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Numerical Research of Positioning Process of Unit Loads by System of Oblique Friction Force Fields

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Abstract

In the paper, the authors present a proposal for modelling the process of positioning of a stream of unit loads in axis of conveyor (e.g. belt conveyor, roller conveyor) realized by means of two directionally-oriented friction force fields. It was accepted during modelling, that the positioning process of loads is aided by additional zone of friction (introduced between oblique friction force fields) forcing the objects motion in accordance with direction of transportation velocity of conveyor. The purpose of presented research is assessment of influence of the constructional and exploational parameters of roller manipulator on positioning precision of unit loads.

Keywords: modelling, friction, positioning precision

1. Introduction

Contemporary conveyor systems transporting unit loads (e.g. postal packages), apart from realizing basic function concerning object conveying, perform a number of automated handling activities on the loads: merging two or more streams with one another, dividing the stream into a number of streams (sorting), rotating and arranging loads in the stream (positioning) 9, 10, 11, 12. These activities are performed by means of highly-efficient no-grip type manipulators built into the

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conveyor structure. They act on the conveyed loads by exerting a properly planned push, impact, sequence of pushes or impacts 1, 3, 9, 11.

Some handling activities fulfill auxiliary functions – prepare the object to perform on it essential actions. To these activities belongs the positioning process consisting in object placing to precisely determined position, e.g. forcing objects position in the axis of conveyor (centering) carried out before the sorting process realization – facilitating object scraping on the both side of the transporter.

The positioning process can be realized by means of manipulators, whose working elements are passive fences, active fences or active carrying surfaces of the conveyor, on which lie the transported loads 1, 3. A practical implementation of concept of active carrying surfaces is manipulator equipped with system of driven rollers or disks, which allow for controlling (programming) the direction of the friction field that exerts force on the load 2, 3, 5, 8, 9.

In the available literature 3, 5, 7, 8 concerning handling process of object by system of friction force fields deal with the analysis of control systems of the microactuators (independently driven disks of two degrees of freedom) equipped with an elaborated system of sensors controlling current position of the load and taking it to a precisely defined destination position. In the subject literature, however, one can not find any description of application of this kind of devices in a highly efficient process of load positioning, in which the role of sensors is reduced to bi-state detection of the presence of load in the working space of the manipulator.

In presented work, in purpose of determination of basic features characterizing positioning process of the unit load' stream by system of two oblique friction force fields, the dynamic model of this process was proposed. The data obtained on basis of research of worked out model can be used as guidelines helpful during design of discussed class of manipulators.

2. Working Conditions of Manipulator

An example of manipulator centering the stream of unit loads, that is built-in into the structure of conveyor, is presented in Fig. 1. Two systems of driven rolls, that are the active carrying surface for transported loads, fulfill the role of working element. The rolls' systems are set up obliquely (convergently) forming an angle α with the conveyor axis. Moreover, the carrying surface consists of auxiliary conveyor belt centrally placed between rollers' systems. An additional conveyor aids positioning process course. The idea of introduction of this conveyor followed on basis of analysis of numeric tests presented in section 4.

Two basic criteria decide about the quality of the course of handling process of unit loads: the minimization of dynamic influences exerted on the moved objects, and certainty and correctness of performed handling operations. The character of manipulator work favours the first criterion fulfilment – the influence of working elements on the object is obtained only by frictional coupling between adjacent

