KINETOSTATICS OF A ROBOTIC PREHENSION DEVICE DRIVEN BY SHAPE MEMORY ALLOY ELEMENTS

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Abstract: This paper presents the kinetostatic calculus for a robotic prehension device driven by shape memory alloy elements. The constructive-functional scheme is presented, as well as the forces that occur in the prehension process. In order to maintain the workpiece orientation and fixing, the prehension force expression and the relation of the necessary driving force are determined.

Keywords: kinetostatics, prehension device, gripper, shape memory alloys, SMA.

1. Introduction

The increasing industrialization process has led to the need for automation of production, aiming to reduce human labor, especially where working conditions are difficult for the human operator. This has led to the robotization of the manufacturing process.

An important role in the construction and operation of industrial robots is that of the prehension devices, also called prehensors or grippers.

Different types of mechanical transmissions can be used in the prehension devices structure, such as with articulated links, with gears, with cam-follower, etc.

The prehension device studied in this paper is characterized by the fact that it is driven by an actuator built from elements with shape memory alloys (SMA), thus removing pneumatic or hydraulic driving, or the driving with electric motors.

Analysis and design of SMA actuators were accomplished in [2], [5], [7], [9], [14], [15].

The implementation of SMA actuators in the structure of robotic prehension devices was analyzed in [1], [3], [4], [6], [10], [12], [13]. SMA actuators were also used within different robotic applications, such as neurosurgery [8] or wall climbing [11].

In order to design, improve the construction and the operation of prehension devices, it is necessary to know the stresses that occur in the links and kinematical joints, and a kinetostatics analysis has to be accomplished.

The driving system with shape memory alloy elements is characterized by the fact that it is in line with the state-of-the-art technologies by using up-to-date computer-controlled technical systems.

It presents a series of advantages, as follows:
- simple construction;
- compact design with low weight;
- small size;
- reduced kinematic errors;
- low electrical power consumption;
- usable in the construction of devices for workpieces orientation and fixing.

This paper shows the way to determine the actuating force of the SMA element required for prehension of a workpiece, knowing the weight of the workpiece and the dimensions of the prehension device elements.

2. The Constructive-Functional Scheme of the Prehension Device

The device variant analyzed involves the replacement of the classic motor (electric, hydraulic, etc.) with an SMA actuator.

The constructive-functional scheme of the device is shown in Fig. 1 and Fig. 2, in the variant without workpiece (Fig. 1) and in the variant with the prehensed workpiece (Fig. 2).

The SMA actuator is solidarized with the fixed element (0). The shape-memory alloy element (1), a cylindrical helical spring, is axially deformed by expansion or compression through a well-defined operating program, developing the actuating force F_a and the prehension force F_2 of the fingers (6), and (7) respectively.

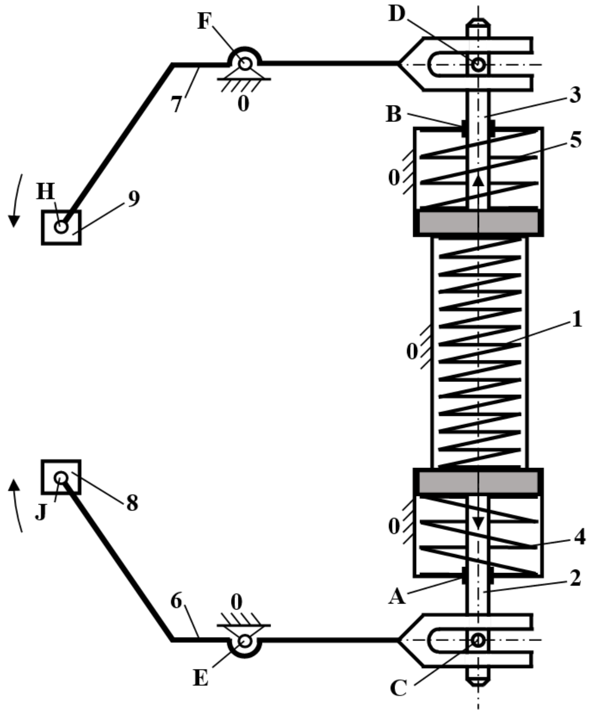

Fig. 1. The constructive-functional scheme of the prehension device without the workpiece, after [13].

