ROBOTIC GRIPPER ACTUATED USING THE SHAPE MEMORY ALLOY ACTUATORS

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DOI: 10.17973/MMSJ.2022_03_2022015

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The article deals with the design of a gripper for a manipulator. The use of a shape memory alloy actuator, which is excited by heating by means of an electric current, is proposed for driving the gripper jaws. Variant solutions of the gripper kinematics and the final design of the gripper arrangement are solved. A gripper kinematics simulation is created to find a suitable gripper geometry.

KEYWORDS

gripper, actuator, shape memory alloy, manipulator, mechanism

1 INTRODUCTION

The gripper is defined as the end effector of the manipulator designed to grip and hold objects. It performs the function of gripping, clamping the object of manipulation and its fixation during its relocation, resp. during the active manipulation of the object, at the same time they participate together with the manipulator in the realization of positioning, resp. orientation (including changes) of the object of manipulation at the place of its delivery.

In paper [Tanaka 2021] is proposed an extension nail mechanism that can be mounted on a parallel gripper. The triangular nail is connected to one end of the stainless-steel belt, and the drive unit is connected near the other end. They achieved stable grasping operations by using the extension nail mechanism of the parallel gripper in accordance with the flexibility of the object.

The article [Suder 2021] describes a technical problem from practice, where a manipulated object made of steel material slipped in the printed PLA jaws of the robot during its working cycle. This work is devoted to increasing the friction force of the robot jaws by adding 3D printed soft inserts.

Gripper actuated by shape-memory-alloy (SMA) wire was designed and fabricated in work [Zhong 2006]. The design took the advantage of the small linear displacement of the SMA wire to convert it into angular movement of the gripping jaws. The SMA actuation is provided by pulsing electric current from a driving circuit. With this method, the risk of the SMA being overheated can be reduced yet providing sufficient power for the useful gripping task. This ensures that the gripper has long and lasting actuation.

The study [Wang 2021] provides an alternative approach, without the need for integrated sensors, to control the deformation of a shape memory alloy (SMA)-based soft planar gripper for grasping deformable objects. The gripper consists of one soft finger which is an SMA-based hinge actuator capable of producing hinge-like bending deformation. The soft finger can automatically achieve the desired deformation by introducing a closed-loop PID control system.

The article [Chautanya 2014] presents a simplest gripper actuated by SMA wire. The mechanical structure of the gripper is comprised of a pair of jaws (one movable) and an actuation means (a SMA wire and a counteracting torsion spring) for the movable jaw. Open loop and closed loop performance of the gripper are experimentally evaluated to manipulate objects of various sizes.

2 GRIPPER CONCEPT

The aim of this work was to design a gripping device for manipulating manipulation objects. The manipulated object will be positioned so that its axis of symmetry will be perpendicular to the pad. The gripping will take place at the point of change of diameters below the lower edge of the larger diameter. When gripping the object, it does not have to be gripped by the contact friction force, but it will therefore be possible to use a form connection when gripping the object (Fig. 1).

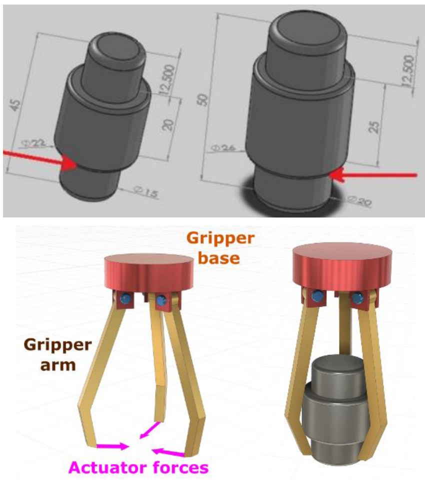

Figure 1. Concept of manipulator gripper and manipulated object

The gripper concept (Fig. 1) in this work is designed based on the application of actuators based on SMA shape memory alloy materials. This means that the force required to grip the gripper arms will be generated by the SMA actuator. This actuator is available under the trade name Nitinol. The external effect of SMA material is the change in shape that occurs during heating and cooling. The heat of an external source, or the heat generated by its heating during the flow of electric current, is used to control Nitinol.

