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JUSTIFICATION OF THE OBJECT OF MANIPULATION PARAMETERS INFLUENCE ON THE OPTIMAL ORIENTATION AND LIFTING CHARACTERISTICS OF BERNOULLI GRIPPING DEVICE

In order to reduce energy consumption while performing transport operations with the help of industrial robots, the theoretical and practical experiments on the influence of movement parameters and the object of manipulation on the optimal orientation of the bernoulli gripping device have been carried out. With its constructive simplicity bernoulli gripping device is reliable in operation and unlike the other suitable for gripping flexible, brittle, fragile, non-metallic, non-rigid, heated and contaminated objects manipulation. Optimal orientation of the bernoulli gripping device will allow reducing minimal necessary attractive force of the object of manipulation, which resists the inertial forces and friction, as well as reducing consumption of the compressed air. The case of the object of manipulation transportation along the rectilinear trajectory with the help of the manipulator IRB 4600 and RobotStudio software has been under study. The adequacy of the model and the efficiency of the use of this method of orientation optimization of gripping devices for minimizing the energy consumption while performing manipulating functions by the industrial robot has been proved.

Keywords: Bernoulli gripping device; object of manipulation; manipulator; orientation; industrial robot.

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ОБГРУНТУВАННЯ ВПЛИВУ ПАРАМЕТРІВ ОБ'ЄКТА МАНІПУЛЮВАННЯ НА ОПТИМАЛЬНУ ОРІЄНТАЦІЮ ТА СИЛОВІ ХАРАКТЕРИСТИКИ СТРУМИННОГО ЗАХОПЛЮВАЛЬНОГО ПРИСТРОЮ

З метою зниження енергозатрат під час виконання транспортних операцій за допомогою промислових роботів, проведено теоретичні та експериментальні дослідження, щодо впливу параметрів руху та об'єкта маніпулювання на оптимальну орієнтацію струминного захоплювального пристрою. Оптимальна орієнтація струминного захоплювального пристрою дозволить знизити мінімальну необхідну силу притягання об'єкта маніпулювання, що протидіє силам інерції та тертя, і в результаті знизити витрату стиснутого повітря. Розглянутий випадок транспортування об'єкта маніпулювання по прямій траєкторії, з проведенням експериментів за допомогою маніпулятора IRB 4600. При цьому використовувалось програмне забезпечення RobotStudio. Доведено адекватність моделі і ефективність використання даного методу оптимізації орієнтації захоплювальних пристроїв для мінімізації енергоспоживання під час виконання промисловим роботом маніпулятивних функцій.

Ключові слова: струминний захоплювальний пристрій; об'єкт маніпулювання; маніпулятор; орієнтація; промисловий робот.

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ОБОСНОВАНИЕ ВЛИЯНИЯ ПАРАМЕТРОВ ОБЪЕКТА МАНИПУЛИРОВАНИЯ НА ОПТИМАЛЬНУЮ ОРИЕНТАЦИЮ И СИЛОВЫЕ ХАРАКТЕРИСТИКИ СТРУЙНОГО ЗАХВАТНОГО УСТРОЙСТВА

С целью снижения энергозатрат при выполнении транспортных операций с помощью промышленных роботов, проведены теоретические и экспериментальные исследования влияния параметров движения и объекта манипулирования на оптимальную ориентацию струйного захватного устройства. Оптимальная ориентация струйного захватного устройства позволит снизить минимальную необходимую силу притяжения объекта манипулирования, что противодействует силам *инерции и трения, и в результате снизить расход сжатого воздуха. Рассмотрен случай транспортировки объекта манипулирования по прямой траектории, с проведением экспериментов с помощью манипулятора IRB 4600. При этом использовалось программное обеспечение RobotStudio. Доказано адекватность модели и эффективность использования данного метода оптимизации ориентации захватных устройств для минимизации энергопотребления при выполнении промышленным роботом манипулятивных функций.*

Ключевые слова: струйное захватное устройство; объект манипулирования; манипулятор; ориентация; промышленный робот.

Formulation of the problem

At the present stage, the issue of energy consumption while transportation and manipulation of the objects at the manufacture has been very urgent. The objects of manipulation are gripped by the device of the industrial robot and transported from one position to another. In gripping devices of Bernoulli type [1-6] the lifting power creates at the expense of aerodynamics effect of attraction which is provided by the use of the compressed air. In papers [7,8] the formulas for the defining of the allowable acceleration of the gripping device while its vertical movement at the conditions of uninterrupted transportation of the manipulating objects have been deduced.