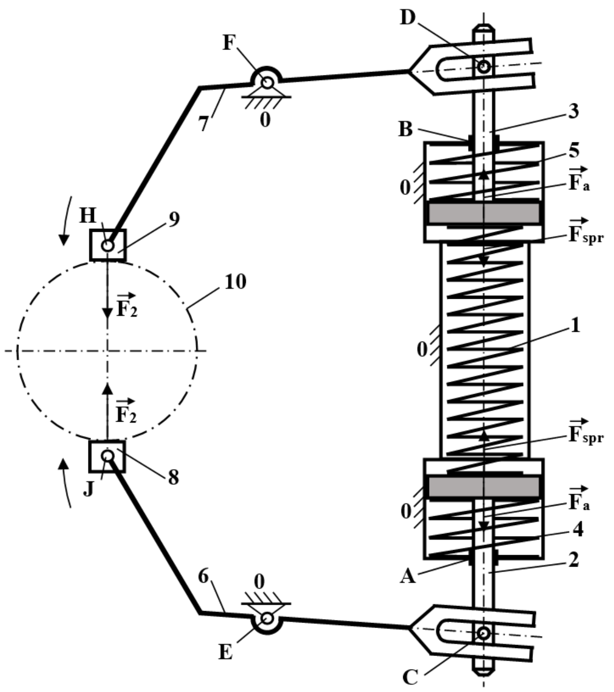

Fig. 2. The constructive-functional scheme of the prehension device with the workpiece prehensed, after [13].

The return to the initial position of the SMA spring and the action of the elastic forces (F_{spr}) of the springs (4) and (5) causes the return of the actuator's driving elements (2) and (3), of the fingers (6) and (7), releasing the working object (10).

For a better prehension, the fingers (6) and (7) are provided with the jaws (8) and (9) respectively.

The component links are connected by means of translational kinematical joints A and B, rototranslational kinematical joints C and D and rotational kinematic joints E, F, H and J.

3. Kinetostatical Analysis

In order to determine the computational relations of forces and reactions in kinematic joints, Fig. 3 shows the scheme for the kinetostatic analysis of the lower finger, which is made on the basis of kinematic and constructive data α, β, l_1, and l_2.

For the design of the prehension device, it is necessary to determine the prehension force F_2, necessary for keeping the workpiece oriented and fixed during handling.

Knowing this force enables the computing of the force F_a developed by the shape memory element, considering the following:
- calculation of the forces acting on the components, the reactions in the kinematical joints and the angle of rotation of the actuator driving elements, as a function of the dimensions of the workpiece;
- the value of the force F_2 required to keep the workpiece oriented and fixed during the handling process;
- the value of the rotation angle α set by the designer, depending on the stroke of the finger jaws (8), (9) and the design theme;
- the elastic force (F_{spr}) of the helical springs for returning to the initial position of the finger jaws (8) and (9), determined at the design stage as a function of: the dimensions of the components, the frictional forces in the kinematical joints, the weight of the components and the working position of the device (horizontal, vertical or inclined).

On the basis of the kinetostatical scheme in fig. 3, knowing the force F_2, taking into account the other forces acting on the component elements and the reactions in the kinematical joints, as well as the angles of rotation depending on the dimensions of the workpiece, it is possible to calculate the required force F_a developed by the SMA element.

For the return of the fingers to the initial position, the force F_a produced by the SMA element acts in reverse, together with the elastic force F_{spr} generated by the return of the springs (4) and (5) to the initial state.

