THE INTERNATIONAL CONFERENCE OF THE CARPATHIAN EURO-REGION SPECIALIST INDUSTRIAL SYSTEMS
6th edition

CALCULATIONS IN DESIGNING GRIPPING HEADS

Anton Palko[1], Juraj Smrček[2], Peter Tuleja[3]
[1]Assoc. Prof. Eng., Ph.D., [2]Prof. Eng., Ph.D., [3]Eng.
[1]Faculty of Manufacturing Technologies of the Technical University of Košice with a seat in Prešov, Slovakia, Department of Production Technologies, Štúrová 31, 080 01 Prešov
[2,3]TU in Kosice, Faculty of Mechanical Engineering, Department of Production Systems and Robotics, B. Nemcovej 32, 042 00 Košice, Slovakia

Abstract :*The methodology of designing gripping heads – grippers is a guarantee of a systematic procedure of preparing an optimal design of a gripper for specified conditions. The calculation of decisive functional parts of the gripper is an inevitable step in the algorithm and its designing. The calculation procedures are part of the concept and principles of solution of the gripper as well as of the direct solution of its structure. The choice of computational procedures, methodology of calculation of the decisive functional parts of the gripper is a condition of operational reliability and safety of operation of the designed gripper in the conditions of its application. This presentation introduces the methodology and procedure of calculating the grippers with both bilateral and unilateral gripping with the emphasis on the final safety of the head.*
Key words : *industrial robot, gripping head, gripper, grasping, grasping element, object of manipulation*

1. INTRODUCTION

The grasping head (gripper) during the working cycle of an industrial robot (robot) provides for the functions of *„grasping“*, *„gripping“*, *„fixation“*, *„carrying“* and *„releasing“* related to the object of manipulation, which the object of production of the robotized process. The above functions depart from the main function of the gripper „gripping and holding“ of the object of manipulation. From both physical and mechanical points of view, the process of gripping the object of manipulation by the gripper and subsequently also the process of manipulation with the object is conditioned by the balance of *external forces* loading the gripper and *internal* forces, derived from the mechanism of the gripper. Recognition and determination of the above forces, which are manifested in the place of contact between the gripper and he object of manipulation, is necessary for designing and dimensioning the decisive functional parts of the gripper.

2. GRASPING HEAD FORCES

External forces $\boldsymbol{F_{iz}}$ are chiefly represented by the forces from the gravity of the object of manipulation, dynamic (inertial) forces (created by the acceleration of the end piece of the robot and the weight of the object of manipulation) and also the forces from the resistances of integration bonds related to the manipulation or technological task performed.

Internal forces $\boldsymbol{F_{ju}}$ (grasping forces, reaction of the gripper) are represented by the reactions of active parts of the gripper itself in performing the function of *„grasping“*, *„gripping“*, *„fixation“*.

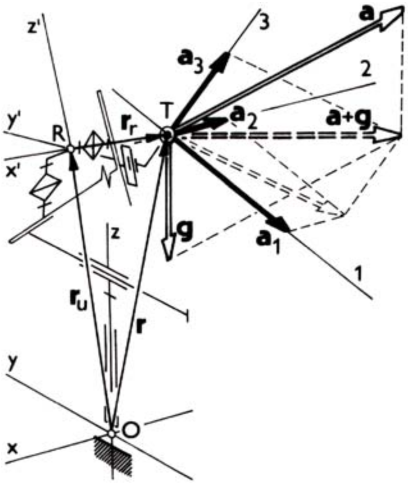
Operational reliability and safety of the function of gripper is conditioned by providing for the balance between $\boldsymbol{F_{iz}}$ and $\boldsymbol{F_{ju}}$, which is guaranteed by the zero relative movement of the object of manipulation in the gripper during the entire time of the robot working cycle.

$$\sum_i F_{iz} = \sum_j F_{ju} \tag{1}$$

It is recommended to determine the dynamic force effects from $\boldsymbol{F_{iz}}$ from the most unfavourable combination of movements of the robot working cycle and the related accelerations. External loading forces are transformed into the point of gravity $\boldsymbol{T}$ of the manipulated object with the coordinate system $\boldsymbol{O_i – X_i – Y_i – Z_i}$, which is usually identified with central axes of the manipulated objects, cf. Fig. 1. Orientation of contact surfaces is determined in accordance with the structural construction and orientation of gripping elements (elements which are in direct contact with the object of manipulation) of the effector.

