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RANGES OF APPLICATION OF SORTING MANIPULATORS

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Abstract

In the paper the applications ranges of sorting manipulators of unit loads (cubiform objects – e.g. postal packages) transported on conveyors in the continuous manner are presented. The exploitation properties of manipulators have been assigned on the basis of numeric optimization of the sorting process. Theoretical models (indispensable for optimization) include the development of physical phenomena occurring while interaction between the object and manipulator actuators. The reaction forces of impact character appearing between the object and the working element of manipulator are defined by means of modified non-linear Kelvin model. The frictional proprieties of the object are modelled by the non-linear friction coefficient using B-spline curve of third degree. The kinematic structures of the manipulators (taken into consideration during research) are representative technical solutions of currently applied methods of impulse exertion directing the objects on the new transports lines in the logistic centres.

Keywords: *sorting process, unit load, nonprehensile manipulator, conveyor, optimization*

1. Introduction

The problem of sorting of unit loads exists in transport nodes which characterize big concentration of goods. Sorting process accompanies the tasks of completion and de-completion of the loads' deliveries in the logistic distributional centres, e.g.: at central post offices, warehouses, airports [1]. Division of the loads into suitable directions (according to destination) is performed by means of nonprehensile manipulators, built in conveying transportation system. These manipulators have no gripping devices, and act on the objects through a push, or through a sequence of pushes or strikes.

The contemporary technical solutions of sorting manipulators are equipped with executive elements which cause: scraping the loads from the conveyor (presented in Fig. 1b, c), moving the objects by directionally-oriented field of friction forces (Fig. 1d), or extorting the gravitational objects' motion to the new line of further transportation (Fig. 1a).

Sorting systems are spatially complex, compound and expensive investment undertakings. The optimum technical solution of executive systems of manipulators should be determined depending on assumed intensity flow of handled objects and their physical properties.

In order to carry out the reasonable selection of sorting manipulators, it is needed an access to an objective data characterizing basic usable features – e.g. used by potential investors or designers of transport centres. One of the more important sources of the data collection is the results analysis of numeric optimization of the sorting process – that is the subject of presented work. The theoretical models have been developed on the basis of selected devices which cover an area of manipulators currently used in the logistic centres and offered by manufacturers.

a)

b)

c)

d)

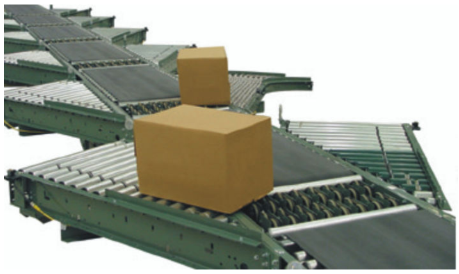


Fig. 1. Examples of executive systems of sorting manipulators: a) tilt tray [2], b) divert shoes [3], c) active rotary fence [4], d) torsional disks [5]

2. Kinetic structures of nonprehensile manipulators

Simple in its form nonprehensile manipulator the ability to manipulate the object obtains as a result of bond with the transportation functions of conveyors – these manipulators usually co-operate with conveyors (e.g. belt or link-belt). Due to the difference in the use of transportation functions of conveyors the manipulators can be divided into two groups: stationary (Fig. 2a) and stream manipulators (Fig. 2b). Stationary manipulators (Fig. 3) are combined with the supporting structure of the conveyor and stand still with respect to them (v_R =0). Executive elements of such manipulators perform their working motions above the surface of the conveyor and have mostly the form of an active rotary fence (the figs. 3a), also an active fence with translational motion (Fig. 3b), or a system of torsional discs Fig. 3c).

In the stream manipulators (Fig. 4), the role of executive elements is played by segments of the link-belt conveyor. These segments are equipped in additional features which can be in the form of: tilt trays (Fig. 4a), the trays with bearing surfaces covered transverse conveyor belts (Fig. 4b), divert shoes sliding along the slats (Fig. 4c). Working elements of the manipulator (which are also segments of the conveyor) wander in the conveyor with the velocity of loads' stream (v_R=v).