As a result, Nitinol can bend or shorten and dynamically change its internal structure at different temperatures. The shape memory phenomenon is a diffusion-free phase transformation in the solid state - the martensitic transformation. At higher temperatures, the phase has a cubic crystal lattice and is called austenite. The phase formed on cooling or by external forces has a crystal lattice with lower symmetry and is called martensitic.

For practical use, it is more advantageous to control the SMA activity by the amount of electric current flowing through this actuator. Nitinol is produced as a wire or spring, which is a very hard and anti-corrosion material. This type of actuator requires a mechanical preload for its proper function, which can be created by a weight or other mass or spring and can also be realized by antagonistic connection of two SMA actuators (Fig. 2). SMA and shape memory materials are often used in space technology, in the mechanical engineering industry, in electrical engineering and in robotic devices, but also in healthcare, where they can perform the required work with small requirements. Their main advantage is that they are noiseless, do not require a magnetic field to operate, they can work even in dusty and humid environments, and they are biocompatible. Due to the biocompatibility of these materials, biomedical applications, instruments and implants are also very often used [Sabol 2010].

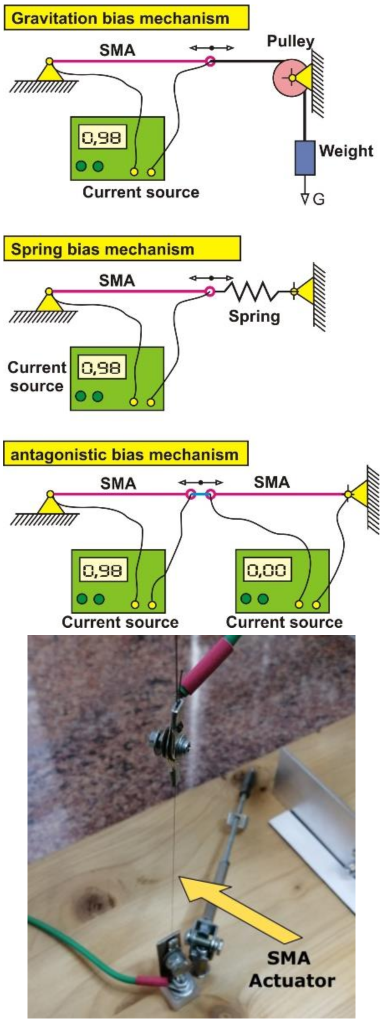

Figure 2. Using of SMA wire actuators

The SMA actuator is held at one end by an electrically insulated mounting so that it can be connected to a power supply (Fig. 2). The other end of the actuator is connected to an object that needs to be moved by that actuator. For the application in the proposed gripper concept, this type of actuator will move the gripper arms so that the manipulated object is gripped [Dovica 2011, Mikova 2015, Kelemen 2015].

3 KINEMATICS OF THE FIRST VARIANT GRIPPER SOLUTION

The overall arrangement of the gripper consists of three arms rotated 120° relative to each other about the gripper axis (Fig 1). All arms will be controlled from a single contact point located in the center of the gripper, where the end of the actuator will be connected to perform the mechanical displacement. The gripper arm consists of two parts (connecting rod and end element) (Fig. 3). To simplify the calculation, only the kinematics of one arm of the end member was solved (Fig. 3), to simplify the resulting relationship. Therefore, to determine the final range of the end term, it is sufficient to multiply the resulting equation by two.
The given span of the gripper is given by the relation:

$$y_1 = c_1 + c_2 \tag{1}$$

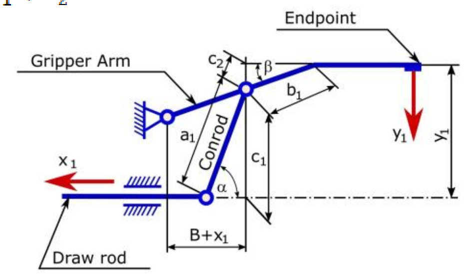

Figure 3. Kinematic scheme of the 1st variant gripper solution

The angle α is given by:

$$\alpha = arccos\frac{B+x_1}{a_1} \tag{2}$$

Where c_1 and c_2 are determined from the following relations (3) and (4):

$$c_1 = a_1 \cdot sin\left(arccos\frac{B+x_1}{a_1}\right) \tag{3}$$

$$c_2 = b_1 \cdot sin\beta \tag{4}$$

The resulting span is given by:

$$y_1 = a_1 \cdot sin\left(arccos\left(\frac{B+x_1}{a_1}\right)\right) + b_1 \cdot sin\beta \tag{5}$$

This relationship is a mathematical model (5) of the proposed gripper concept and can be used to study the properties of the gripper. The influence of parameters on the output quantity, i.e., the range of movement of the gripper arm y_1 was examined for different combinations of gripper geometry and the results graphically shown in fig. 4. It follows from this simulation that the optimal combination of parameters is a_1 = 30 mm and b_1 = 20 mm, B = 20 mm, angle α = 80°, this value is represented in the graphical form by the extreme (Fig. 4).

