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OPTIMIZATION OF BERNOULLI GRIPPING DEVICE'S ORIENTATION UNDER THE PROCESS OF MANIPULATIONS ALONG DIRECT TRAJECTORY

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Summary. *There was appointed the task to define the optimal orientation of bernoulli gripping device aiming to minimal consumption of compressed air under given parameters of bernoulli gripping device, manipulation object and trajectory. The author suggested splitting of rectilinear trajectory into 5 sections. These sections secure permanent transportation of manipulation object by means of pure momentum and weight power. Two intermediate re-orientation sections secure permanent transportation being limited with gravitation of gripping device. There was presented the task solution for the particular example under permanent transportation of manipulation object along the whole trajectory.*

Key-words: *bernoulli gripping device, manipulation object, permanent transportation, manipulator, orientation, industrial robot.*

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Problem setting. The modern stage of automation requires the decrease of energy consumption during transportation of and manipulation with industrial objects. Manipulation objects are gripped and relocated by industrial robot into different positions. The lifting power in bernoulli gripping devices is formed by aerodynamic gravitation effect due to compressed air. One has to limit motion and acceleration speed to retain equilibrium of manipulated object. It will result in increasing of manipulation time and energy consumption respectfully.

Analysis of the latest research and issues. The research project [1 – 3] stipulates the definition of admissible acceleration of bernoulli gripping device during vertical motion for permanent transportation of manipulation object. There was investigated one of the most adverse cases of gripping device allocation relatively manipulation object. There were stipulated the rotation parameters ω, ε, which secure relative equilibrium of manipulation object.

Research objectives. One has to optimize the orientation of bernoulli gripping device during plate-type object manipulation along direct trajectory.

Task setting. Let's investigate the case when gripping device, which was designed for transportation of NCT (non-contact transport unit) [2]. The operation principle for this device is shown on Fig. 1.

Motion along the given rectilinear is made by means of IRB 1200 (ABB corporation) manipulator which has 6 stages of freedom. Software and motion simulation (Fig. 2) of gripping device towards manipulation object is carried out by means of RobotStudio (ABB corporation).

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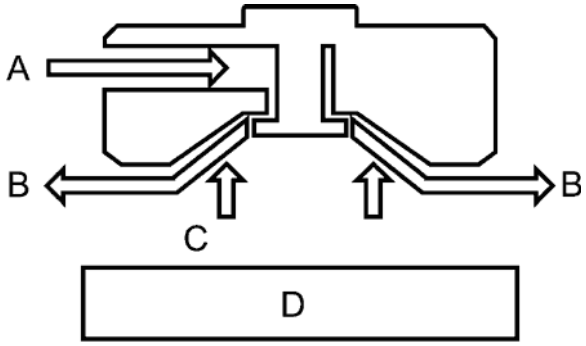

Figure 1. The principle of the device for non-contact transportation NCT:
A – compressed air, B – air flow, C – lift, D – object

