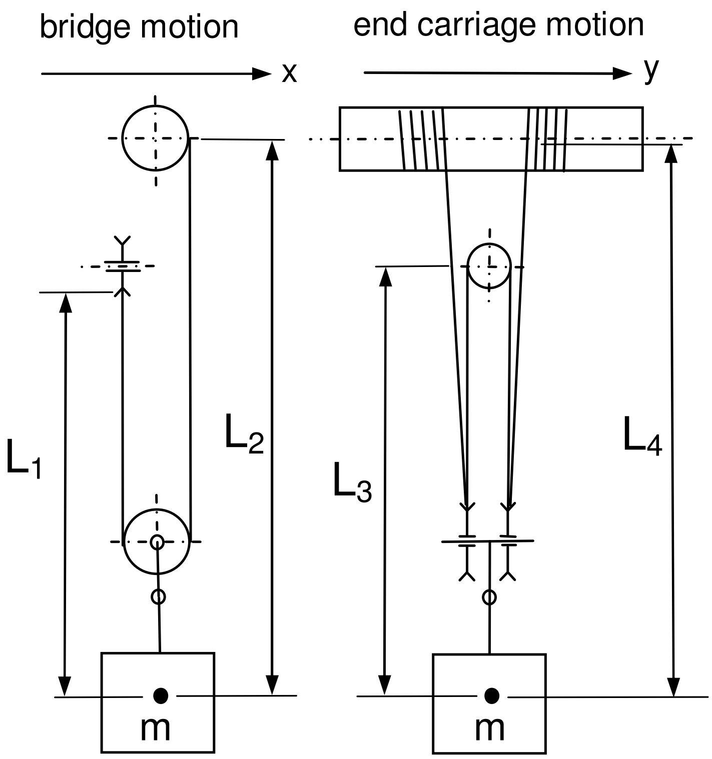


Fig. 1. Different lengths of the load mass centre suspending
Rys. 1. Różne odległości podwieszenia środka masy

The load suspending of ropes has been assumed as mathematical pendulum making of the spherical motion (fig. 2) [1]. The following assumptions have been taken for model:

- oscillations of the suspended on the ropes load are small,
- the load has been assumed as particle,
- winch ropes are weightless and don't change their lengths,
- acting on the load resisting force of air is proportional into the load velocity.

The vector equation of the physical load motion model is as follows:

$$m_Q \frac{d\bar{v}_Q}{dt} = \bar{H} + \bar{R}_Q \tag{1}$$

where: $\bar{v}_Q$ - resultant vector of the load horizontal velocity, $\bar{H} = c_Q \bar{r}$ - horizontal force component of the force in ropes, $\bar{R}_Q = f_Q \bar{v}_Q$ - the load resisting force of air, $\bar{r}$ - resultant horizontal deflection of the load against to point of the string hanging.