Owing to the minimal contact with the object of manipulation and the use of the compressed air, Bernoulli gripping devices are becoming popular in the industry. The reliability of such devices significantly depends on the quantity of the consumed air to preserve the balance of the object of manipulation as to the gripping device while the transportation. This matter calls forth to study the influence of the parameters of the object of manipulation for the optimal orientation of the gripping device which ensures uninterrupted transportation of the object of manipulation at minimal expenses of the compressed air.

Analysis of last investigations and publications

In the paper [9,10] the model for the optimal orientation of the gripping device while transportation of the manipulation object along the rectilinear trajectory has been suggested, as well as the model for the orientation of the gripping device with the off-centered masses. The study [11] deals with the influence of the base elements on the object of manipulation and tactile actions on the hand.

The purpose of the investigation

The aim of this paper is to study the influence of the object of manipulation parameters (the area of the object of manipulation surface, off-centering the masses of the object of manipulation as to the axis of the gripping device, the mass of the object of manipulation, coefficient of the friction between the object of manipulation and friction elements of the gripping device) on the optimal orientation of Bernoulli gripping device which will in its turn influence the minimal necessary attractive force.

Statement of the basic material of the investigation

At given parameters of Bernoulli gripping device (Fig. 1, a) and the trajectory of its direction it is necessary to study theoretically and experimentally the influence of the object of manipulation parameters on the optimal orientation which will have the influence on the minimal necessary attractive force of Bernoulli gripping device.

During the experimental research the experimental unit has been designed and produced for the research of the transportation processes with the possibility of changing parameters of the performed process (Fig. 1 b, c, d).

Parameters of the object of manipulation will influence forces which will occur in the process of the object of manipulation transportation. Each parameter will influence the optimal orientation of the gripping device depending on the movement parameters of the gripping device.

For the theoretical research of this influence the orientation modeling methods introduced in the study (10) have been used. The first parameter under study is the optimal orientation of the gripping device, which can be defined from the equation:

$$\begin{gathered} m\left[\varepsilon\left(R^2+\frac{Hd}{2f}\right)-\frac{d}{f}\omega^2 E\right]+ \\ +m\left\{\frac{d}{f}\big(g\sin(\alpha)-a\cos(\alpha+\beta)\big)-g\left(E\cos(\alpha)-\frac{H}{2}\sin(\alpha)\right)-a\left(E\sin(\alpha+\beta)+\frac{H}{2}\cos(\alpha+\beta)\right)\right\}- \\ -Q_1\left[\left(\frac{d}{f}+\frac{A}{2}\right)\cos(\alpha+\beta)+\left(E-\frac{A}{2}\right)\sin(\alpha+\beta)\right]+Q_2\left[\left(\frac{d}{f}+H\right)\cos(\alpha+\beta)+E\sin(\alpha+\beta)\right]=0, \end{gathered} \quad (1)$$

Were A - length of the object of manipulation, H - height of the object of manipulation, E - distance from the center of the mass of the object of manipulation to the axis of the gripping device projection Oy, d - distance from the center of the gripping device to the friction element of gripping, R - distance from the center of mass of the object of manipulation to the center of the gripping device, a - acceleration of the object of manipulation movement, β the angle between the trajectory and the global plane XOY, m - mass of the object of manipulation, ε - angular acceleration, f - coefficient of friction, ω - angular velocity, Q1 and Q2 frontal resistance force, Fin - inertial force, Fli - lifting force.