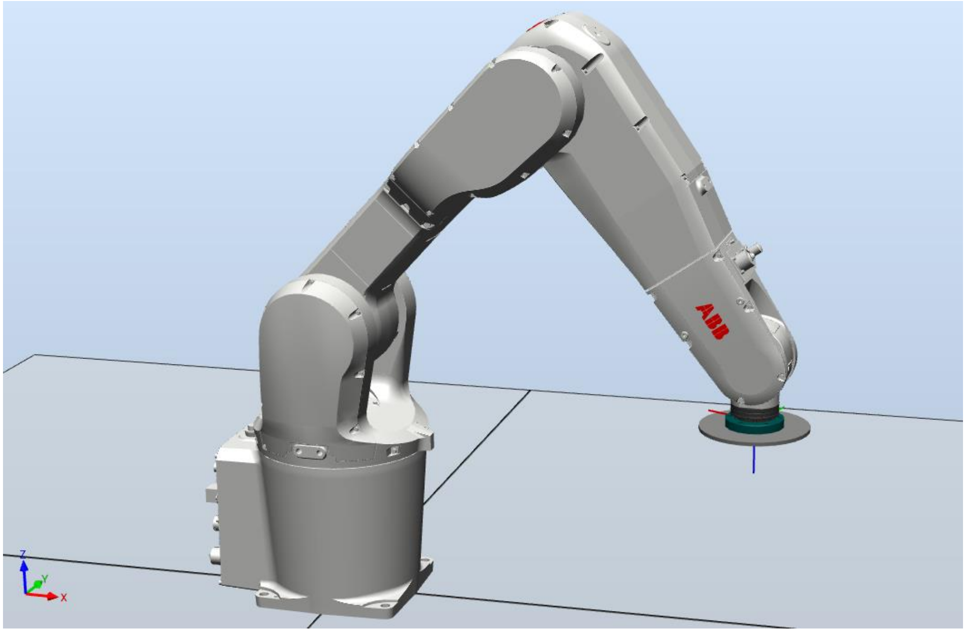

Figure 2. Visualization robot (IRB 1200), gripping device (NCT 60) and manipulation object in the software environment RobotStudio 6.0

Under given parameters of manipulator, bernoulli gripping device, manipulation device and trajectory the task is to optimize the orientation of gripping device at which the consumption of compressed air is minimal.

Investigation results. Let us study the ordinary method of plate-type plane units' transportation by means of bernoulli gripping device (Fig. 3). One can see that along entire transportation period the gripping device, which is parallel with x-y plane of global coordinate system in such way that orientation axis of gripping device $\bar{n}$ is directed contrariwise to global axis Z. So, the gripping device orientation was not changed during entire manipulation period since gripping device has seized the manipulation object. It means that outflow of compressed air is constant (maximal) during entire manipulation period.

Let us assume that it is necessary to move manipulation object MO from position A_0 into position B^* (Fig. 4.). We think that both positions can be reached by the manipulator. To grip MO in initial position it is necessary that orientation axis of gripping device (GD) $\bar{n}$ is oriented counter-wise to global axis *Z*. Analogically, for assembling of details in position B^* GD should also be oriented the same way as in initial state. For simplifying B^* coincides with з B_0. We are going to plan the motion trajectoty in the form of three rectilinear areas – A_0A_1, A_1B_1, B_1B_0. Along section A_0A_1 there is made MO lifting and changing of GD orientation so it would be optimal in energy consumption during retaining of permanent transportation along section A_1B_1. Along section B_1B_0 there is made MO sinking down to storage place and changing of GD orientation to necessary one in final position. The usage of compressed air on these two sections is sufficient for all types of operations (for example, maximal). Along the section A_1B_1 we are going to plan MO movement and orientation in such way that energy consumption of compressed air will be minimal. For this purpose it is necessary to cut the motion time along this section to minimal one, and GD orientation should cut to minimum the consumption of compressed air.

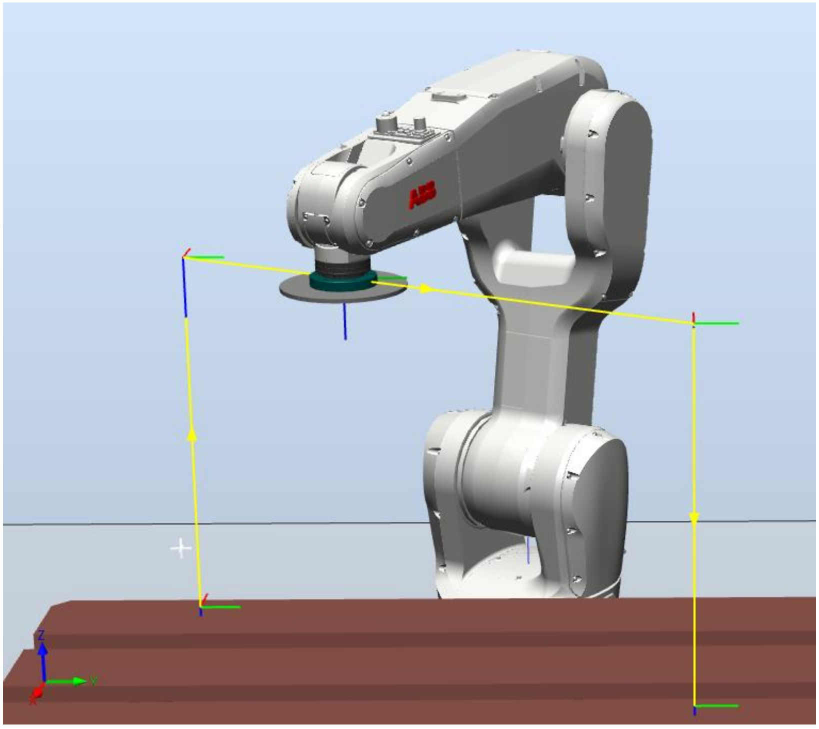

Figure 3. Trajectory without reorientation of gripping device while manipulating RobotStudio 6.0 software