Fig. 2. Nonprehensile manipulators: a) stationary, b) stream; 1 – handled object, 2 – conveyor, 3 – working element of manipulator, v – velocity of load stream, v_R – velocity of manipulator, Δc – distance between heads of loads

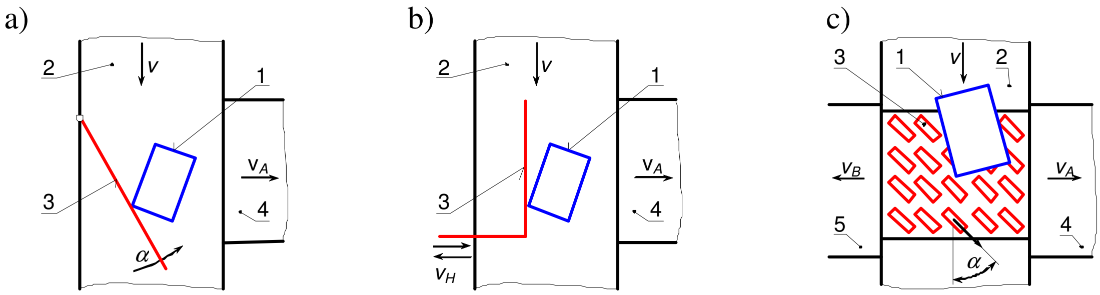


Fig. 3. Examples of kinematic structures of stationary nonprehensile manipulators: a) manipulator with an active rotary fence, b) manipulator with an active fence with translational motion, c) manipulator with torsional disks; 1 – unit load, 2 – main conveyor, 3 – working element, 4 and 5 – delivery lines, v – velocity of transportation of main conveyor, v_A i v_B – velocity of transportation of new transport lines

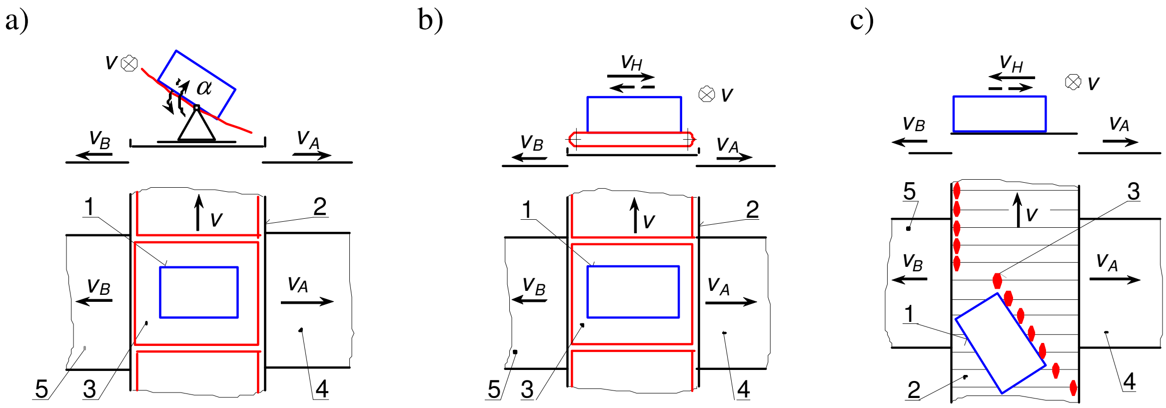


Fig. 4. Examples of kinematic structures of stream nonprehensile manipulators: a) tilt tray, b) belt tray, c) divert shoes; 1 – unit load, 2 – main conveyor, 3 – working element, 4 i 5 – delivery lines, v – velocity of transportation of main conveyor, v_H – velocity of working element, v_A i v_B – velocity of transportation of delivery conveyor

3. Basic assumptions of sorting process models

The indications and indispensable recommendations necessary for design new solutions of manipulators and to define an application ranges of existing sorting devices are obtained from the analysis of the results of numeric optimization [9], [10], [11], [12], [14]). In the study there were used the theoretical models of the sorting process, which include the development of physical phenomena occurring while interaction between the object and manipulators actuators (oblique impact, the dry friction). The reaction forces of impact character appearing between the object and the working element of manipulator are defined by means of modified non-linear Kelvin model [8]. The frictional proprieties of the object are modeled by the non-linear friction coefficient using B-spline curve of third degree [13]. The sorting process is treated as a sequence of discreet stages of the movement, which occur one after the other until the reaches the its location in the destination place. The stages, into which one can divide the considered continuous process, are distinct kinematic-dynamic states of the load, significantly different from one another, resulting from current interactions of the object and depending on its location relative to the sorting device.