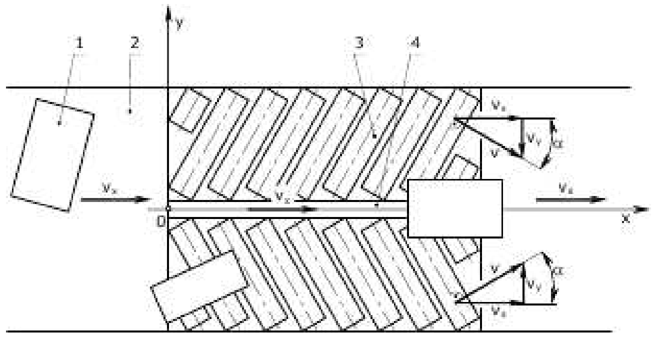

Fig. 1. An example of manipulator centering stream of unit loads: 1 – unit load, 2 – conveyor belt, 3 – working element of manipulator (system of oblique driver rollers), 4 – conveyor belt stabilizing positioning process, v – velocity of transportation, α – setting angle of rollers

surfaces (between object and rolls). Thanks to this, the loads are treated softly and they shouldn't be subject to mechanical damage. The estimation of the second criterion requires the data which would determine dependences between the course of positioning process and constructional and exploational parameters of the manipulator. This data can be determined on the basis of numeric tests of theoretical model proposed in the further part of the work.

3. Model of Object Motion

The load motion, in the manipulator working space, is evoked by the carrying surfaces, which can be divide into three zones: A and C – that include the system of oblique driven rollers, and B (aiding positioning process) that is determined by conveyor belt centrally placed with respect to zones A and C. Depending on dimensions and position of the load and the width of zone B, the load can be in contact with one, two or with all zones simultaneously. In the physical model of load positioning, one assumes a rectangular reference coordinate system Oxy connected with the manipulator's frame, whose origin coincides with the front manipulator area, and the direction of axis x is consistent with the axis of main conveyer (Fig. 2). Additionally:

- the positioning process is assumed to be a planar motion on the plane of main conveyor,
- the load is treated as a rigid body with uniformly distributed mass,
- the load has identical frictional properties on all of its surfaces,
- the rolls forming active carrying surface have dimensions much smaller than manipulated objects,
- the power-driven rolls of manipulator are free of axis-direction error, i.e. they don't exhibit any lateral whip error,
- friction phenomena are described in accordance with the Coulomb's law,

- one takes into account the existence of static and kinetic friction,
- the influence of random disturbances is neglected.

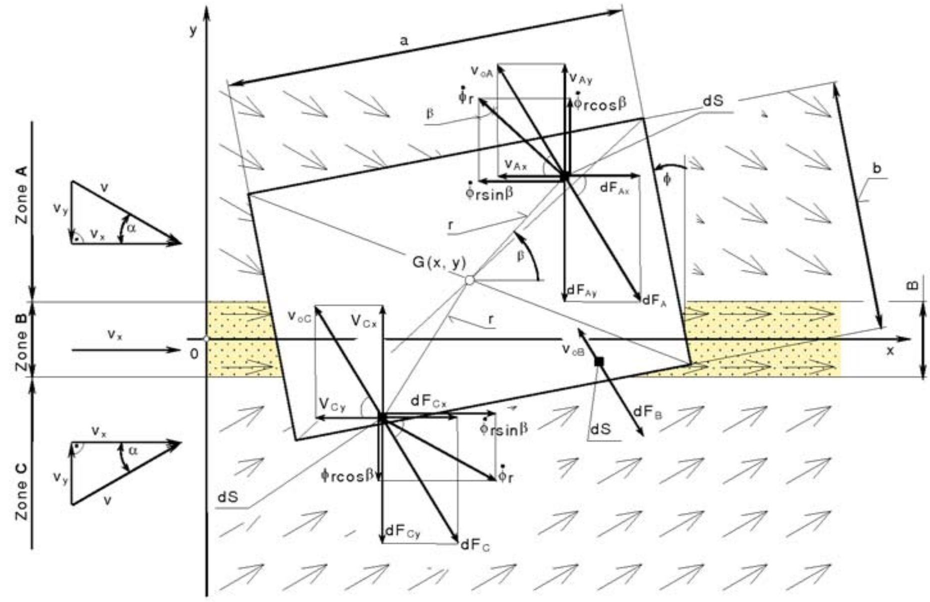

Fig. 2. Scheme of forces acting on the object during positioning by manipulator with a system of two oblique friction force fields