It is known that motion during the shortest time under limited power of manipulator drives is made when the movement on a first half of trajectory A_1B_1 goes on with maximal acceleration, and with maximal deceleration on the second half of trajectory.

Let us find the optimal GD orientation on the section part where MO moves with maximal acceleration $\bar{a}$.Lifting force of GD is directed counter-wise to GD orientation axis $\bar{n}$. Obviously, orientation axis should be directed in such way so the MO aggregate power from gravitation and inertia forces would perform the rple of lifting power. Figure 4 shows that manipulator orientation axis is focused in vector $\bar{n}$ direction.

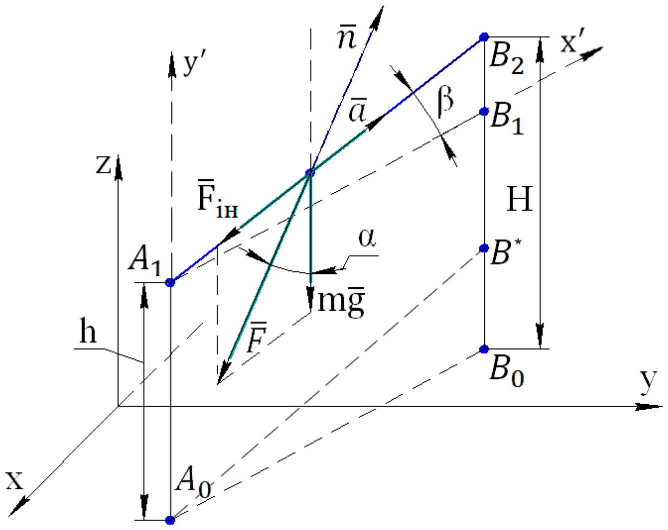

Figure 4. The forces acting on MO during manipulation (acceleration) in global coordinates

Resulting force (without lifting force) is equal to:

$$\overline{\mathrm{F}} = \overline{\mathrm{F}}_{in} + m\overline{\mathrm{g}} \tag{1}$$

$$\overline{\mathrm{F}}_{in} = -m\overline{a} \tag{2}$$

Elaborating vector equality (1) on axis x', y' we will find:

$$\begin{cases} -\mathrm{F}\sin\alpha = -ma\cos\beta \\ -\mathrm{F}\cos\alpha = -ma\sin\beta - m\mathrm{g} \end{cases} \tag{3}$$

Having found the solution for obtained equality system relatively to F and α, we will get:

$$\mathrm{F} = \sqrt{m^2\left(a^2 + \mathrm{g}^2\right) + 2m\mathrm{g}a\sin\beta} \tag{4}$$

$$\alpha = actg\,\frac{a\cos\beta}{\mathrm{g} + a\sin\beta} \tag{5}$$

Formula (5) determines the optimal angle of GD orientation during movement with acceleration $\overline{a}$, if $\beta = 0$ then $\alpha = arctg\,\dfrac{a}{\mathrm{g}}$.

Let us find optimal GD orientation (i.e. angle α) for the situation when the movement will be with maximal deceleration (Figure 6).

Elaborating vector equality (1) on axis x', y' we will find:

$$\begin{cases} \mathrm{F}\sin\alpha = ma\cos\beta \\ -\mathrm{F}\cos\alpha = ma\sin\beta - m\mathrm{g} \end{cases} \tag{6}$$

Having found the solution for obtained equality system relatively to F and α, we will get:

$$F = \sqrt{m^2\left(a^2 + g^2\right) - 2mga\sin\beta} \tag{7}$$

$$\alpha = actg\,\frac{a\cos\beta}{g - a\sin\beta} \tag{8}$$

If $\beta = 0$ then $\alpha = arctg\,\dfrac{a}{g}$.

