

Automatic System for Clamping Objects on Rotary Executive Links of Robotics for Safety Critical Application: Solution and Software for Modelling

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Abstract — A new method is proposed to improve the mechanisms for object fixation in robots handling critical application objects to ensure safety. The approach recommends utilizing software products developed specifically for this purpose. The applications improve the device's prototyping capabilities, visualize its structural schemes, and calculate its individual performance characteristics. The structural diagram of the proposed device complies with the formulated security recommendations.

Keywords — *technological capabilities for safety, structure visualization software, characteristic calculation software, prototype selection software.*

I. INTRODUCTION

Robotics is one of the most common technological items used in safety critical applications, especially in such areas as nuclear engineering, space, explosive and toxic facilities, etc. There are a number of expressions of the dependability of the functioning of safety critical application robot (SCAR) in these areas. One of the most important directions, which requires constant development, is ensuring the safety of the operation of robots in this sphere. At the same time, the area of ensuring the safety of robots in critical applications by improving their technological capabilities is underdeveloped. The characteristics of the robot's executive link with the device for fixing objects (DFO) for manipulation play a key role in this area.

The implementation of high-quality fixation of objects of manipulation (OM) in critical applications of any kind by its clamping (gripping) has a common feature. That can be described as the requirement to ensure a high level of control over the magnitude of the force interaction between the object and the clamping elements of the automatic fixation device. This is critical to avoid negative consequences, such as elastic and plastic deformations of the object, its displacement relative to the clamping elements in static under the influence of weight forces or during movement under the influence of dynamic forces or forces resulting from force interaction with other parts of the process equipment (e.g., tools, stops etc.).

Taking into account the widening range of material characteristics of OM (brittle, elastic, biological, etc.) and constructions (thin-walled, partially damaged, etc.), it becomes necessary to provide the widened range of possibilities of its clamping force regulation. For example, it is necessary to change the clamping force several times during its holding for multi-stage manipulation. This makes it possible to provide a temporary change of clamping forces

necessary for performing certain stages of manipulation, e.g. with a peak force interaction at the beginning of unscrewing a component of the OM, etc. At the same time, the clamping force should be reduced to the minimum required values during the stages of OM manipulation that do not require significant force interaction. Thus, the achievement of this characteristic contributes to the expansion of the technological capabilities (range of possible operations) of the DFO, as well as to the increase of the reliability and safety of the operations, which is expressed in the reduction of the probability of critical plastic deformations of the OM or the initiation of its integrity violation (cracks, etc.).

The safety of the process of manipulation of the OM by the robot is positively affected by reducing the number of its repeated grips to reinstall the OM and transfer it to other devices. For example, this can be achieved by improving the technological capabilities of the robot's executive link and enhancing its ability to operate in spindle unit mode. This enables the execution of multiple supplementary processing operations by OM during its single-time gripper. Each new technological capability of the robot's executive links imposes specific restrictions and requirements on the parameters of the functioning of their DFO. Developing an approach that enables the use of special software products to determine the parameters of the DFO is a relevant task.

II. STATE-OF-THE-ART

The paper [1] overviews the main robot's technical features but does not suggest safety improvement solutions. The authors of [2] suggested a way for the robot to function in space but did not present any methods of enhancing functionality. The paper [3] has interesting information about teleoperated robots, but it is unclear how dependability is guaranteed. Research [4] offers solutions for how robots can work in areas exposed to radiation but does not explain how to ensure safety. In work [5], a method of remote control of the robot is shown but does not discuss how remote control of robots guarantees safe operation. Paper [6] examines robots with manipulator arms but does not conclude their safety. The authors of papers [7, 8] have created an assistant robot, but no data is available regarding its use in critical security conditions. The paper [9] helps discuss anthropomorphic grasping but does not cover its full technological abilities. Likewise, in [10], grippers for heavy items are discussed, but there is no mention of the technological capabilities that could ensure safety. In a study [11], the robot's ability to collect non-standard objects is explored, but there is no reference to using it for safety-

critical applications. The paper [12] describes the dual robot gripper but does not mention its potential to enhance safety. The study [13] on rigid links for industrial manipulators does not provide information on how they are used for safety-critical applications. Maintenance strategies are discussed in [14], but there is no information on their safety-critical applications. The authors [15] developed a robot that can move in any direction, but there is no data on its usage in critical infrastructure areas.

Among the available studies, no approaches aimed at increasing the safety of OM manipulation by expanding the technological capabilities of robots for safety critical application were found. The increasing safety requirements for robots' functioning in critical application spheres indicate the relevance of developing approaches to ensuring their operation reliability by extending technological capabilities. Expanding technological capabilities of robots also requires the development of effective means to identify the necessary parameters of their elements and, in particular, special software.