The planar motion of load on the manipulator roller surfaces is described in the rectangular system of coordinates Oxy by the following system of equations (according to Fig. 2):

$$\begin{cases} m\ddot{x} = F_{Ax} + F_{Bx} + F_{Cx} \\ m\ddot{y} = -F_{Ay} - F_{By} - F_{Cy} \\ I\ddot{\phi} = -M_A - M_B - M_C \end{cases} \tag{1}$$

where:

$F_{ix} = \dfrac{mg}{S}\displaystyle\int_{S_i} \mu_i(v_{io})\frac{v_{ix}}{v_{io}}dS, \quad F_{iy} = \dfrac{mg}{S}\displaystyle\int_{S_i} \mu_i(v_{io})\frac{v_{iy}}{v_{io}}dS$ – components of load friction force in zones i=A, B, C,

$M_i = \dfrac{mg}{S}\displaystyle\int_{S_i} \frac{\mu_i(v_{io})}{v_{io}}\left[v_{iy}\,(x - x_G) + v_{ix}\,(y - y_G)\right] dS$ – moments of load friction forces in friction zones i=A, B, C,

$v_{Ax} = v_{Bx} = v_{Cx} = v_x - \dot{x} + \dot{\phi}\, r \sin\beta$ – components of sliding velocity of infinitesimal friction surface dS of load in direction of axis x in zones i=A, B i C,

$v_{Ay} = v_y + \dot{y} + \dot{\phi}\, r \cos\beta$, $v_{By} = \dot{y} + \dot{\phi}\, r \cos\beta$, $v_{Cy} = -v_y + \dot{y} + \dot{\phi} r \cos\beta$ – components of sliding velocity of infinitesimal friction surface dS of load in direction of axis y in zones i=A, B i C,

$v_x = v\cos\alpha$, $v_y = v\sin\alpha$ – components of transportation velocity,

$v_{io} = \sqrt{v_{ix}^2 + v_{iy}^2}$ – resulting sliding velocity of infinitesimal friction surface dS,

$r = \sqrt{(x_S - x)^2 + (y_S - y)^2}$ – distance between infinitesimal surface dS and gravity centre G of load,

$\beta = arctg\left(\dfrac{y - y_S}{x - x_S}\right)$ – inclination angle of radius r,

x, y, ϕ – coordinates of gravity centre G and rotation angle of load, respectively,

x_S, y_S – coordinates of infinitesimal surface dS,

m, I – mass and mass moment of inertia of load, respectively,

g – acceleration of gravity,

$\mu_i(v_{io}) = \begin{cases} \mu_{ki} + 0,03 v_{io} & v_{io} > 0 \\ \mu_{si} & v_{io} = 0 \end{cases}$ – friction coefficient between load and conveyor in function of sliding velocity v_{io} 4,

μ_{ki}, μ_{si} – friction coefficients relating to kinetic and static friction in zones i=A, B, C.

The special case of positioning process is the situation in which the load before inserting to the manipulator working space is parallel oriented with respect to the conveyor axis (ϕ=0) and does not possess initial angular velocity ($\dot{\phi} = 0$).Thanks to this, the third equation in system of equations (1) may omit. Moreover, accepting that the manipulator will have sufficient working space to take the load to the assumed destination place, the main course of positioning process can reduce to the load motion of one degree of freedom – in transverse direction to the conveyor axis. Such motion describes the equation:

$$\ddot{y} + \frac{g}{ab}\left(\mu_A(v_{Ao})S_A(y)\frac{v\sin\alpha + \dot{y}}{|v\sin\alpha + \dot{y}|} + \mu_B(v_{Bo})S_B(y)\frac{\dot{y}}{|\dot{y}|} + \mu_C(v_{Co})S_C(y)\frac{-v\sin\alpha + \dot{y}}{|-v\sin\alpha + \dot{y}|}\right) = 0 \tag{2}$$