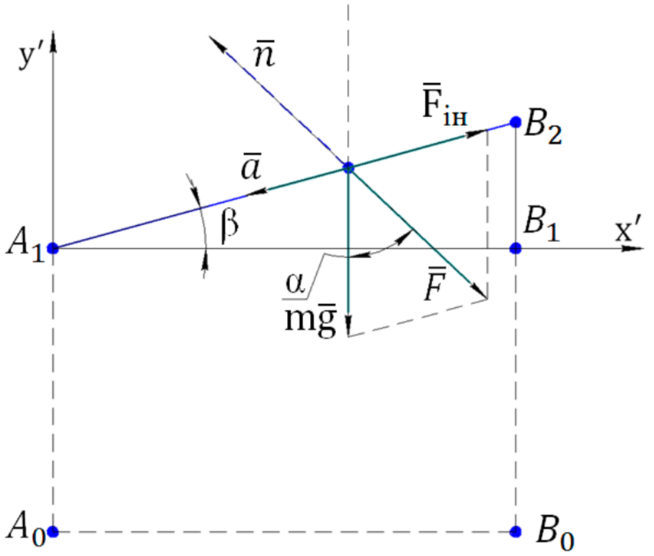

Figure 5. The forces acting on MO during the deceleration in one plane

Now one has to simulate the given trajectory to get authentic data, but with changed orientation in points A_1, B_2 of the straight line into analogic to global system of coordinates.

During the inspection of simulation software it turned out that manipulator with such GD parameters could not provide the appropriate orientations because during movement to initial point of the straight line and further motion of gripping device with manipulation object there happens the collision of manipulation object with manipulator.

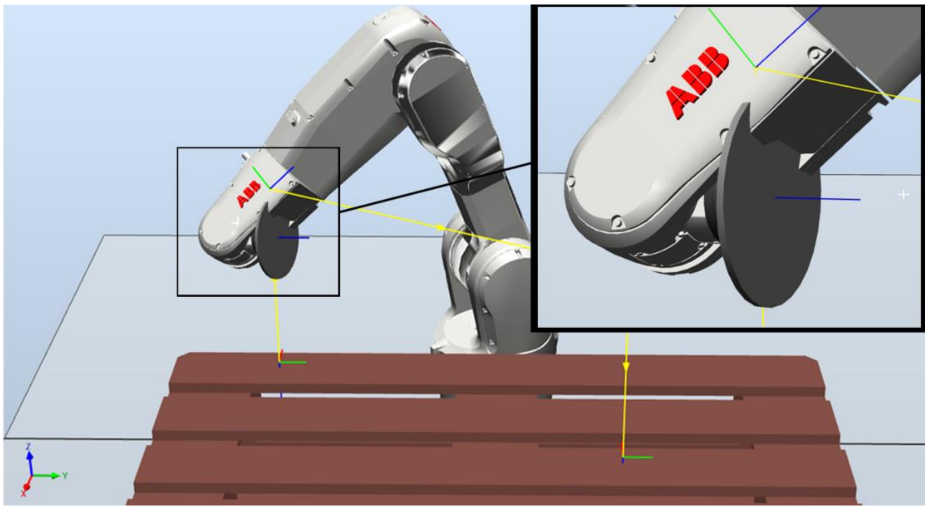

Figure 6. The collision of manipulation object with manipulator

That is why we suggested using popular methods that are applied during contour welding; in particular it was proposed to extend the GD bolting and shift GD axis quadrant depression $\bar{n}$ on 30 degrees relatively to final link orientation (Figure 7). Owing to this the manipulator can easily regenerate any required orientation.