III. STAGES OF DEVELOPMENT OF AN AUTOMATIC SYSTEM FOR CLAMPING OBJECTS IN SAFETY CRITICAL APPLICATION

A. Purpose and objectives of the research

The purpose of the work is to increase the safety of robots functioning for critical application, which is achieved by increasing their DFO's reliability and reducing the number of OM reinstallations due to the expansion of their technological capabilities—an extended range of operations in one grip on one robot.

The following tasks are required to achieve the objective:

- formulate the main aspects of the expansion of robot technological capabilities, which contribute to increasing the safety of the object manipulation process;
- to develop specialized software for execution of the main stages of the proposed approach for DFO improvement:
 - search for a prototype;
 - formation of the DFO structural scheme;
 - calculation and modeling of the main operational parameters.

The object of the research is an automatic device for fixing objects in executive links of robotics for safety-critical application. The subject of the research is methods of ensuring the technological capabilities of the robot, and in particular its executive link, which contribute to increasing the safety of manipulating objects in the conditions of safety-critical application. The main hypothesis of the research is expanding the technological capabilities of robotics for safety-critical applications by improving their DFO contributes to increasing the level of safety of their functioning. The assumptions in the studies are that manipulations performed by robotics for safety-critical applications are multi-stage and require a wide range of operations. To simplify the study, bodies with ultra-low rigidity (a significant change in shape under the influence of gravity) of their materials and construction are not considered as objects for manipulation.

B. Structure of device for fixing objects

According to design principles, the information generated in the early stages of design determines the qualitative characteristics (technological abilities) of the projected object to a great extent. The main types of tasks for SCAR:

- removal OM from the initial location (e.g. explosives);
- transportation OM to the work area;
- maintenance of the OM processing (e.g. utilization): disassembly, cutting, etc.

The process of fixing objects is ensured by the functioning of a number of structural elements (Fig. 1): energy source – ES; control unit – CU; motor – M; drive mechanism – DM; actuator of device – AD; mechanism for holding the object MHO. Description of DFO structure at different levels of their complexity can be presented by using their structural elements' force interaction – "power flow structure." Description in cylindrical coordinate system, where: F_a , F_r , F_t – axial, radial, tangential forces (underlined designations means change in force direction); M_a , M_r – torques with axial and radial axes; P – pressure.

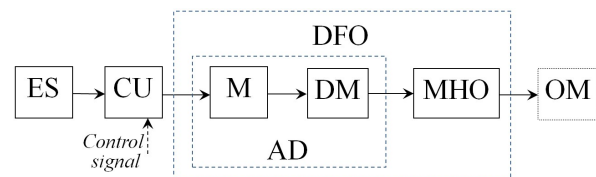


Fig. 1. General structure of DFO functioning

DFO's functioning characteristics are to be ensured in accordance with the goal of the work: maintaining the nominal clamping force of the OMCI in case of loss of power to the DFO; provide the nominal functioning qualities when high-speed rotation - operation in the spindle mode; the possibility to change the magnitude of clamping force during any stage of operation; absence of additional units for preparing and supplying input energy to the DFO to increase reliability and ensure mobility.

C. Prototypes selection for device for fixing objects

Advantages of using existing automatic clamping mechanisms (ACM) of different areas as DAF prototypes:

- availability of information on production tests;
- tested technical solutions for the implementation of the designed scheme;
- possibility of assessing the feasibility of using certain device structures to efficiently perform the necessary tasks.

Main types of traditional ACM's disadvantages in the context of application in SCAR (should be eliminated):

- centrifugal forces of radially movable and unbalanced elements can affect stability and may cause vibrations (shaking, chattering) during high-speed rotation;
- additional energy converters (pneumatic, hydraulic, mechanical) and outer mechanisms for preparing and supplying energy for powering ACM lead to reduced reliability of holding OM and SCAR mobility;
- probability of clamping force loss in case of ACM power failure and the complicated changing of the clamping force during holding OM.

To facilitate the process of selecting DFO prototypes, software (Fig. 2) has been developed that facilitates the effective review and selection of mechanisms for fixing objects with the required characteristics. To evaluate a prototype, it is convenient to use the characteristics of its structure, which can be described at different levels of detail using the "power flow". To visualizing structures of DFO subsystems special software (Fig. 3) has been developed.