where: $S_i(y)$ – contact area of the load with friction zone i=A, B, C, assuming that ϕ=0:

$$S_A(y) = \begin{cases} a\left[(b - B)/2 + y\right] & \text{if } (b - B)/2 + y > 0 \\ ab & \text{if } (b + B)/2 - y \le 0 \\ 0 & \text{otherwise} \end{cases} \tag{3}$$

$$S_C(y) = \begin{cases} a\left[(b - B)/2 - y\right] & \text{if } (b - B)/2 - y > 0 \\ ab & \text{if } (b + B)/2 + y \le 0 \\ 0 & \text{otherwise} \end{cases} \tag{4}$$

$$S_B(y) = ab - S_A(y) - S_C(y) \tag{5}$$

4. Numerical Experiments

It was accepted during simulation, that the carrying surfaces A and C have the same friction properties – $\mu_{AC} = \mu_A = \mu_C$.

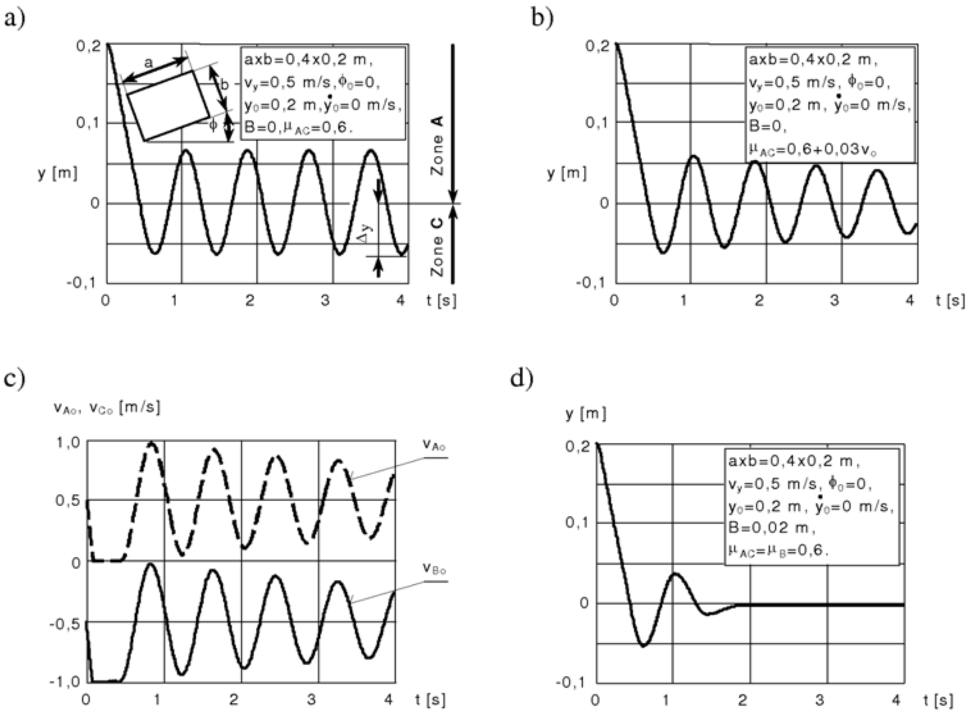

Fig. 3. The oscillations of the load motion obtained during simulation of positioning according to data: a) constant friction coefficient μ_{AC}=0,6=const and B=0, b) i c) friction coefficient dependent on sliding velocity μ_{AC}=0,6+0,03v_o and B=0, d) constant friction coefficient μ_{AC}=0,6=const and B=0,02 m

In Fig. 3a, Fig. 3b and Fig. 3d, the motion paths of the load gravity centre (load's dimension axb=0,4×0,2 m) are presented, assuming that: the initial position of load y_0=0,2 m and ϕ_0=0 rad and initial velocity $\dot{y}_0$=0 m/s and $\dot{\phi}_0$=0 rad/s. In case of lack of zone B in the manipulator and assumption of constant value of friction coefficient of the surface of the manipulator working elements (μ_{AC}=const) the load perform (during positioning) unfading oscillations around the equilibrium position – around symmetry axis of centering device – Fig. 3a.