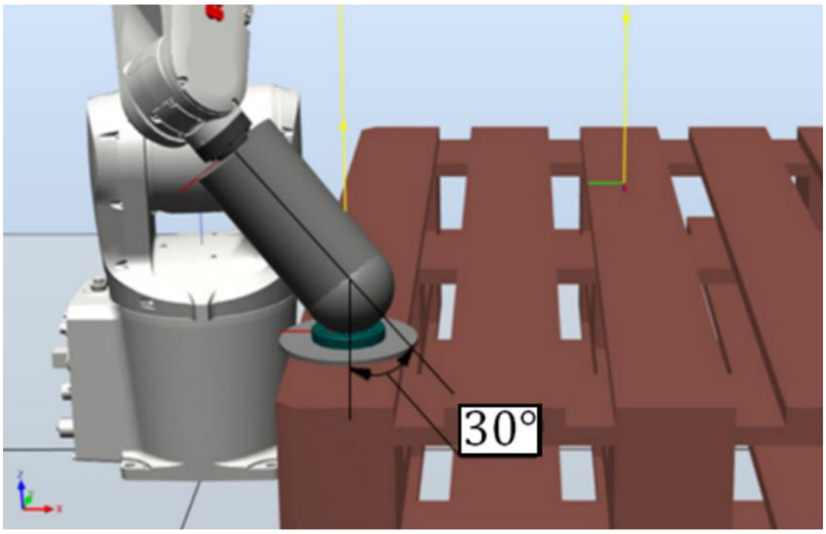

Figure 7. Extension of gripping device with reorientation

Before the simulation one has to mark the main points of reorientation on our rectilinear trajectory as it is shown on Figure 8. It is also necessary to limit the acceleration along entire distance by means of function PathAccLim (PathAccLim TRUE \AccMax:= 2, TRUE\DecelMax:= 2;).

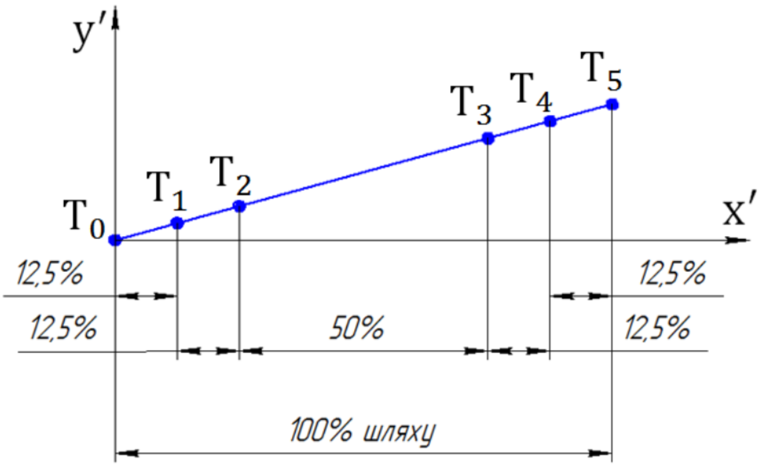

Figure 8. – Reorientation points location on rectilinear path

Having done the simulation with extender, we will obtain the velocity graph for manipulation object (Figure 9). As we need the trapezoid velocity profile, one sufficiently has to limit velocity to point M, which has the slowest speed on path interval $T_1 - T_5$ by means of function VAR speeddata vmedium (0,44 meters per second).

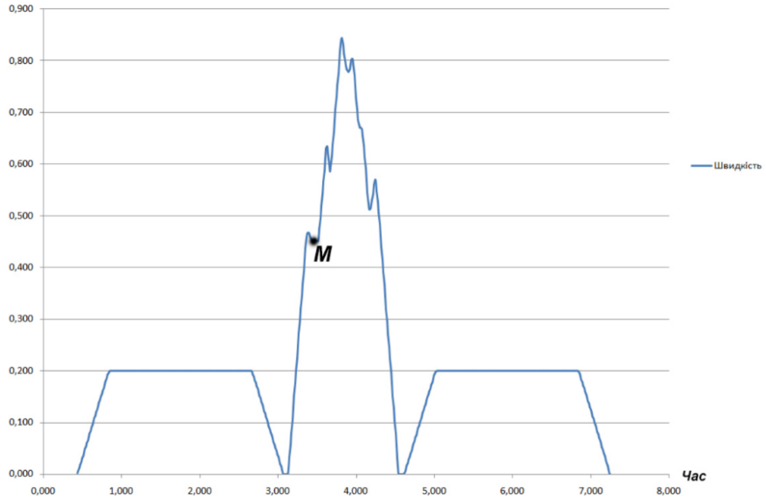

Figure 9. Velocity of manipulation object

Having limited the velocity to 0,44 meters per second, we obtained the trapezoid velocity profile (Figure 10).