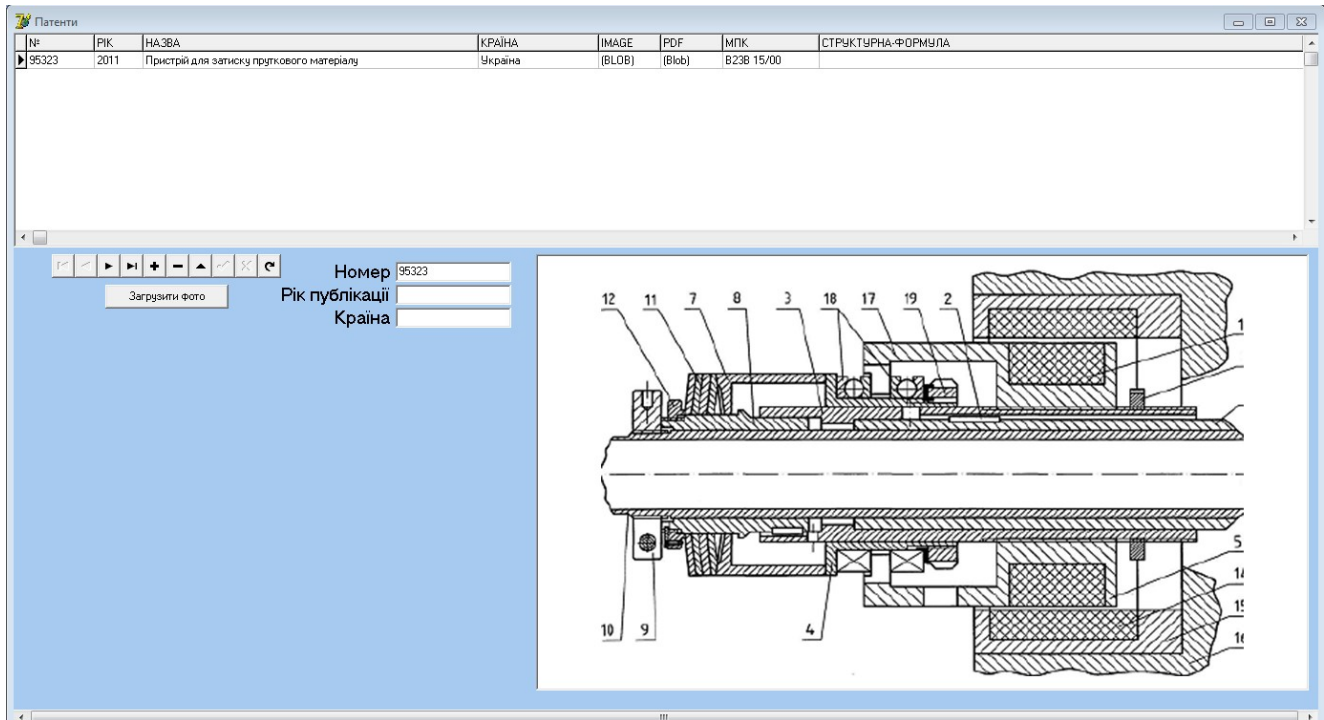


Fig. 2 Software for saving and searching subsystems of prototypes for DFO

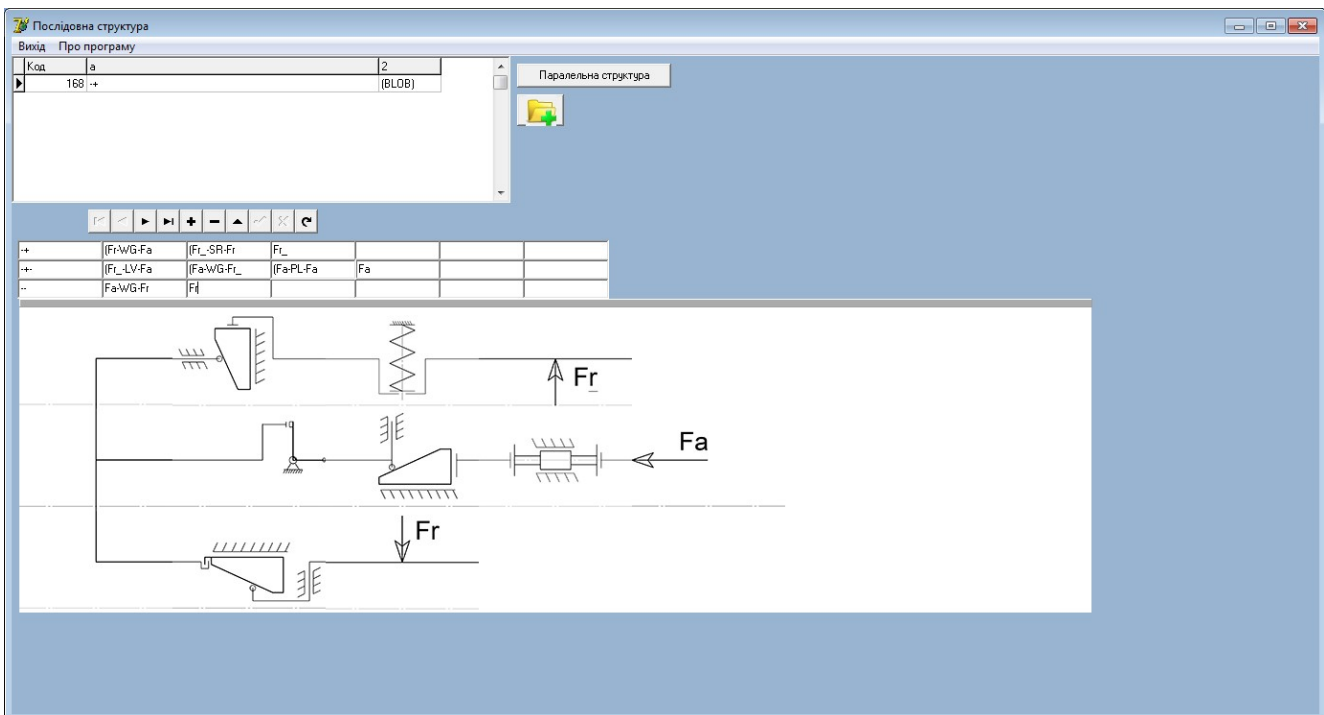


Fig. 3 Software for DFO's elements structure visualization

Most general basic level description of DFO «power flow structure» shows their main input-output characteristics: what type of SCAR the DFO can be installed on (type of input energy); what type of OM can be manipulated – external or internal clamping surfaces. The main two subsystems of the DFO provide its different characteristics: AD – determines the power characteristics of DFO and input energy supply conditions; MHO – determines the accuracy of positioning and the ability to grip certain surfaces. The requirements for DFOs with advanced technological capabilities that contribute to the safety of SCAR operation

by improving the technological process of object manipulation are formulated: supplying energy to a rotating DFO for operating in spindle unit mood; change the value of the clamping force during manipulation and during the operation of the executive link in the spindle unit mode; maintain clamping force when the power supply is lost. These restrictions form the requirements for the “power flow” realized in the AD. As a result of consideration of AD of existing ACM at the basic level of description of their “power flow structures”, four main groups were identified (Fig. 4). As a basis for building the AD in accordance with