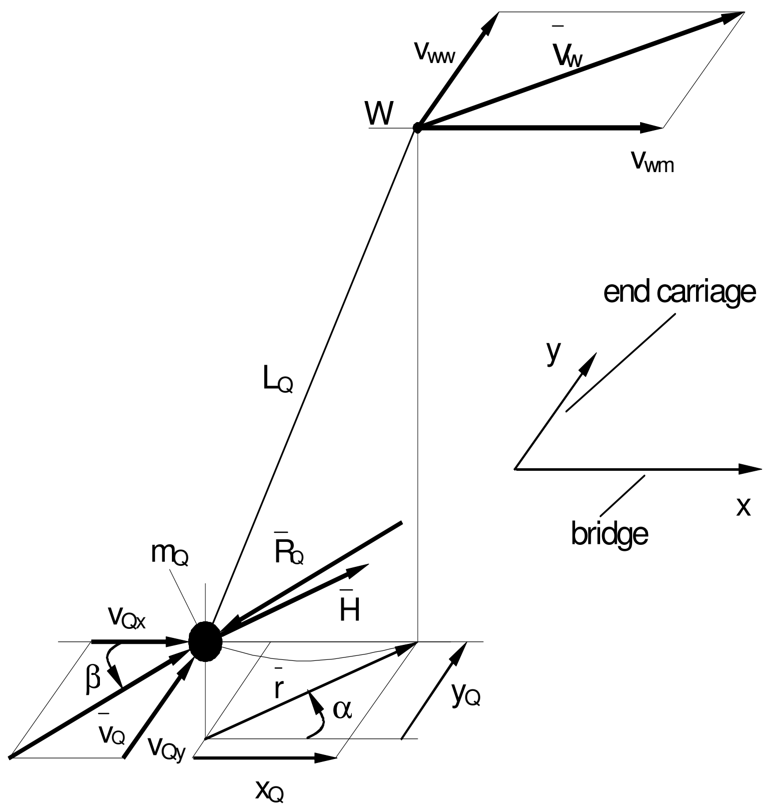


Fig. 2. Dynamic model of swinging load
Rys. 2. Model dynamiczny wahającego się ładunku

Projecting of the equation (1) on the motion bridge direction x and on the relative into the bridge motion of carriage end direction y the following equations can be assumed:

$$m_Q \quad \frac{dv_{Qx}}{dt} = c_{Qx} \quad \left|\bar{r}\right| \quad \cos\alpha \quad f_{Qx} \quad \left|\bar{v}_Q\right| \quad \cos\beta \tag{2}$$

$$m_Q \quad \frac{dv_{Qy}}{dt} = c_{Qy} \quad \left|\bar{r}\right| \quad \sin\alpha \quad f_{Qy} \quad \left|\bar{v}_Q\right| \quad \sin\beta \tag{3}$$

Parameters of their equations are known load and pulley block mass $m_Q$ and demanding to fixing values of load suspending rigidity $c_{Qx}$, $c_{Qy}$ and dumping coefficients $f_{Qx}$ and $f_{Qy}$. The load suspending rigidity for small oscillations can be determinate by the equations as follow:

$$c_{Qx} = \frac{m_Q \quad g}{L_{Qx}} \tag{4}$$

$$c_{Qy} = \frac{m_Q \quad g}{L_{Qy}} \tag{5}$$

Values $L_{Qx}$ and $L_{Qy}$ are resituated lengths of the load suspending in appropriate plates of the load oscillations.

## 3. IDENTYFICATION METHOD OF MODEL PARAMETERS

For experimental determinations unknown load motion equations parameters the researches of partly dumping proper oscillations in the appropriate plates and simultaneously spherical oscillations of the load motions have been used. The identifications method is empirically based on the researches of dumping load oscillations separately in the direction of bridge and end carriage and simultaneously spherical oscillations. Values of the load free oscillations, dumping coefficients, position of load and pulley block centre and load suspending rigidity have been determinate. The accuracy of the theoretical model has been determinate on basic of the theoretical and experimental runs comparing.

The example of experimental swing angle of the load in direction of end carriage motion is shown in figure 3.

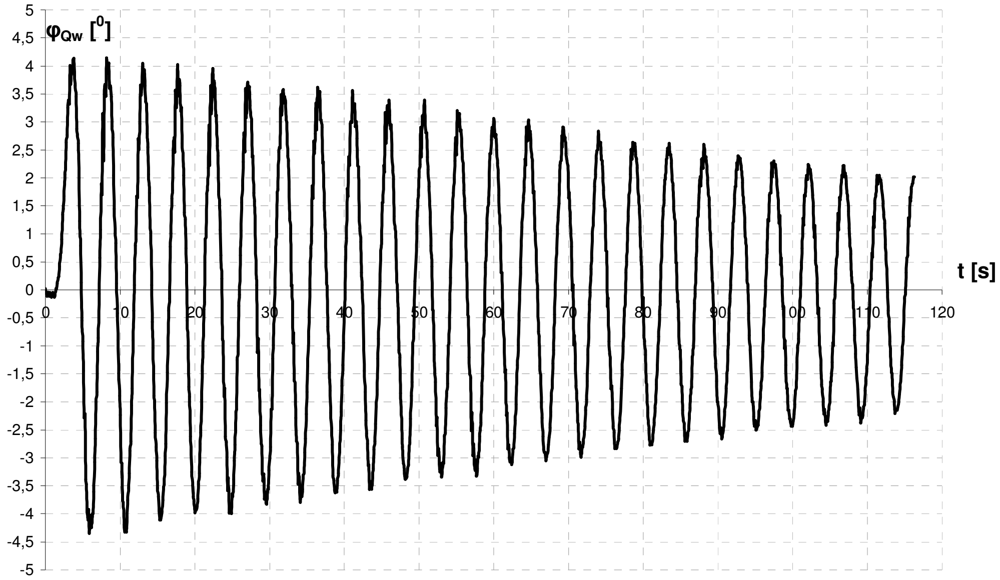


Fig. 3. Swinging of the load in direction of end carriage motion, $\varphi_{Qw}$ – load swing angle
Rys. 3. Wahania ładunku w kierunku jazdy wózka, $\varphi_{Qw}$ – kąt wychylenia ładunku