The physical proprieties of the manipulated objects, indispensable from the point of view of the assumed models, are determined during experimental tests. The friction proprieties of the objects are investigated with the use of method of backward friction force fields [13], while the elastic-damping properties are examined by means of free fall method consisting in dropping the object down from a height on a rigid ground or an elastic beam [8]. Moreover, these tests give the possibility of experimental verification to confirm the correctness of the assumptions accepted in modelling the phenomena of dry friction and inelastic impact of bodies.

4. General recommendations of applying various groups of nonprehensile sorting manipulators

The data presented in Fig. 5÷Fig. 10 constitute synthesis of the basic structural-exploational properties of manipulators specialized in sorting stream of unit loads, developed on the basis of the numeric optimization results [9], [10], [11], [12], [14].

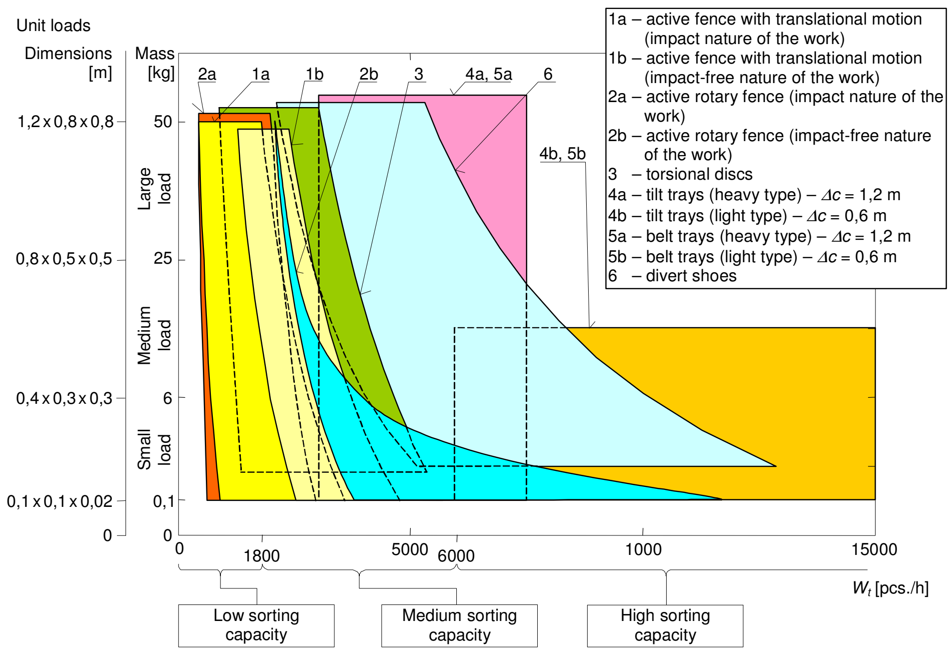


Fig. 5. Space of constructional solutions of sorting manipulators

There were studied the potential utilitarian properties of selected kinematic structures of manipulators relating to sorting the cuboidal objects (in rectangle shape in the conveyor plane) of length $A \in \langle 0{,}1; 1{,}2 \rangle$ m and width $B \in \langle 0{,}1; 0{,}8 \rangle$ m at the transportation velocity of unit load stream $v \in \langle 0{,}2; 2{,}5 \rangle$ m/s and the conveyor width $s = 0{,}7$ m. The most inconvenient variants of the load stream location to obtain the successful course of the sorting process were considered. These variants result from association of the extreme values of the objects' parameters: their geometrical dimensions, density distribution, frictional properties, and initial position on the main conveyor. An accepted admissible dynamic reactions which can be exerted on the sorted objects are equivalent to the overload risen during the object impact at free fall on the undeformable ground from the height $H_{dop} = 0{,}3$ m.