Damping is inserted to the system by taking into consideration the dependence of the friction coefficient on sliding velocity of the load. This damping causes only insignificant oscillation decay (the Fig. 3b) – assuming even the largest changeability of the friction coefficient: according to the work 4 μ_{AC}=0,6+0,03v_o.

The static and kinetic friction acceptance (assuming $\mu_s > \mu_k$) also doesn't cause decrementation of the load motion oscillation. The positioning process of loads by a system of two friction force fields runs first of all in the conditions of kinetic friction. The standstill conditions of load in relation to the manipulator active surfaces appear sporadically, e.g. only in the initial stage of the positioning process (Fig. 3c).

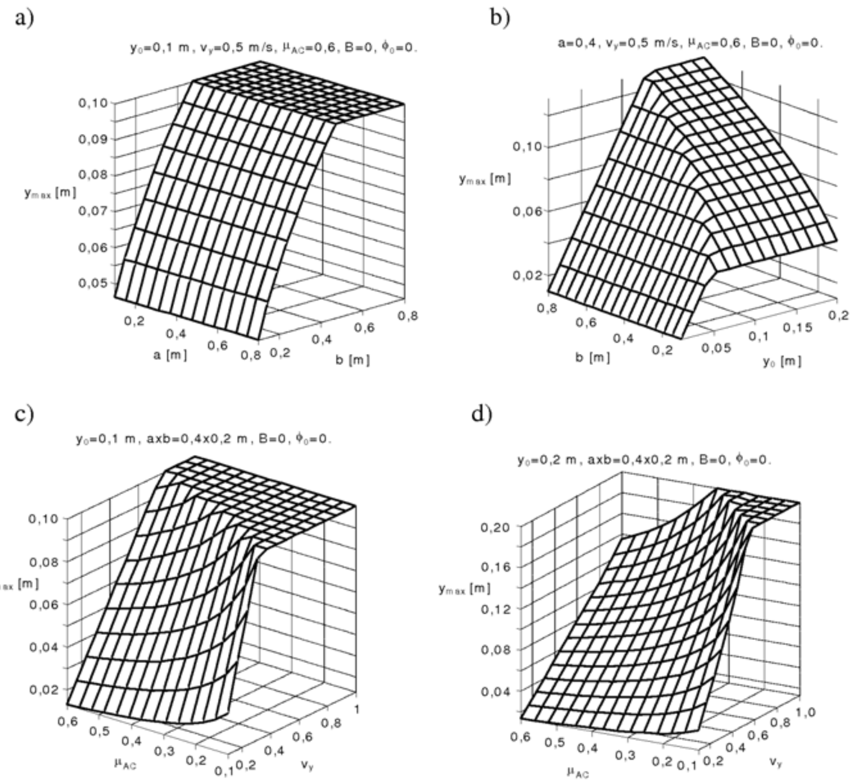

Fig. 4. Amplitude of oscillation of the load gravity centre determined in function of: a) load dimensions axb, b) initial position y_0 of load on conveyor and load width b, c) friction coefficient μ_{AC} and component of velocity v_y (y_0=0,1 m), d) friction coefficient μ_{AC} and component of velocity v_y (y_0=0,2 m)

The energy dissipation of the load's oscillatory motion can be intensified by introduction to the working space of manipulator an additional friction zone – the zone B (Fig. 2) placed in the manipulator axis. Small width of this zone (Fig. 3d – B=0,02 m) causes already the decided improvement of the effectiveness of manipulator work – duration shortening of transient load motion. The creation of zone B, beyond the effect of damping strengthening of oscillatory load motion it causes also the flow improvement of small-sized unit loads, which could not too firmly move on the border of zones' influence of the rollers' system of the manipulator.