The first step of identification method is determination of the dumping oscillation period and angle frequency by equations as follow:

$$T_h = \frac{t_c}{c} \tag{6}$$

$$\omega_{Qh} = \frac{2\pi}{T_h} \tag{7}$$

$t_c$ [s] – summary time of number c of dumping oscillation periods.

The load oscillations dumping coefficients is determinates in the next step of method by means of positive and negative load angle amplitudes runs testing which is shown in figure 4 and 5. The exponential trend lines and exponents κ of natural number are determinate for each of their runs.

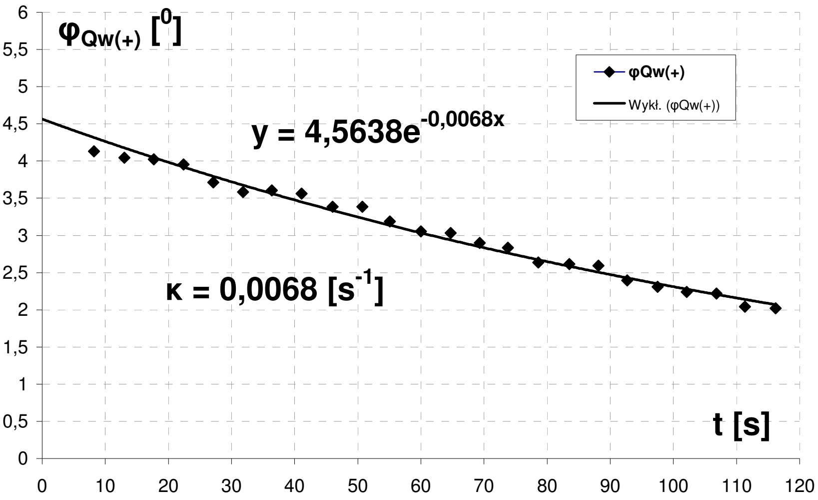


Fig. 4. Running of load oscillation positive amplitudes $\varphi_{Qw(+)}$ in direction of end carriage motion and exponential trend line

Rys. 4. Przebieg wartości amplitud dodatnich $\varphi_{Qw(+)}$ wahań ładunku w kierunku jazdy wózka i linia trendu

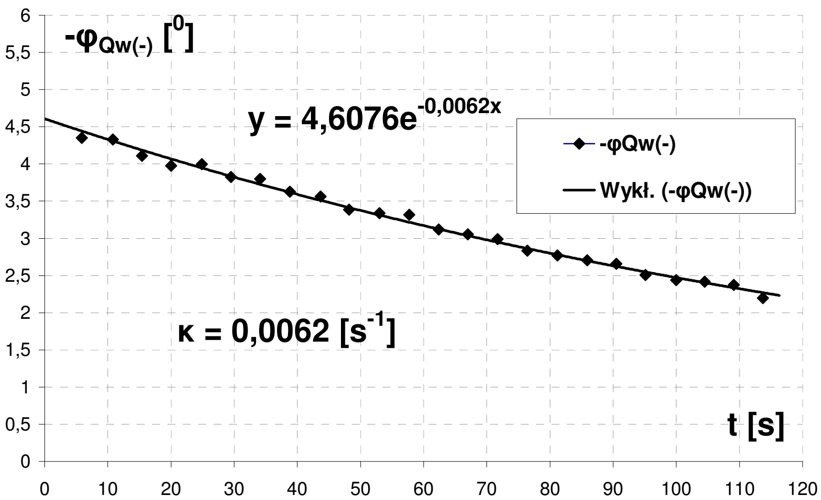


Fig. 5. Running of load oscillation negative amplitudes module $\varphi_{Qw(-)}$ in direction of end carriage motion and exponential trend line