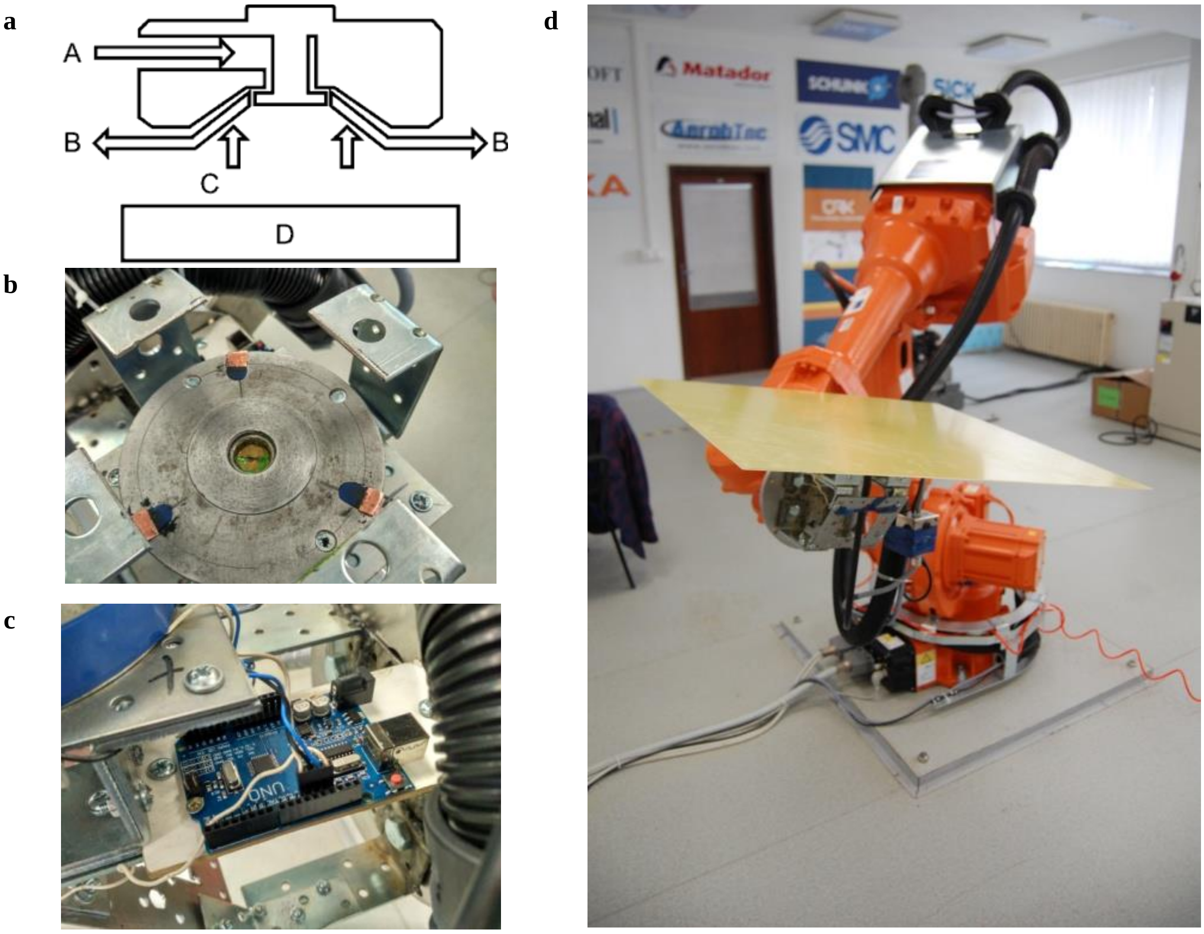

Fig. 1. Experimental Unit: (a) the principle of Bernoulli gripping device functioning, (b) fixed on the terminal effector of the manipulator of the gripping device, (c) the controller of the object of manipulation separation from the gripping device based on Arduino UNO, (d) the unit based on the manipulator IRB 4600 with object of manipulation

The second parameter under research is the minimal necessary attractive force of the griping device, which can be found from the following equation:

$$F_{li} = m\left[g\left(\frac{\sin(\alpha)}{f} - \cos(\alpha) \right) - \omega^2 \left(\frac{E}{f} - \frac{H}{2} \right) + \varepsilon \left(\frac{H}{2f} + E \right) \right] - \\ -\left(Q_1 + Q_2 + F_{in} \right)\left(\frac{\cos(\alpha+\beta)}{f} + \sin(\alpha+\beta) \right). \qquad (2)$$

The experimental research has been conducted with programming the industrial robot for the movement of the object of manipulation along the rectilinear trajectory. This trajectory has been realized with the help of the manipulator IRB 4600 (ABB). The data for the model check have been received with the help of the software RobotStudio (12) at National Centre of Robotics (NCR) at Slovak University of Technology in Bratislava (13).

Let us analyse the influence of the object of manipulation area on the optimal orientation of the gripping device while manipulating along the given trajectory (Fig. 2), received with the help of the formulae (1,2) and the methodology (10). The calculation has been conducted at the given parameters: d=0.04 [m], a=4 [m/s2], m=0.9 [kg], f=0.404, H=0.005 [m], β=0 [rad], ω=0 [rad/s], ε=0 [rad/s2].