the formulated requirements for the new DFO, a structure with a basic description $M_{a0}-F_{a1}$, is chosen.

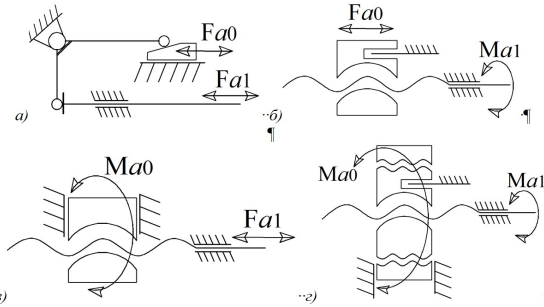


Fig. 4. Revealed AD structures at most general level of "power flow structure" description

D. Block diagram of the proposed DFO

The proposed design of the AD for the new DFO (Fig. 5) provides new technological capabilities and characteristics of OM manipulation. This AD powered directly by electric energy contains a rotor, an electric motor stator, and a screw gear (SC). When power is applied to the stator of the AD, its rotor starts to rotate with torque M_{a0} and generates an axial force F_{a1} in the SC. This force F_{a1} is transmitted to the lever clamping chuck, which generates clamping forces to fix the OM. The fixation force is maintained after the power is disconnected from the stator of the AD due to the braking in the SC. After the fixation process, the DFO can also rotate (from a special rotational drive) in the spindle assembly mode. The power supply to the AD is carried out in a contactless way. The electrical insulation of the DFO bearing supports ensures the electrostatic isolation of the

OM which is important for the safe processing of certain types of objects of critical applications. The magnitude of the OM clamping force can change even during the rotation of the executive link by supplying current to the AD stator with characteristics that ensure its rotation relative to the screw of SC gear.