Rys. 5. Przebieg modułu wartości amplitud ujemnych $\varphi_{Qw(-)}$ wahań ładunku w kierunku jazdy wózka i linia trendu

No dimensional damping coefficient for small load deflections and dumping can be determinate by equations as follow:

$$\xi = \kappa \quad T_0 \approx \kappa \quad T_h \tag{8}$$

The theoretical equation of angle $\varphi_Q$ running in directions of overhead crane bridge or en carriage motion is as follows:

$$_Q = \quad _{Qm(1)} \quad e^{\kappa \ (t \ \ t_0)} \quad sin[\omega_{Qh} \quad (t \quad t_0)] \tag{9}$$

The logarithmic damping decrement has been calculated on basic of theoretical angle running using the equation as follows:

$$\Lambda_t = ln \frac{Qm(i)}{Qm(i+1)} \tag{10}$$

The angular frequency for small displacements and week damping is given by the equation:

$$h_Q = \frac{\Lambda_t}{T_0} \approx \frac{\Lambda_t}{T_h} \tag{11}$$

Taking this value into account the free vibration of swinging load and their period can be calculated by equations as follow:

$$\omega_{Q0} = \sqrt{\omega_Q^2 + h_Q^2} \tag{12}$$

$$T_0 = \frac{2 \quad \pi}{\omega_{Q0}} \tag{13}$$

For small oscillations the replaced string length of the load suspending can be calculated with equation:

$$L_Q \approx \frac{g}{\omega_{Q0}^2} \tag{14}$$

After the calculation of values described by equations (8) and (10 – 13) the settings of the swinging load model parameters: load suspending rigidity $c_Q$ and damping coefficients $f_Q$ can be possible by equations:

$$c_Q = \omega_{Q0}^2 \quad m_Q \tag{15}$$

$$f_{Qs} = \frac{2 \quad \xi \quad m_Q}{T_o} \tag{16}$$

The comparing of theoretical and experimental swing angles runs in direction of the end carriage motion is shown in figure 6. Different of runs are not visible to the naked eye in this figure.

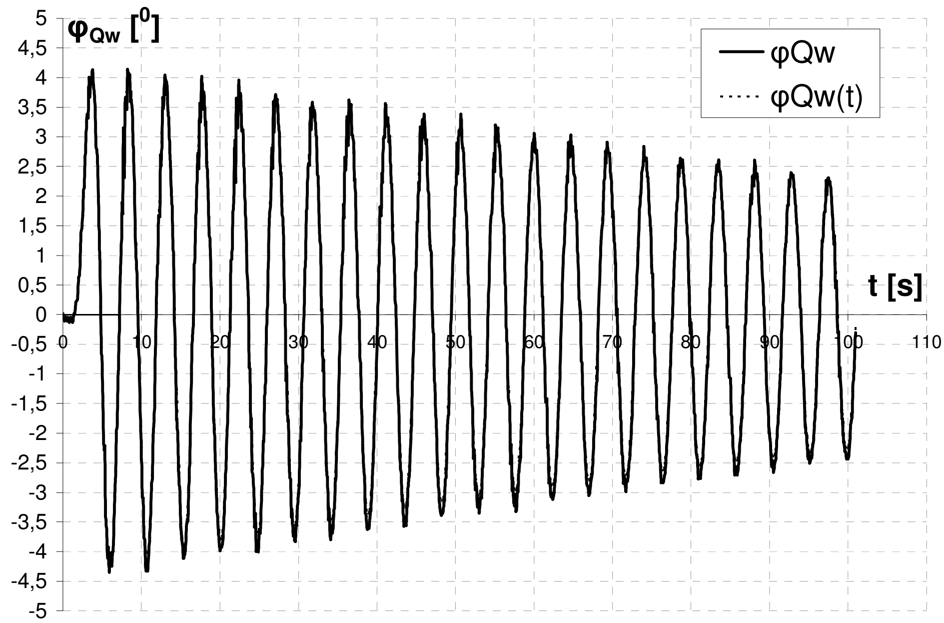


Fig. 6. The real $\varphi_{Qw}$ and theoretical $\varphi_{Qw(t)}$ load swinging in direction of end carriage motion
Rys. 6. Wahania ładunku rzeczywiste $\varphi_{Qw}$ i teoretyczne $\varphi_{Qw(t)}$ w kierunku jazdy wózka

The identification accuracy has been precise on basic of load angle experimental and theoretical displacements runs different $\delta_{\varphi Q}$. It is shown in appropriate scale in figure 7.