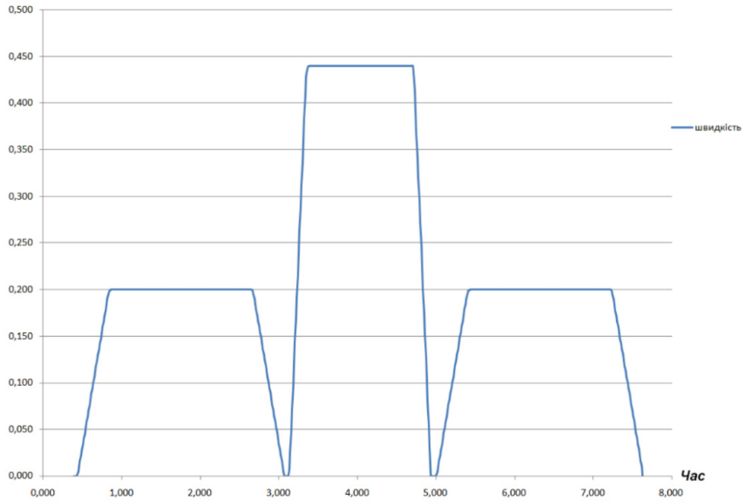

Figure 10. Graph of trapezoid velocity profile of the manipulation object

Now it is possible to build the graph of gripping device acceleration (Figure 11), which is necessary to find orientation.

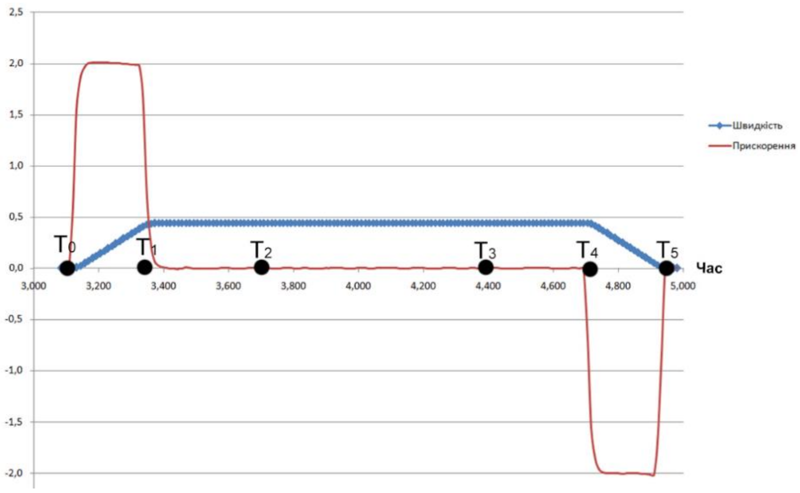

Figure 11. Graph of gripping device acceleration

Next step is downloading of GD orientation, particularly the angle between axis's $\bar{n}$ and Z on the section T_0T_1 we download equal to angle α (5) for acceleration on the section T_4T_5 – to angle α (8) for deceleration. On the section T_1T_2 we download the change of orientation from angle α (5) to zero as there is no acceleration on the middle section T_2T_3, orientation stays unchanged and the angle to global system of coordinates is equal to zero. Next step is downloading of orientation variable on section T_3T_4 from zero to angle α (8), which is optimal on the section with further deceleration. Such orientation is retained on the section T_4T_5.

One has to admit from mentioned above that there are two sections T_1T_2 і T_3T_4 of trajectory where we are not sure in secure MO transportation. Perhaps, the most unfavorable option will occur when in point T_1 the acceleration is equal to zero, and the angle here is still equal to angle α (5) (Figure 12). Let us find the limits for lifting force rate in this case. If there is no acceleration, then as result of orientation with angle α (5) MO can lose relative balance and move in $\bar{S}$ direction. As result, there appears friction force in points of contact between MO and GD, due to $F_{fr} = fN$, where *f* friction rate.