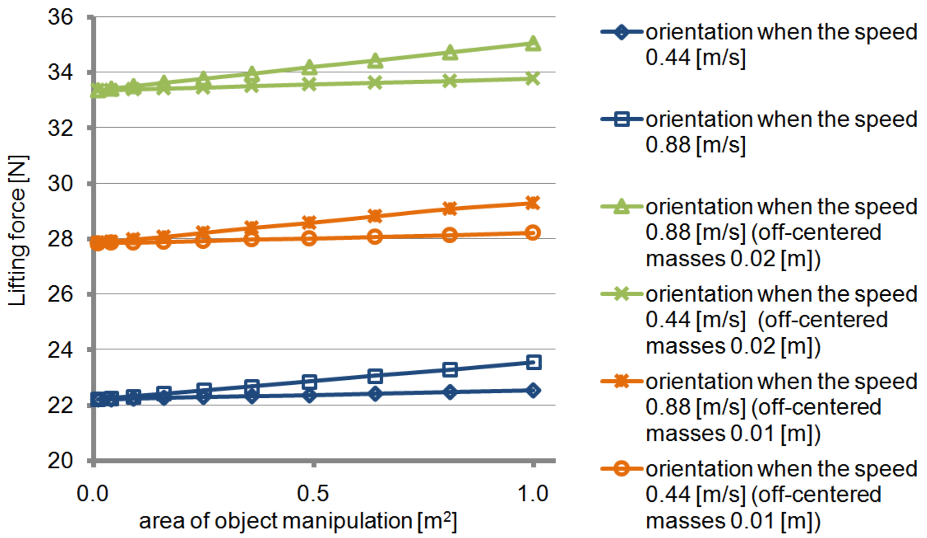

Fig. 2. Diagram showing the influence of the object of manipulation area on the gripping device optimal orientation at different movement parameters

As Figure 2 shows, the orientation is being changed while increasing the area of the object of manipulation and the movement speed of the gripping device at the expense of the frontal resistance forces increase which have an effect upon the object of manipulation. Thus, while calculation of the optimal orientation for the massive details which move with great speed it will be reasonable to include the frontal resistance force into the calculation scheme.

The most significant influence on the optimal orientation of the gripping device will be provided by the off-centered masses of the object of manipulation which in its turn will influence the minimal necessary attractive force.

To study the influence of the off-centered masses of the object on the minimal necessary attractive force (Fig. 3) the experiment has been conducted (Fig. 1. d) based on the following experimental parameters: A=0.585 [m], H=0.005 [m], v=0.64 [m/s], d=0.04 [m], β=0 [rad], a=2 [m/s2], m=0.9 [kg], ω=0 [rad/s], ε=0 [rad/s2], f=0.404.

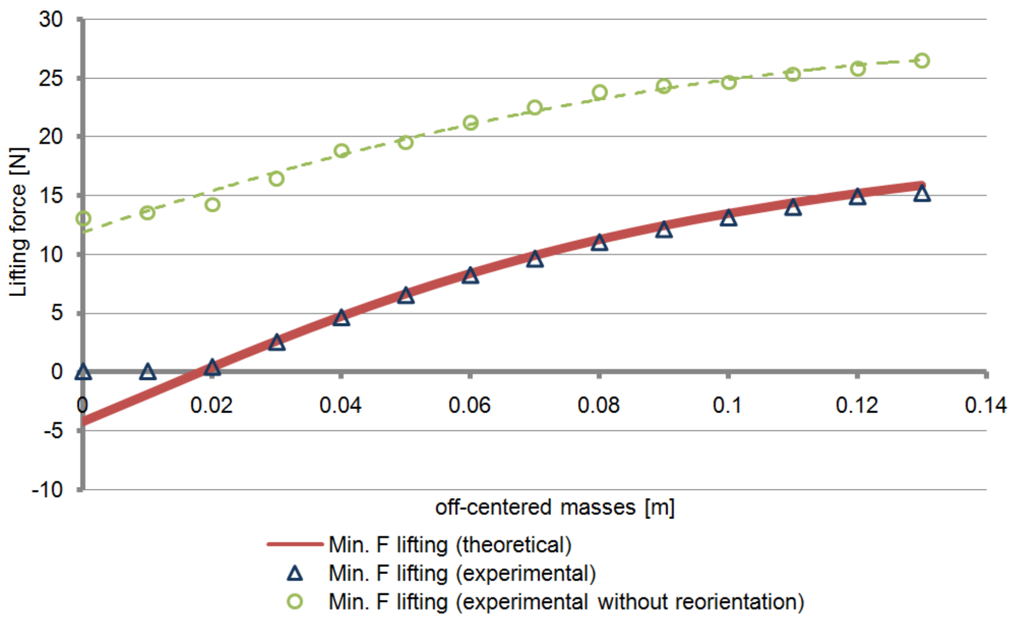

Fig. 3. The graph of the off-centered masses influence on the necessary minimal attractive force of the gripping device