The values of exploational properties of manipulators (presented in the charts) are marked through shaded areas. Each manipulator has attributed area of different colour whose meaning was explained in the legend of Fig. 5. The interpretation of marks (occurring on all drawings) is common. Simultaneous mapping of the properties of several manipulators in one drawing leads sometimes to mutual covering of areas attributed to the manipulators. In order to enable their full identification, each area at least partly is drawn in the foreground, and the hidden edges are mapped by a dotted line. For a few areas there have been difficulties in their presentation in the foreground – even partial one. An improvement of visibility of these areas was obtained by their insignificant „extraction" beyond the declared maximum value of the dimensions of objects – from this reason some areas goes beyond dimensions 1,2 x 0,8 x 0,8 m.

The division of the capacity of sorting manipulators into ranges (low, middle and high – Fig. 5) is based on definitions used in the work [6], and division relating to the loads' sizes (small, middle and large) – in the work [7]. The divisions mark out the ranges associating the manipulator groups with the sorting process properties – they attribute the suitable technical solution in the reference to exploational expectations.

The markings of manipulators with active fences take into account two types of work nature: impact (1a, 2a) or impact-free (1b, 2b). Accepted types, result from the organization of the stream of loads on the conveyor. Initial position of load decides, if while sorting the object will impact against the fence or only slides (without impact) along this fence.

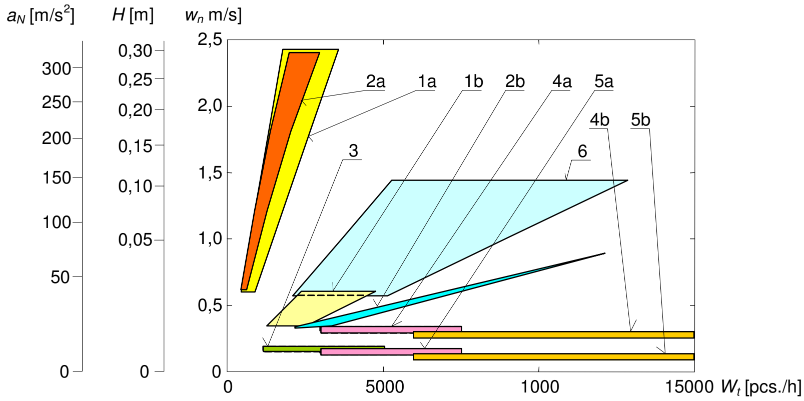
The sorting capacity of the tray manipulators is closely related to the size of applied trays – not to the sizes of objects resting on their bearing surfaces. The largest foreseen object for sorting should fall inside the tray in whole. Due to this reason, the areas concerning tray sorting devices have shapes of rectangles (Fig. 5).

The division of tray manipulators into two types: heavy (4a, 5a) and light (4b, 5b) is dictated the economic consideration: light trays are designed for objects of small dimensions, and heavy – for large objects [7].

The data relating to belt tray devices (5a, 5b) characterizes the close affinity to tilt tray manipulators (4a, 4b) in the range of the achieved capacity of sorting in the function of the objects' dimensions (Fig. 5) and the velocity of main conveyor (Fig. 7 and Fig. 8). Difference between these solutions concerns the level of dynamic interactions exerted on objects (Fig. 6) and the frictional properties of objects provided for sorting. The objects (in the case of belt trays) are exposed to the dynamic overload whose value results from friction coupling between object and the active bearing surface of manipulator – similarly, like in case of manipulator with torsional discs (3). An acceleration which is exerted by tilt tray on the object, can be larger - it can reach approx. 1,5g (g – gravity acceleration) [9]. Manipulators with tilt trays are not designed for objects' sorting of too large friction properties. Belt tray manipulators do not possess such limitation – the conveyors covering trays are made of materials of high friction coefficient – considerably higher than in case of surface of tilt trays.

The edges limiting the areas from the left side (presented in Fig. 5) relate to sorting capacity obtained at minimum dynamic overload exerted on loads (Fig. 6) and at the low velocity of conveyor transportation (Fig. 7 and Fig. 8). The movement in the range of area in the direction of the right edge causes obtainment of higher sorting capacity, an increase of dynamic overloads exerted on the load and conveyor velocity increase. This rule obviously does not apply to the tray manipulators (4a, 4b, 5a, 5b).