Conditions of MO balance are the following

$$N - mg\cos\alpha - F_n = 0,$$

$$F_{fr} - mg\sin\alpha = 0.$$

Out of the first equation we will find

$$N = mg\cos\alpha + F_n.$$

Then $f\left(\mathrm{m}g\cos\alpha + \mathrm{F}_n\right) = -mg\sin\alpha = 0$

To provide permanent MO transportation it is necessary to accomplish the condition

$$\mathrm{m}g\cos\alpha + \mathrm{F}_n \geq \frac{mg}{f}\sin\alpha,$$

$$\textit{або}\ \mathrm{F}_n \geq mg\left(\frac{\sin\alpha}{f} - \cos\alpha\right). \tag{9}$$

The analogical limits of lifting force rate (9) are on section T_3T_4 but the angle is important (8).

For device with *m* = 0,1 kg, friction rate *f* = 0,2, angle *α* = 11.3° we obtain the following limit:

$$\mathrm{F}_n \geq -0{,}0294$$

It indicates that on sections T_1T_2 and T_3T_4 the transportation will be permanent and without applying of lifting force i.e. without supply of GD with compressed air. Under other given parameters there can appear a necessity in lifting force. It can be done on theses sections with opening of automatic valve of compressed air supply.

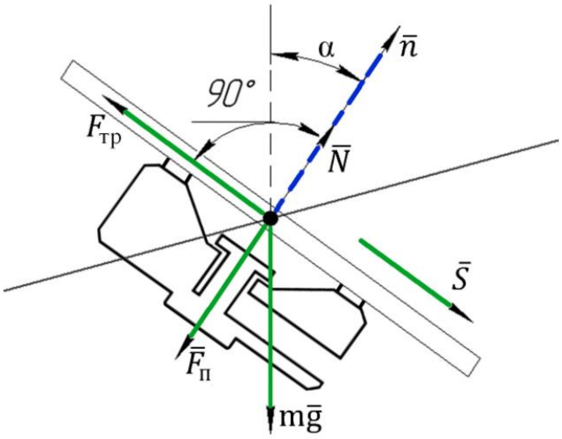

Figure 12. The forces acting on the object of manipulation at the point T_1 under the most unfavorable conditions

During ordinary transportation of MO (Figure. 3), GD provides lifting force along the whole route under the most unfavorable conditions. In our case it is defined by formula [5]:

$$\mathrm{F}_n \geq m\left[g + a\left(\frac{\sin\gamma}{f} - \cos\gamma\right)\right], \tag{10}$$

where γ is an angle between acceleration vector and axis $\bar{n}$. In our case $\gamma = 90°$, then lifting force is needed:

$\mathrm{F}_n \geq 14{,}98 \approx 15$ H.

Due to technical characteristics of GD [4], at lifting force 15 H. the rail pressure of $\mathrm{P_m} = 600$ kPa is required, and weight loss of compressed air through crack is $\mathrm{G_c} = 0{,}0055$ kg/s. Having obtained these data, we can calculate GD consuming power:

$\mathrm{N}_c = \dfrac{P_m \cdot G_c}{\rho_a} = 2640$ J/s.

Now one can find work that has to be used to seize MO with GD on the section T_1T_5, where transportation time is 4 sec.:

$A_{gd} = N_c \cdot t = 10560$ J

Under planned transportation of MO the required F_n on section T_1T_5 is less than zero. It means that there is no necessity in compressed air and work A_{gd} is equal to zero.

Besides the work that is required for MO maintenance there is a job the manipulator does during transportation and orientation of GD with MO. We shall obtain the data by means of RobotStudio (ABB corporation) software.

During the transportation without reorientation we will get the following data (Figure 13) about contributed into MO transportation work.

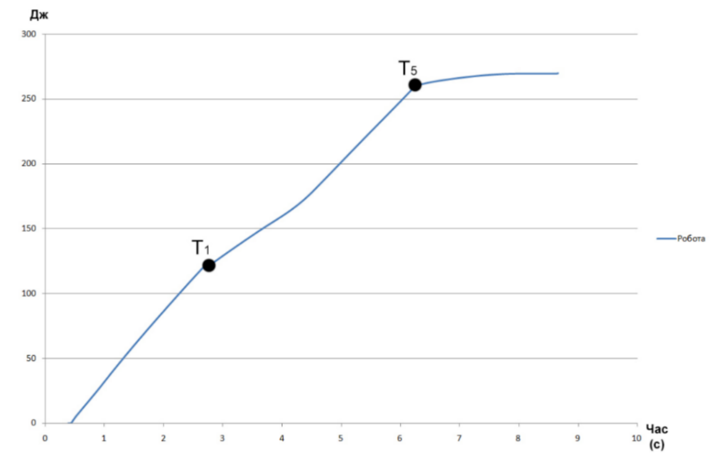

Figure 13. Work spent on transportation of manipulator of the object manipulation without reorientation