The following holds true for the transformation of the immediate output acceleration and gravitational acceleration into the basic system os $\boldsymbol{O_i – X_i – Y_i – Z_i}$:

$$a + g = a_1 + a_2 + a_3, \tag{2}$$



Obr. 1 Representation of the output acceleration

whereas

$$a = \frac{F_d}{m}, \tag{3}$$

For vector components of external forces (apart from the resistance forces), if $\boldsymbol{m.g}$ is the point of gravity of the object of manipulation, then the following holds true:

$$F_d + m \,.\, g = F_{1z} + F_{2z} + F_{3z}, \tag{4}$$

3. GRASPING HEAD SAFETY

The balance between $\boldsymbol{F_{iz}}$ and $\boldsymbol{F_{ju}}$, as per the relation (1), is to also include the coefficient of safety $\boldsymbol{k}$, considering safety of the utility function of the gripper. Interpretation of the above condition is considered in determining the operational gripping force $\boldsymbol{F_{ju}}$ (gripping force representing the vector sum total of all the contact forces, by which the end elements of the gripper exert impact on the object of manipulation).

$$\sum_j F_{ju} = k.\sum_i F_{iz}, \tag{5}$$

whereas $\boldsymbol{k}$ is chosen according to the significance of the influencing factors (disposition of the robotic workplace, character of operation, type of gripper, type of gripping elements, ...).

The value $\boldsymbol{k}$ is determined by means of partial coefficients $\boldsymbol{k_i}$, Fig. 1, considering decisive influences exerting impact on the functional reliability of *grasping and gripping* the object of manipulation in the gripper.

$$k = k_1 \,.\, k_2 \,.\, k_3 \,.\, k_4 \,.\, k_5 \,.\, k_6, \qquad (6)$$

From experience, the following may be recommended as points of orientation for ***k,*** according to the types of grippers: mechanical grippers **(**1,5 - 3,0), magnetic grippers (1,5 - 2,0), vacuum grippers (4,0 - 8,0). Lower values are used in manipulation with lighter objects in lower velocities of manipulation with fluent movement without a stroke. Higher values are used for a more demanding operation, which may contain collision with the attendance (person). With vacuum grippers, higher values are opted for also in instances when the surface of the object is not smooth and does not guarantee perfect sealing of the vacuum space of the sucker.

Table 1 Values of partial safety coefficients

Partial coefficient	**Explanation of the coefficient**	**Note**	**Value**
$\mathbf{k_1}$	Coefficient of the object of manipulation weight	Safe function at 120% maximum load-bearing capacity	1,20
$\mathbf{k_2}$	Coefficient of limiting the mode of grasping the object of manipulation	Unilateral grasping Bilateral grasping Trilateral grasping	4,00 – 6,00 1,30 – 1,70 1,15
$\mathbf{k_3}$	Coefficient considering the condition of surface (untreated) of the objects of manipulation	According to maximum admissible surface roughness (forgings, moulds, ...)	1,20 – 1,40
$\mathbf{k_4}$	Coefficient considering floating of the level of the driving power	Pneumatics Hydraulics	1,20 – 1,30 1,10
$\mathbf{k_5}$	Coefficient considering the dynamics of the robot working cycle	Amplitude, frequency, period of attenuation	1,20 – 2,00
$\mathbf{k_6}$	Coefficient considering operational conditions of the robotized system at the user´as place	Regular Hindered Strenuous	1,00 1,15 1,30

Operation of the robot in relation to the gripper, apart from the above influences, contains a risk of a sudden change of the robot configuration (malfunction, breakdown), the robot movements start exerting unprogrammed motions, which may the reason for releasing the object of manipulation by the failure of gripper function.