Figure 3 confirms the adequacy of the mathematical model for the optimal orientation of the Bernoulli gripping device (the maximal relative indication error is 5%). One can also see the level of the decrease of the necessary minimal attractive force at using the optimization model comparing with the transportation without the re-orientation of the object of manipulation. Based on what is shown in Figure 3, the off-centered masses of the object of manipulation have the significant impact on the necessary minimal attractive force.

For the interval of the off-centering on the masses from 0 to 0.02 m, one can notice the tendency of the attractive force towards the needlessness of retention of the object of manipulation on the gripping device. The value of the interval for which this tendency will preserve significantly depends on the coefficient of the object of manipulation friction to the friction elements of the gripping device.

Figure 4 shows the influence of the friction coefficient on the necessary minimal attractive force. For calculation the following parameters were taken: A=0.11 [m], H=0.02 [m], v=0.64 [m/s], d=0.04 [m], β=0 [rad], E=0 [m], m=0.9 [kg], ω=0 [rad/s], ε=0 [rad/s2].

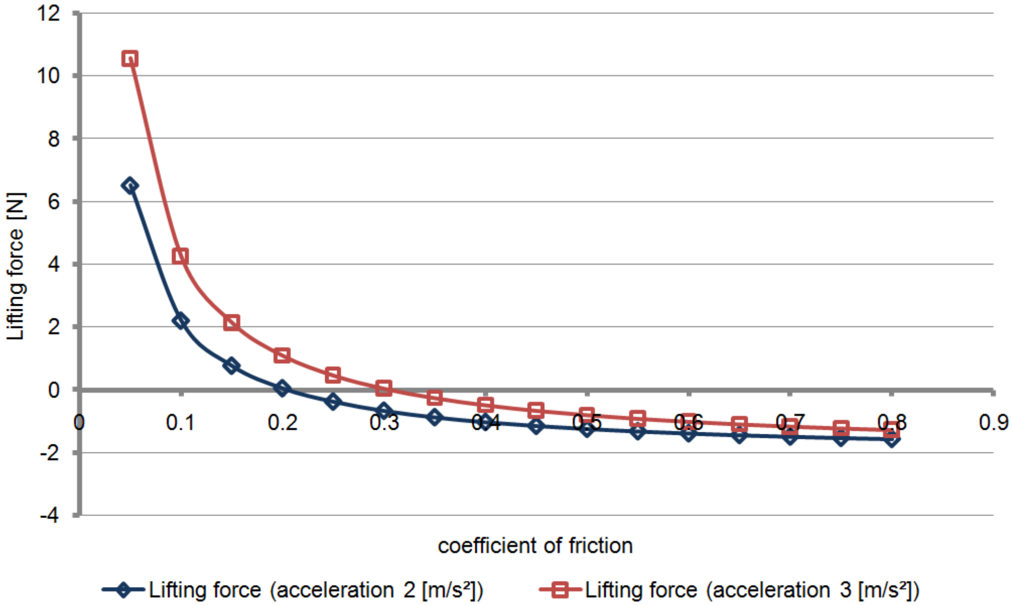

Fig. 4. The graph of the friction coefficient influence of the object of manipulation to the friction elements on the necessary minimal attractive force

Figure 4 shows that low values of the friction coefficient demands the attractive force increase that is the increase in the compressed air consumption. The conclusion may be drawn that it is necessary to provide as high friction coefficient as possible in order to minimize the attractive force of the gripping device.

As the attractive force of the gripping device significantly depends on the acceleration of the final one of the manipulator's effector, thus inertial force, the influence of the object of manipulation mass should be studied (Fig. 5) as a main parameter which influences the inertial force. The calculations have been conducted at the following parameters: A=0.11 [m], H=0.02 [m], v=0.64 [m/s], d=0.04 [m], β=0 [rad], E=0 [m], ω=0 [rad/s], ε=0 [rad/s2].