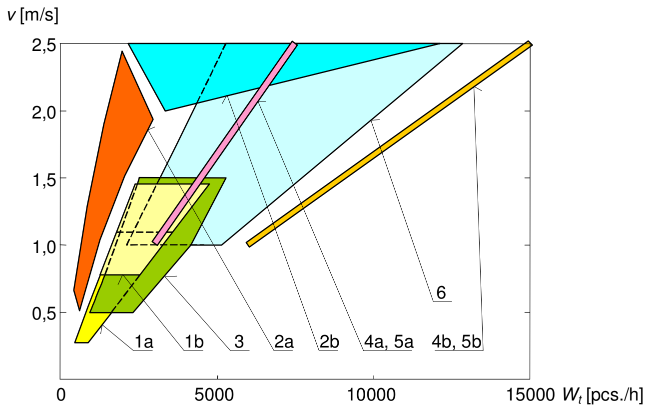
The values of dynamic interaction exerted on the object by manipulators (presented in Fig. 6) are expressed through the impact velocity, height H of the load free fall on undeformable ground, and acceleration a_N. The values of each quantities have been so calculated to reconstruct relationships occurring between these quantities during the load impact (in [8], according to Table 1 – tested load with placed inside seismic sensor is surrounded by a sponge of thickness 0,03 m) at the free fall on undeformable ground from the height H. The conversion of the impact velocity into adequate acceleration w_n transmitted to load, do not take into account actuators flexibility of manipulators. An influence of this flexibility on mitigation of dynamic interaction exerted on the objects is presented in [10].



1a – active fence with translational motion (impact nature of the work)
1b – active fence with translational motion (impact-free nature of the work)
2a – active rotary fence (impact nature of the work)
2b – active rotary fence (impact-free nature of the work)
3 – torsional discs
4a – tilt trays (heavy type) – Δc = 1,2 m
4b – tilt trays (light type) – Δc = 0,6 m
5a – belt trays (heavy type) – Δc = 1,2 m
5b – belt trays (light type) – Δc = 0,6 m
6 – divert shoes

Fig. 6. Space of dynamic overloads exerted on objects by manipulators: a_N – acceleration exerted on object, H – height of free fall of the object on undeformable ground, w_n – relative impact velocity of the object against working element in normal direction

An increment of the sorting capacity has the small influence on the value variation of the objects' overload in case of tilt manipulators (4a, 4b, 5a, 5b) and with torsional discs (3) (Fig. 6) – in contrast to manipulators with an active fences (1a, 1b, 2a, 2b) and with divert shoes (6). The edges of the left side of the areas (Fig. 6 and Fig. 7) designate the capacity of sorting loads with the maximum dimensions, and right edges – loads of minimum dimensions.



1a – active fence with translational motion (impact nature of the work)
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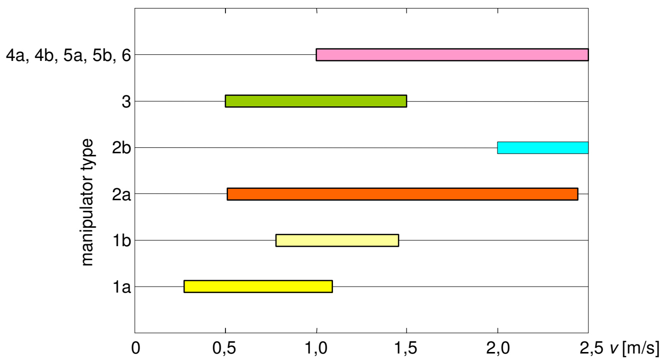
5a – belt trays (heavy type) – Δc = 1,2 m
5b – belt trays (light type) – Δc = 0,6 m
6 – divert shoes

Fig. 7. Ranges of transportation velocity of main conveyor during sorting

The chart in Fig. 8 is worked out on the basis of information contained in Fig. 7, using one of the coordinate data – preferred velocity of loads' stream. Recommendation of the objects' sorting at the range of low velocity of the main conveyor refers to the manipulators with an active fences with translational motion (1a, 1b) and manipulators with torsional discs (3). Higher velocity of transportation of load stream is appropriate for the work of manipulators: with trays (4a, 4b, 5a, 5b), with an active rotary fence (2a, 2b) and with divert shoes (6).