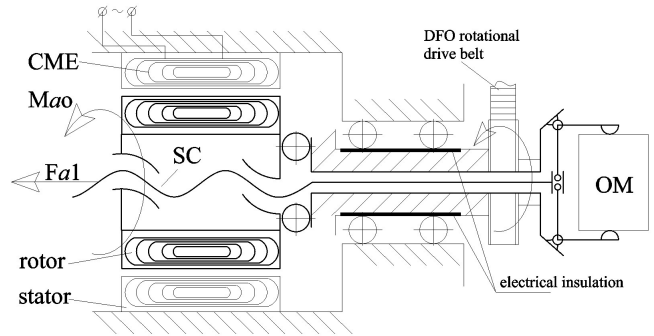


Fig. 5. "Detached" rotatable DFO with the lever MHO based on the selected AD structure

To determine the quantitative characteristics of the functioning of the new proposed type of AD as part of the DFO, special software (Fig. 6) is developed. The results of the calculations are presented in the form of time dependencies of the characteristics. The use of this software helps to increase the accuracy and efficiency of the selection of the parameters of the power characteristics to achieve the necessary parameters of the operation of the DFO.

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314,0	88,77
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2,415	5,84
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Графік залежності від часу

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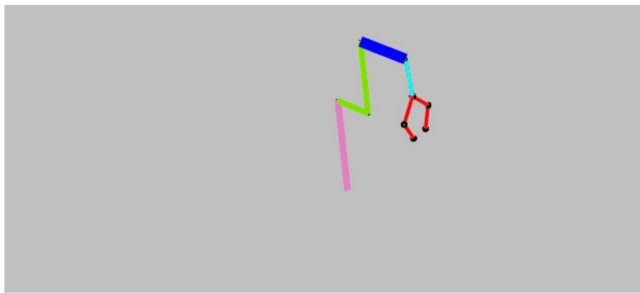
Час аналізу

1,5

Fig. 6 Software for building graphs of characteristics of the created type AD

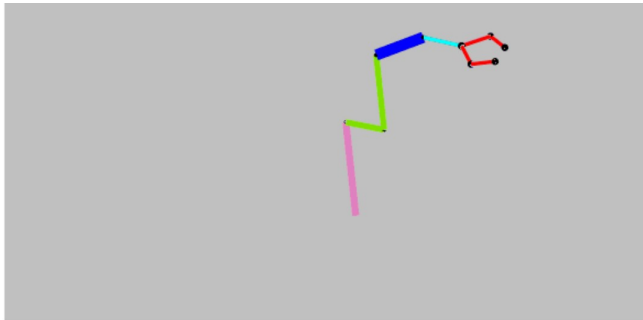
For a preliminary approximate assessment of the main characteristics of the movements of the SCAR executive link containing the developed DFO, the emulation has been

performed (Fig. 7). This emulation includes two main states of the SCAR executive link – the manipulator mode and the spindle unit mode.



$(X_0, Y_0, Z_0), (X_1, Y_1, Z_1), (X_2, Y_2, Z_2), (X_3, Y_3, Z_3), (X_{4u}, Y_{4u}, Z_{4u}), (X_{4d}, Y_{4d}, Z_{4d})$

a)



$(X_0, Y_0, Z_0), (X_1, Y_1, Z_1), (X_2, Y_2, Z_2), (X_3, Y_3, Z_3), (X_{4u}, Y_{4u}, Z_{4u}), (X_{4d}, Y_{4d}, Z_{4d})$

b)

Fig. 7. Fragments of emulation of SCAR with enhanced technological capabilities operation with the proposed DFO in the modes: (a) object manipulation, (b) spindle unit

V. CONCLUSION AND FUTURE WORK

The proposed approach contributes to improving the safety of robots in critical applications by expanding their functionality, which allows for improved technological processes for manipulating objects. In particular, this can be achieved by reducing the number of repeated installations of the object, improving the control of force interaction with the object, reducing the number of object transfers between different types of equipment, etc. One of the features of the proposed method is the active use of prototypes operated in other areas and built on the basis of certain structures that determine the necessary qualitative characteristics of their functioning. It also contributes to obtaining more relevant information about the results of production tests and operations, which provides improved opportunities for eliminating critical states of the new DFO. To increase the efficiency of solving problems when applying the proposed approach, software has been developed that facilitates the processes of prototype selection, visualization of structural diagrams, and determination of certain characteristics of a new electromechanical DFO. As a result, the design of the output link of the robot for critical applications, which has the ability to operate in the spindle assembly mode with its electrical isolation, is proposed, and the possible movements of the structural elements of the robot with the executive link in the form of the proposed DFO are emulated.

The next stage of this research will involve developing the proposed DFO's design in greater detail and determining the parameters of its technological possibilities. This will facilitate the assessment and enhancement of the created software and the theoretical stances taken in the study.

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