The results of simulation of positioning process of the unit load without taking into consideration the influence of friction zone B (B=0) are presented in Fig. 4. These investigations are carried out in order to influence assessment of parameters of positioning process on the amplitude value y_{max} of the oscillatory load motion. The knowledge of these dependences is helpful during relationships determination between reasons causing the amplitude increase of oscillation and required width of the zone B.

From the analysis of Fig. 4a it follows, that the amplitude of the oscillation of the load depends on width of handled objects (dimension b – in case of parallel initial load position in relation to the conveyor axis, ϕ=0) and is not sensitive to the load length a. The value of this amplitude does not exceed the value of ordinate y_0 of the initial position of load in the working space of manipulator. An increase of distance of the initial position y_0 and width b of the handled load causes the increment of the oscillation according to dependence presented in Figs. 4b. Relationships, which exist between friction coefficient μ_{AC} of the load in the zones A and C, transportation velocity v_y in transverse direction to the manipulator axis and amplitude y_{max} is shown in Fig. 4c. It folows from the analysis of this figure, that the smaller value of friction coefficient μ_{AC} and bigger transportation velocity v_y, the larger amplitude of the oscillation become. Moreover, the oscillation amplitude doesn't exceed an assumed initial position y_0 of the load – similarly like in Fig. 4a, b. The acceptation of bigger distance of the initial position y_0 (Fig. 4d) causes expected extension of the influence of parameters μ_{AC} and v_y on the oscillation amplitude – to the border determined by y_0.

An effectiveness of zone B in damping of oscillatory motion is caused by friction force introduction opposing the load motion independently on velocity sense of oscillation. Moreover, in every oscillation cycle, the load achieves the standstill in relation to the friction zone B, in which the static friction appears – also favorable to the oscillation decay of the load motion.

The position y_k of the load gravity centre after the oscillation extinction can be determined on the basis of the analysis of static equilibrium of friction forces in zones A, B and C – according to equation (1_2):

$$\left|-F_{Ay} - F_{Cy}\right| \leq F_{By} \tag{6}$$

The ordinate y_k of the load achieved after positioning can calculate by means of inequality (substituting (2)÷(5) for (6)):

$$|y_k| \leq \frac{B\mu_B}{2\mu_{AC}} \tag{7}$$

In Fig. 5, the space marked in grey color relates to the possible load positions (in the function of width of zone B) obtained as a result of the handling actions

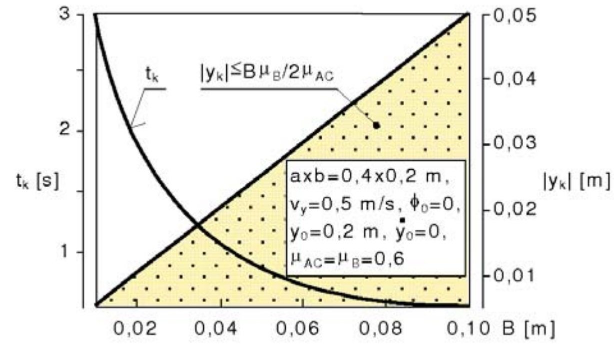

Fig. 5. An influence of width of zone B on the time t_k of the oscillation decay and precision of positioning (the position y_k of the load gravity centre after oscillation extinction)

(according to inequality (7)). In this figure, the curve t_k determines the duration of oscillation decay – on basis of numeric tests of system of equations (1). From the analysis of presented data it follows, that aspiration for achievement of high precision of object positioning (in conveyor axis) requires minimal width of friction zone B acceptation, that causes longer duration t_k of oscillation decay. However, the duration t_k of oscillation decay can be shortened (without need of zone B increase) by acceptation of small value of the inclination angle α (lowering of the component of rollers' transportation velocity v_y) and assumption of large friction properties of zones A and C (Fig. 4c).