One of the basic features characterising the loads stream, subjected to automatic sorting process is the distance Δc between the heads of transported loads. This distance should be so chosen to obtain continuous and collision-free supply the workspace of manipulator. Dependencies occurring between sorting capacity of manipulators and recommended distance between the heads of loads transported on the main conveyor are shown in Fig. 9. The upper edges of the areas (presented in the figures) relate to the objects of the maximum external dimensions, lower – to the minimum dimensions of objects. The required distance Δc becomes smaller and smaller along with an increase of sorting capacity (excluding tray manipulators – (4a) (4b) (5a) (5b)). Obtained effect is a natural consequence of the relationship between the dimensions of load and the sorting capacity: the smaller the load, the less possible distance Δc and higher capacity of sorting (Fig. 5). The requirement of the largest distance application ($\Delta c \cong 5{,}5$ m) is assigned to the manipulators with an active rotary fences (2a) and (2b), and the smallest distance ($\Delta c \cong 0{,}6$ m) – to the manipulators with trays (4b) and (5b).



1a – active fence with translational motion (impact nature of the work)
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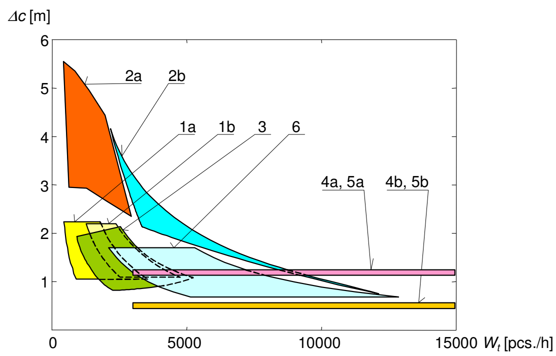
5b – belt trays (light type) – Δc = 0,6 m
6 – divert shoes

Fig. 8. Velocity of conveyors co-operating with sorting manipulators (worked out on the basis of Fig. 7)



1a – active fence with translational motion (impact nature of the work)
1b – active fence with translational motion (impact-free nature of the work)
2a – active rotary fence (impact nature of the work)
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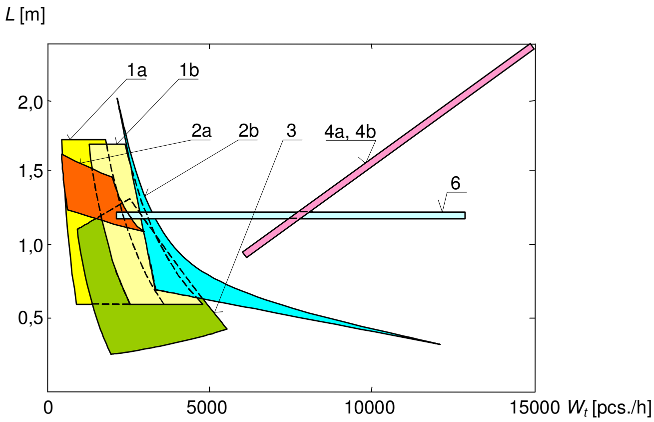
5b – belt trays (light type) – Δc = 0,6 m
6 – divert shoes

Fig. 9. Distance between heads of loads transported in the main conveyor, ensuring uninterrupted and collision-free supply of the manipulators

Shaded areas shown in Fig. 10 present the minimum lengths of the working space occupied by the manipulators. These lengths also determine the length of the minimum distance between destination chutes – have an influence on the number of division lines attributed to the unit length of an automatic sorting line. The longest workspace can be attributed to the manipulators with tilt trays (4a) and (4b), and the shortest – to manipulators with torsional discs (3). Manipulator with an active rotary fence (2b) can be simultaneously qualified to sorting devices with the shortest required working space (in case of loads sorting of minimum dimensions, and transported at high velocity of main conveyor) and to devices with large length of this space (in case of loads sorting of maximum size). The length of the workspace of manipulator with divert shoes (6) does not depend on the sorting capacity.