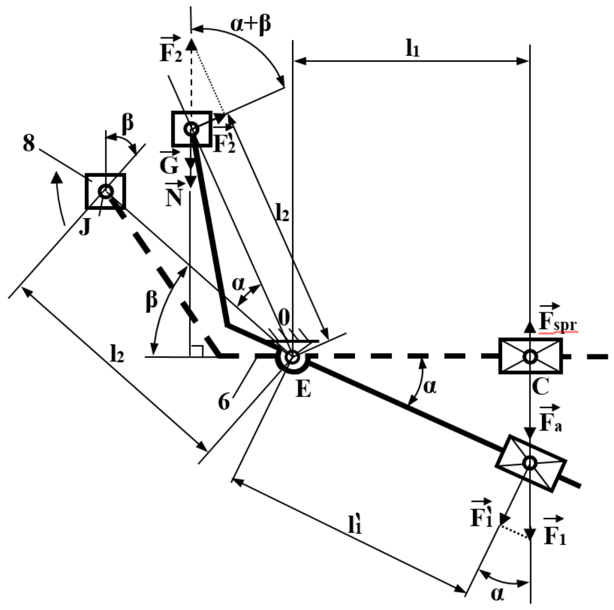

Fig. 3. Scheme for kinetostatical analysis of the lower finger.

The actuating force F_a of the SMA element and the elastic force of the cylindrical helical spring F_{spr} generate the resultant force F_1:

$$\vec{F}_1 = \vec{F}_a + \vec{F}_{spr} \,. \quad (1)$$

The module of resultant force F_1 is:

$$F_1 = F_a - F_{spr} \,. \quad (2)$$

The component of the resultant force F_1 on the direction perpendicular to the finger, denoted by F_1', determines the rotation of the finger (6) by angle α. The force F_1' is calculated as follows:

$$F_1' = F_1 \cdot \cos\alpha \,. \quad (3)$$

Substituting the expression of F_1 from relation (2) into relation (3), is obtained:

$$F_1' = \left(F_a - F_{spr}\right) \cdot \cos\alpha \,. \quad (4)$$

In the kinematical joint J acts the prehension force F_2, necessary to orient and fix the workpiece, which opposes the weight G and the normal reaction N of the workpiece.

$$\vec{F}_2 = \vec{G} + \vec{N} \,. \quad (5)$$

The module of prehension force F_2 is:

$$F_2 = G + N \quad (6)$$

and:

$$G = m \cdot g \,, \quad (7)$$

where m is the mass of the workpiece and g is the gravitational acceleration.

In the prehension process, the normal reaction N of the workpiece increases with the increasing of prehension force F_2.

The component of the prehension force F_2 on the direction perpendicular to the rotation radius l_2 is denoted by F_2' and it can be determined with the relation:

$$F_2' = F_2 \cdot \cos(\alpha + \beta) \,. \quad (8)$$

With respect to point E, the bending moment of the resultant force F_1 is equal to the bending moment of the weight G and the workpiece reaction N:

$$\vec{M}_{F_1} = \vec{M}_{G+N} \,, \quad (9)$$

or:

$$F_1 \cdot \cos\alpha \cdot l_1' = (G + N) \cdot \cos(\alpha + \beta) \cdot l_2 \,. \quad (10)$$

Since the length l_1' can be written:

$$l_1' = \frac{l_1}{\cos\alpha} \quad (11)$$

and substituting the expression of F_1 from relation (2), relation (10) becomes:

$$\left(F_a - F_{spr}\right) \cdot \cos\alpha \cdot \frac{l_1}{\cos\alpha} = (G + N) \cdot \cos(\alpha + \beta) \cdot l_2 \,. \quad (12)$$

From relation (12), the expression of F_a is determined as follows:

$$F_a = (G + N) \cdot \cos(\alpha + \beta) \cdot \frac{l_2}{l_1} + F_{spr} \,. \quad (13)$$

With this relation the force F_a developed by the SMA element, necessary to achieve the force F_2 required to fix the workpiece is calculated.

Based on relations (10) and (11), the expression of SMA actuator driving force F_1 can be determined as follows:

$$F_1 = (G + N) \cdot \cos(\alpha + \beta) \cdot \frac{l_2}{l_1} . \,. \quad (14)$$

4. Conclusions

In order to determine the value of the driving force F_1 developed by the SMA actuator, by using the relation (14), it is necessary to know:
- the value of the force F_2, necessary for keeping the workpiece oriented and fixed in the prehension device;
- the value of the angle α, which is set by the designer depending on the dimensions of the workpiece, i.e. the stroke of the finger jaws (8) and (9);
- the elastic force (F_{spr}) of the helical springs for returning to the initial position of the finger jaws (8) and (9).

Knowing the forces and reactions, the calculus for the dimensioning and verification of the constructive elements of the robot prehension device can be accomplished.

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