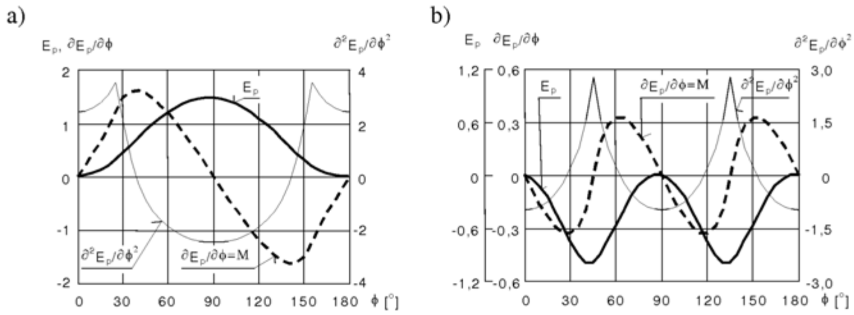

Fig. 6. The charts of potential energy of friction force moment E_p and its first and second derivative in the function of the angle of rotation of the load in the shape of: a) rectangle – a×b=0,4×0,2 m, b) square – a×b=0,4×0,4 m; initial load position on the conveyor y_0=0, B=0 m, m=5 kg

The handling process of loads by a system of oblique friction force fields beyond translational positioning (centering on the conveyor) also causes rotary positioning. The results of analysis of object equilibrium states in rotary motion (Fig. 6) shows this fact. The analysis is carried out on the strength of Dirichlet's criterion 6. The basis of this analysis is the investigation of the potential energy changes of moment of load friction forces $E_p = \int M d\phi$. The object is in the stable equilibrium state when potential energy of the analyzed material system achieves minimum, the first derivative is zero (($\partial E_p/\partial\phi=0$) and the second derivative possesses the positive value ($\partial^2 E_p/\partial\phi^2>0$). The state of instable equilibrium corresponds to positions of the object for which potential energy achieves maximum and $\partial E_p/\partial\phi=0$ and $\partial^2 E_p/\partial\phi^2<0$. It follows from the analysis of the data presented in Fig. 6, that tested object is oriented on the conveyor in this way that the longest axis of object symmetry coincides with the conveyor's symmetry axis. In case of load positioning of rectangle shape (in the plane of conveyor) the state of stable equilibrium is achieved in two positions (ϕ=[0;180]°, Fig. 6a), and square load – in four (ϕ=[45;135;225;315], Fig. 6b).

5. Conclusion

The following final remarks were formulated:

- The load motion control three friction zones: zones A and C representing the system of driven oblique rolls and B – identifying the conveyor belt placed centrally on the manipulator. The friction zones A and C move the load to the position in the axis of the manipulator symmetry and turn the load that its the longest axis of symmetry coincides with the main direction of conveyor transportation. The zone B stabilizes and streamlines the course of realized process.
- In order to requirements' fulfillment of effectiveness and precision of the course of the loads' positioning process the following assumptions should be taken into consideration: acceptation of the largest possibly value of the friction coefficient of the surfaces of the manipulator working elements, the smallest value of the inclination angle α of friction forces' direction of zones A and C, and minimal width of friction zone B.
- On basis of analysis of equations (1) and (2) it follows that in case of lack of the friction zone B in manipulator and constant value assumption of friction coefficient of manipulator working elements ($\mu_A = \mu_C$=const) the load performs motion of the harmonic oscillator (in relation to symmetry axis of conveyor). So presented vibrating system does not possess damping. Taking into consideration the fact, that the positioning process observations on the laboratory stand don't confirm thesis of the undamped oscillations of the load motion 12, the damping element should be inserted in the equations (1) and (2). The role of this element fulfills the variability of friction coefficient, which depends (among other things) on the sliding velocity. An assumption of linear dependence of friction coefficient on sliding velocity causes viscous damping introduction to the system.

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