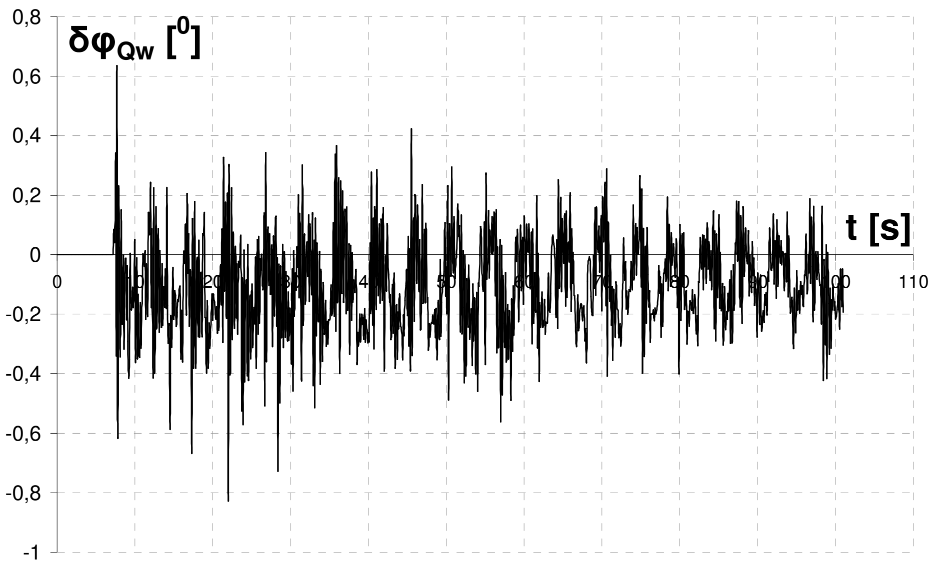


Fig. 7. The different $\delta\varphi_{Qw}$ of experimental and theoretical values
Rys. 7. Różnice $\delta\varphi_{Qw}$ wartości eksperymentalnych i teoretycznych

The identification method accuracy can be esteemed on the basic of displacements runs different arithmetic average $\bar{\delta}_{\varphi Q}$, displacements runs different range $R_{\delta\varphi Q}$ and variance of error $S^2_{\delta\varphi Q}$ determined by equations:

$$\bar{\delta}_{Q} = \frac{1}{n}\sum_{1}^{n}\delta_{Qi} = 0{,}1033^{0} \tag{17}$$

$$R_{\delta Q} = \delta_{Q\,max} \quad \delta_{Q\,min} = 0{,}5764^{0} \tag{18}$$

$$S^2_{\delta Q} = \frac{1}{n}\sum_{1}^{n}(\delta_{Qi} \quad \bar{\delta}_{Qn})^2 = 0{,}0272 \ \ (1^{0})^2 \quad . \tag{19}$$

The number values taken out by working out identification method using have been shown in this equations.

## 4. RESUME

The possible simple and well-identificated dynamic model of flexibly suspended load is required for automatic control of cranes working in the conditions of wind disturbances. Especially it is necessary by using the state observer in the control system.

The using of oscillation analyse for identification of flexibly suspending on the ropes load model brings the good results. The method can be used for appropriate elements of mechanical systems whit elastic constrains and small damping and oscillations.

**References**

1. Tomczyk J. etc.: *Badania jakości sterowania mechanizmami dźwignic z wykorzystaniem obserwatora stanu w warunkach zakłóceń działaniem wiatru.* Praca badawcza Nr 502 003. Politechnika Łódzka, Łódź 2009.
2. Tomczyk J., Cink J.: *Automatyzacja transportu ładunków dźwignicami sterowanymi numerycznie, suwnice – transport poziomy*. Przegląd Mechaniczny, 10 /2001. s. 16 - 21.
3. Tomczyk J., Cink J., Kosucki A.: *Metody rozwiązywania problemów automatyzacji sterowania dźwignicami.* Przegląd Mechaniczny nr 1, 2003, s. 9-16.

Received 11.06.2009; accepted in revised form 12.03.2010