The above risks may pose a danger to man in fulfilling his/her chores in the robotized workplace and damage the robot, co-operating devices or the devices outside the space of the robotic system by the catapulted object of manipulation. For these reasons it is recommended to observe the following principles in designing the gripper:

- the gripper must perform a reliable and safe operation with the object of manipulation with the weight of at least 120% of the determined available lifting capacity ($\boldsymbol{k_1}$ - 1,2),
- the gripper must perform a reliable and safe operation also at critical regime of overloading the robot to 150% of the permitted value of maximum velocity and acceleration ($\boldsymbol{k_5}$ min. 1,5),
- with grippers with unilateral grasping it appears necessary to dimension the elements with the overall safety coefficient ***k*** (7 - 20), the lower limit is recommended for simple manipulation acts at the acceleration of up to 3g,
- with grippers whose operation may be influenced by impacts, heat strains, and similar unfavourable force effects, it is recommended to increase the partial safety coefficient $\boldsymbol{k_6}$. It is advisable to verify the gripper safety by simulation or experimental tests.

- safety of grasping the object of manipulation by the gripper should be guaranteed also in case of dropout of its driving power (by applying mechanisms guaranteeing this property),
- to correctly determine the partial coefficient k_3 in respect of the value of co-efficient of friction μ (between the grasping elements of the gripper and the object of manipulation). He value of the co-efficient μ, Tab. 2., depends from the material of grasping elements and the object of manipulation, roughness and condition of surfaces in the place of contact.

The influence of the co-efficient of friction μ may be reduced by structural adjustment of roughness of active surfaces of grasping elements of the gripper, Tab. 3.

Table. 2 Co-efficient of friction μ

Contact materials	**Contac surface**		**Contact materials**	**Contact surface**	
	dry, clean	**dirty**		**dry, clean**	**dirty**
steel – steel	0,12 – 0,17	0,05	steel – rubber	0,30	0,15
steel – cast iron	0.20	0,05	steel – leather	0,60	0,25
steel – brass	0,20	0,05	steel – ferodo	0,60 – 0,70	0,00
steel – bronze	0,20	0,05	steel – plastic	0,10	0,00

Table 3 Coefficients of friction μ after adjusting the surface

Adjustment of the active surface of the inter-active element	**Co-efficient of friction μ**
Unquenched jaws	0,12 – 0,15
Quenched jaws with roughing in form of fish-tails	0,30 – 0,35
Jaw surface longitudinally knurled	0,30
Jaw surface transversally knurled	0,40
Jaw surface with cross-wise knurling	0,40 – 0,60
Jaw surface with sharp incisions for penetrating into the object of manipulation	0,80 – 1,00

4. CALCULATION OF MECHANICAL GRIPPERS

The most frequently appearing gripper in the robotic systems applications is a mechanical gripper. The decisive parameter for solving and dimensioning the functional parts of such a gripper are grasping (internal) forces F_{ju} , generally, the following holds true for their determination:

$$\sum F_{ju} = \sum F_{mv}.\eta_{mv}.i_n.\eta_{in}, \qquad (7)$$

where F_{mv} are forces of performance elements, η_{mv} is efficiency of performance elements, i_n is the transmission between the performance elements and the end interactive element, η_{in} is the transmission efficiency.

For mechanical grippers with bilateral grasping in calculating F_{ju} and the subsequent dimensioning of functional parts of the gripper it appears necessary to consider the influence of the form of the manipulated object, influence of the form of contacts of the grasping elements, as well as the influence of the position of point of gravity of the manipulated object against the geometric centre of central axes of grasping elements, which may be with set-out,