1a – active fence with translational motion (impact nature of the work)
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5a – belt trays (heavy type) – Δc = 1,2 m
5b – belt trays (light type) – Δc = 0,6 m
6 – divert shoes

Fig. 10. Ranges of minimum length of working manipulators' spaces

5. Summary

The analyses of research results of the sorting process of unit loads transported on conveyors indicate that:

- Highly efficient sorting devices belong to the class of nonprehensile manipulators. Basic methods of impulse generation that leads the objects to the new transport lines are achieved through: pushing of the object by working elements of manipulator, effect of the directionally-oriented fields of friction forces, and an influence of gravity force on the object causing its sliding down from the conveyor.
- Presented results of investigations fulfill cognitive function – they can be used, as guidelines on the stage of formulating the constructional assumptions of new technical solutions of sorting manipulators, and for optimum control already existing manipulators.
- The main constraints to obtain higher sorting capacity are: the dynamic effects exerted on the loads, considerable velocity achievement by loads leaving the main conveyor, the increase of the length of the working space occupied by the manipulator causing reduction of the amount of new transport lines that fall on unit length of the main conveyor. An activity of these constraints depends on the kinematic structure of each group of manipulators.

References

[1] *Postal Technology International*, UK & International Press, Dorking, 2007.

[2] *Tilt Tray Sorter DDS*, Commercial folder published by Mannesmann Dematic AG, Offenbach, Niemcy, www.dematic.com (accesed: 2010-10-27).

[3] *DRS Demag Rapid Sorter*, Commercial folder published by Mannesmann Dematic AG, Offenbach, Niemcy, www.dematic.com (accesed: 2010-10-27).

[4] *Autosort 4 – Flat Face Arm Sorter*, Commercial folder published by Automotion Inc., Oak Lawn, IL, USA, www.automotionconveyors.com/Cut%20Sheet%20PDFs/SC4%20Flat%20Face.pdf (accesed: 2010-07-24).

[5] *ProSort SC1*, Commercial folder published by Hytrol Conveyor Company Inc., Jonesboro, AR, USA, www.hytrol.com/mediacenter/catalog_sheets/ca_prosortsc.pdf (accesed: 2010-07-28).

[6] *Sortation Systems*, Commercial folder published by Diamond Phoenix Corporation (USA), www.diamondphoenix.com/page.php?page=sortSys (accesed: 2010-09-04).

[7] *Sandvik Sorting Systems. Range of Products*, Commercial folder published by Sandvik Materials Technology, Sandviken, Sveden, www.sorting.com (accesed: 2007-09-04).

[8] Piątkowski T., Sempruch J., *Model of inelastic impact of unit loads*, Packaging Technology and Science, John Wiley & Sons, 22/1, 2009, 39-51.

[9] Piątkowski T., *Modelling and analysis of dynamic properties of tilt tray manipulator*, Editors: Cretu S.-M., Dumitru N., New trends in mechanisms, Academica-Greifswald, Germany, 2008, 157-176.

[10] Piątkowski T., *Active fence with flexible link. Journal of Theoretical and Applied Mechanics*, 1, 48, 2010, 87-109.

[11] Piątkowski T., *Analiza i modelowanie procesu sortowania strumienia małogabarytowych ładunków jednostkowych*, Monograph 139, University of Technology and Life Sciences UTP in Bydgoszczy, 2010.

[12] Piątkowski T., *Model and analysis of the process of unit-load stream sorting by manipulator with torsional disks*, Journal of Theoretical and Applied Mechanics, 4, 47, 2009, 871-896.

[13] Piątkowski T., *Analysis of translational positioning of unit loads by directionally-oriented friction force fields*, Mechanism and Machine Theory, Elsevier, 46, 2011, 201–217.

[14] Piątkowski T., *Dynamic identification of sorting process of unit loads stream performed by means of active fence with translational motion*, Logistyka 6/2008, 281-286.