During transportation without reorientation on the section T_1T_5 the MO contributed $A_m = A_m(T_5) - A_m(T_1) = 140$ J of work, and during transportation with reorientation on the section T_1T_5 the MO contributed $A_m = 256$ J of work.

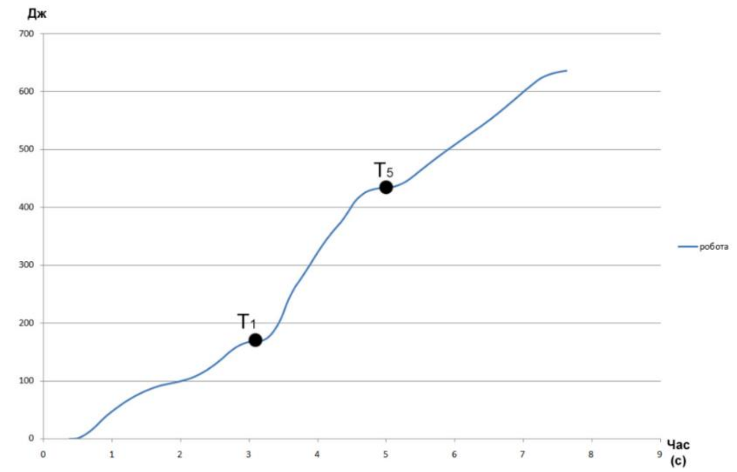

Figure 14. Work spent on transportation by manipulator of the object with reorientation

Now we can obtain the aggregate work contributed into MO transportation under two different types of movement.

During transportation without reorientation the aggregate work on section T_1T_5 is equal to:

$$A_1 = A_{gd} + A_m = 10700 \text{ J},$$

and during transportation with reorientation the aggregate work on section T_1T_5 is equal to:

$$A_2 = A_{gd} + A_m = 256 \text{ Дж}.$$

Let us find the efficiency coefficient for MO transportation with reorientation:

$$\eta = \frac{A_1}{A_2} = 40.$$

It means that MO transportation with reorientation allows minimizing the loss of compressed air and decreasing the contributed work into MO transportation along rectilinear trajectory.

Conclusion. There was proposed the optimization of the orientation of the gripping device during the transport of object manipulation on a straight-line trajectory. Transportation using the optimum orientation allows reducing in 40 times the energy consumption comparing to transportation without reorientation.

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УДК 621.865.8

ОПТИМІЗАЦІЯ ОРІЄНТАЦІЇ СТРУМИННОГО ЗАХОПЛЮВАЛЬНОГО ПРИСТРОЮ В ПРОЦЕСІ МАНІПУЛЮВАННЯ ПО ПРЯМІЙ ТРАЄКТОРІЇ

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Резюме. *Поставлено задачу при заданих параметрах маніпулятора, струминного захоплювального пристрою, об'єкта маніпулювання і траєкторії визначити оптимальну орієнтацію захоплювального пристрою, при якому споживання стисненого повітря буде мінімальним. Запропоновано розділення прямолінійної траєкторії на 5 ділянок. Визначається оптимальна орієнтація на першій, середній і кінцевій ділянці. На цих ділянках забезпечується безвідривність транспортування об'єкта маніпулювання за допомогою лише сили інерції і сили ваги. На двох проміжних ділянках переорієнтації забезпечується безвідривність транспортування з обмеженням на силу притягання захоплювального пристрою. Наведено розв'язання задачі для конкретного прикладу, при забезпеченні безвідривного транспортування об'єкта маніпулювання на усій траєкторії.*

Ключові слова: *струминний захоплювальний пристрій, об'єкт маніпулювання, безвідривне транспортування, маніпулятор, орієнтація, промисловий робот.*

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