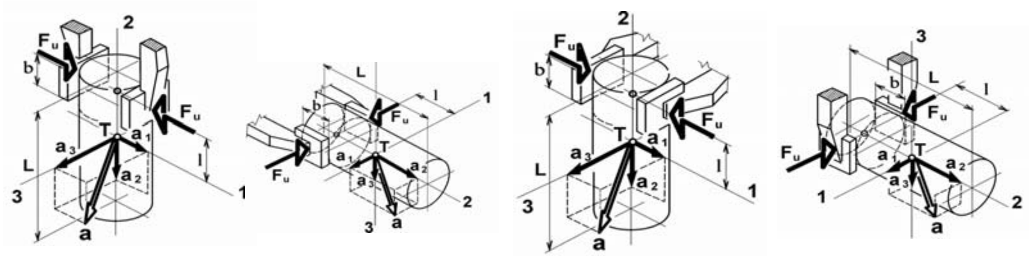
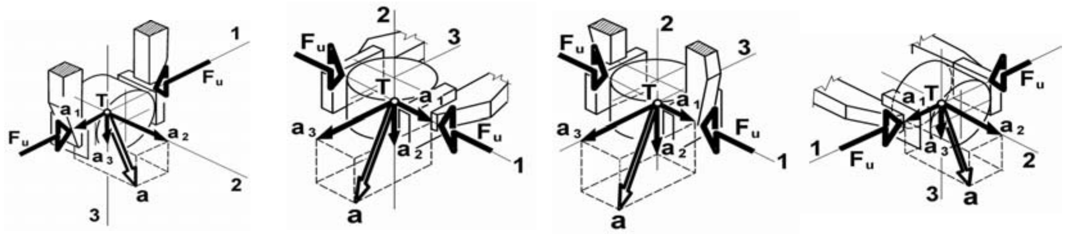


Fig. 2, or without set-out Fig. 3.

Fig. 2 Object with the set-out point of gravity
Fig. 3 Object without the set-out point of gravity

The method of calculation, which is prepared on considering the above influences and dependence, is governed by the following principles:

- Suitable chosen co-ordinate system of the object $\boldsymbol{0_j\text{-}X_j\text{-}Y_j\text{-}Z_j}$ is made use of (the co-ordinate system of of mechanical interconnection $\boldsymbol{0_m\text{-}X_m\text{-}Y_m\text{-}Z_m}$, the coordinate system of the tool $\boldsymbol{0_n\text{-}X_n\text{-}Y_n\text{-}Z_n}$) defined by the axes ***1, 2, 3***; for the axis ***1*** the principle holds true that it is parallel with the axis of effectiveness of grasping force or the axis ***1*** is identical with the



axis of the grasping force; for the axis ***2*** the principle holds true that it is identical with the geometric axis of the object; for the axis ***3*** the principle holds true that it is perpendicular to the axes ***1*** and ***2***; the coordinate system of the object $\boldsymbol{0_j\text{-}X_j\text{-}Y_j\text{-}Z_j}$ passes through the object point of gravity; the effects of external loading forces are transformed into this coordinate system,
- static load from the object of manipulation own point of gravity is transformed from the axis ***Z*** of the coordinate system of the base $\boldsymbol{0_1\text{-}X_1\text{-}Y_1\text{-}Z_1}$ into the coordinate system of the object $\boldsymbol{0_j\text{-}X_j\text{-}Y_j\text{-}Z_j}$. At the robot working cycle, completed also by the changed orientation of the gripper, the orientation of the point of gravity against the coordinate system of the object $\boldsymbol{0_j\text{-}X_j\text{-}Y_j\text{-}Z_j}$ is changed. In determining the effects of external loading forces it is necessary to respect this fact. Subsequently, the necessary gravitational acceleration is needed or to split the object of manipulation point of gravity and add to the immediate components of acceleration or to the dynamic force elements effecting in the direction of individual axes of the coordinate system of the object $\boldsymbol{0_j\text{-}X_j\text{-}Y_j\text{-}Z_j}$.
- in the calculation it appears necessary to consider the influence of designing the contact between the object of manipulation and the grasping element, Fig. 4.

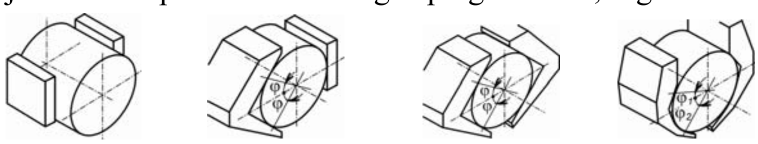


Fig. 4 Standard modes of bilateral grasping the object

- the resulting value of the grasping force $\boldsymbol{F_{ju}}$ is determined as a sum total of the components of the force from individual axes of the coordinate system of the object $\boldsymbol{0_j\text{-}X_j\text{-}Y_j\text{-}Z_j}$, effecting at the most unfavourable operational conditions of the robot working cycle,
- the force analysis of the gripper mechanism elements, in direct relation to the concept and design of the gripper, is to depart from defining their static relations in the process of *gripping* the object of manipulation by the gripper. The process of implementation may be given on the gripper, Fig. 3.16, designed on the principle of linear (rectilinear) performance element (engine) and joint transmission mechanism providing for the movement of grasping elements.