In the alteration range of the object of manipulation mass from 0-1.5 kg, the optimal orientation of Bernoulli gripping device changes not more than in 5%. Figure 6 displays that by off-centering of the masses and the mass of the object of manipulation, the necessary minimal attractive force will increase significantly. This is determined by the disturbed balance of the forces affecting the object of manipulation as to the gripping device caused by off-centered masses. To direct all resultant forces affecting the object of manipulation towards the direction of the attractive force of the gripping device, the angle of the orientation should be increased which may negatively influence the necessary attractive force.

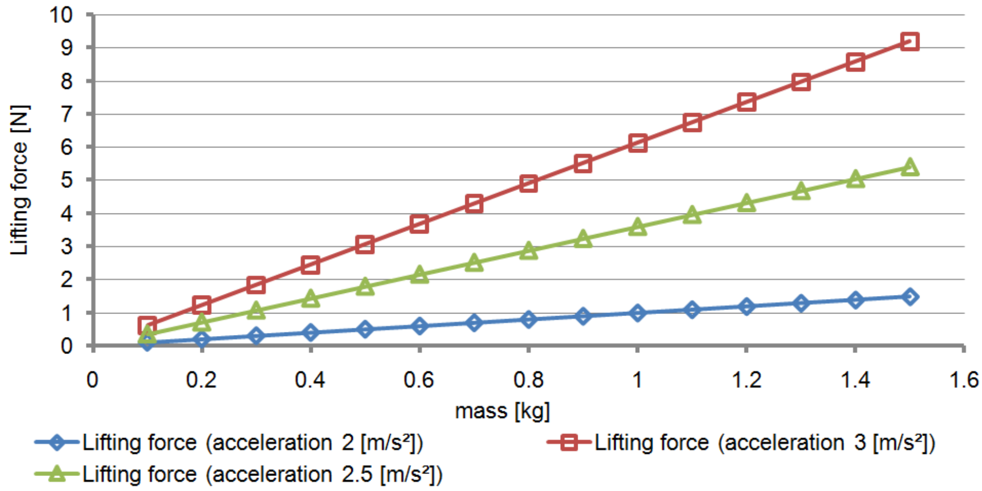

Fig. 5. The graph of the object of manipulation mass on the necessary minimal attractive force of the gripping device

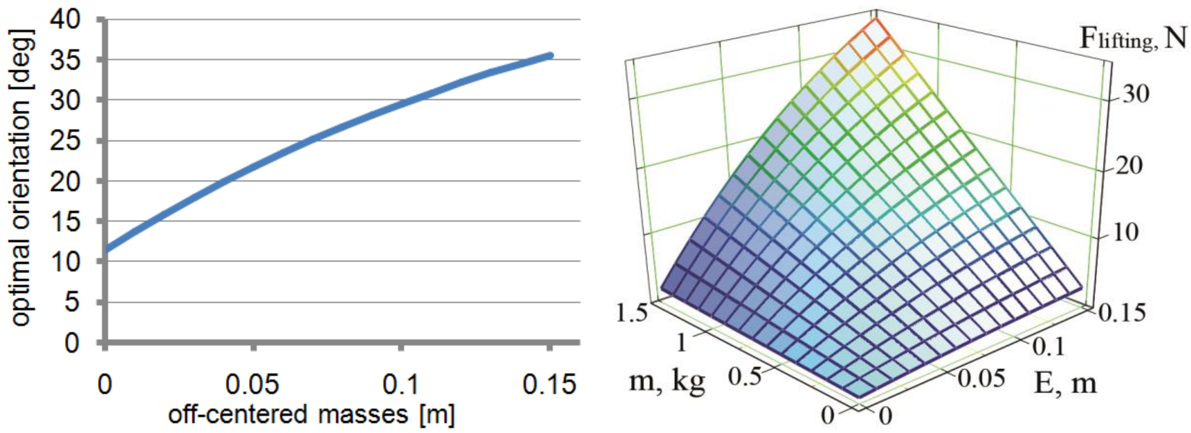

Fig. 6. The graph of the mass and off-centering of the masses of the object of manipulation influence on the optimal orientation and minimal necessary attractive force of the gripping device

Conclusion

The influence of the object of manipulation parameters on the necessary minimal attractive force of Bernoulli gripping device for different parameters of the movement has been studied. The case of the object of manipulation transportation along the rectilinear trajectory with the experimental research with the help of the manipulator IRB 4600 (ABB) has been under study. The software RobotStudio was used at the site of National Centre of Robotics at Slovak University of Technology in Bratislava. The adequacy of the model and efficiency of the use of this method of the orientation optimization of gripping devices for minimization of energy consumption while performing manipulative functions by the industrial robot has been proven.

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