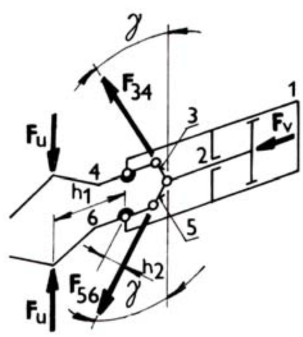


Fig.. 5 Force relations in the gripper with the joint mechanism

From the balance of input $\boldsymbol{F_v}$ (driving) forces and output forces $\boldsymbol{F_{34}}$ (force by which the element ***3*** exerts effect on the arm ***4***) and $\boldsymbol{F_{56}}$ (force by which the element ***5*** exerts effect on the arm ***6***), i.e. grasping forces in the joint on the output (rod) of the performance element, the following follows:

$$F_{34} + F_{56} + F_v = 0, \tag{8}$$

whereas the following holds true for determining the forces in the elements:

$$F_{34} = F_{56} \frac{F_v}{2 sin\gamma}, \tag{9}$$

where $\boldsymbol{\gamma}$ is the angle of transmission (it is recommended for the process of grasping for the above principle within the extent of 5° through 7°). From the momentary balance of the arm ***6*** against the axis of rotation and the relation for determining $\boldsymbol{F_{34}}$ and $\boldsymbol{F_{56}}$ the relation may be determined between the grasping force $\boldsymbol{F_u}$ and the input force of the performance element $\boldsymbol{F_v}$

$$F_u = F_{56} \frac{h_2}{h_1} = \frac{F_v}{2 sin\gamma} . \frac{h_2}{h_1}, \tag{10}$$

5. CONCLUSION

The indicated methodology documents the significance of the above influences for enclosing the required operational reliability and safety of the gripper function as early as in the stage of designing the same. On the basis of the above knowledge, apart from their valuation in the general theory of end effectors of robots, the methodology has been proposed of designing and structuring of end effectors, including the related computer support.

Developmental trends in the field of end effectors are at present parked by developing the methods and means of their designing with the aim of creating systematic tools guaranteeing designing and structuring of effectors for the defined parameters and properties. The introduced approach and the related methodology is one of the possible ways how to fulfil and implement modern trends of development in the field of end effectors.

6. SOURCES

(1) Chen F. Y.: Force Analysis and Design Considerations of Grippers. Industrial Robot, Vol. 14, Bradford (UK) 19869

(2) MarcinčinJ.N, Smrcek J.: Biorobotika,teoria,princípy,aplikácia v technickej praxi,Elfa Košice, 1998

(3) Palko A., Smrček J.: Robotika. Koncové efektory pre priemyselné a servisné roboty. Navrhovanie – konštrukcia – riešenia. Edícia vedeckej a odbornej literatúry SjF TU Košice, Vienala Košice, Košice 2004

(4) Palko A., Smrček J., Tuleja P.: Koncové efektory pre roboty I. – IV. Strojárstvo / Strojírenství. Media/ST Žilina, roč. VIII. – X., č. 12/2004 (s. 56-57), č. 03/2005 (s. 56-57), č. 12/2005 (s. 60-61), č. 03/2006 (s. 16-18)

(5) Rustelholtz R.: A Gripper and Tool – Change System for Increasing the Flexibility of Assembly Robots. Robot Grippers. IFR Publications Bedford, Bedford (UK) 1986

(6) Sandler B. Z.: Robotics – Designing the Mechnisms for Automated Machinery. Accademic Press London, London (UK) 1991

(7) Skařupa J., Mostýn V.: Metódy a prostředky návrhu průmyslových a servisních robotů. Edícia vedeckej a odbornej literatúry SjF TU Košice, Vienala Košice (SK), Košice 2002

(8) Tolnay M.: Priemyselné roboty a manipulátory. Edícia STU SjF Bratislava, Bratislava (SK) 1992

Note: This presentation is part of the project 3/3157/05 supported by the agency KEGA, Ministry of Education of the Slovak Reoublic.