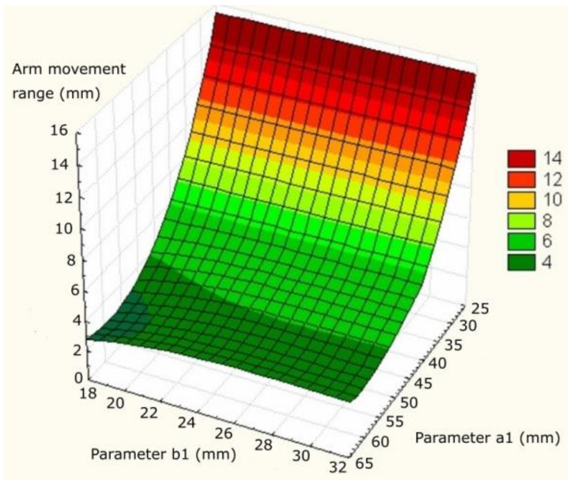

Figure 4. Range of movement of the gripper arm at different values of the arm parameters for the variant solution 1

This variant solution (Fig. 3) does not have a suitable kinematics for the realization of the gripper - end effector because when moving the contact point with the actuator (Nitinol) direction x_1, the range of motion of the gripper arm (Δy_1) is insufficient to grip the defined manipulation object. Therefore, nitinol with a longer length should be used for the implementation, which is unsuitable in our case due to the lack of space for nitinol placement.

4 KINEMATICS OF THE SECOND VARIANT GRIPPER SOLUTION

The overall arrangement of the gripper consists of three arms (Fig. 1) which are rotated at an angle of 120 ° about the axis of the gripper. All arms will be operated from a single point of contact (Fig. 5) located in the center of the gripper, where the end of the actuator performing the mechanical displacement will also be connected. The gripper arm is formed by one component (Fig. 5).

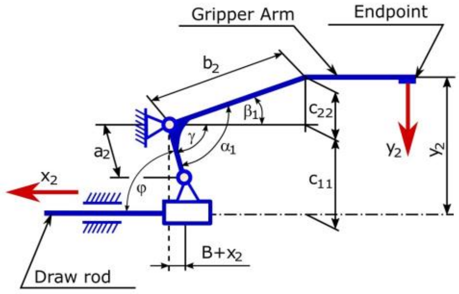

Figure 5. Kinematic scheme of the 2nd variant gripper solution

The span of the gripper is given by the relation:

$$y_2 = c_{11} + c_{22} \tag{6}$$

The angle φ is given by:

$$\varphi = arccos\frac{B_1 + x_2}{a_2} \tag{7}$$

Where c_{11} is determined from the relation:

$$c_{11} = a_2 \cdot sin\varphi \tag{8}$$

Then the following relation applies to c_{11}:

$$c_{11} = a_2 \cdot sin\left(arccos\left(\frac{B_1 + x_2}{a_2}\right)\right) \tag{9}$$

The angle β_1 is given by:

$$\beta_1 = \alpha_1 - \gamma \tag{10}$$

Where:

$$\gamma = a_2 \cdot arcsin\left(\frac{c_{11}}{a_2}\right) \tag{11}$$

Then we determine the value of c_{22}:

$$c_{22} = b_2 \cdot sin\left(\alpha_1 - arcsin\left(\frac{c_{11}}{a_2}\right)\right) \tag{12}$$

The resulting span can then be expressed:

$$y_2 = a_2 \cdot sin\left(arccos\left(\frac{B_1 + x_2}{a_2}\right)\right) + b_2 \cdot sin\left(\alpha_1 - arcsin\left(\frac{c_{11}}{a_2}\right)\right) \tag{13}$$

Mentioned relation (13) represents a mathematical model of the proposed gripper concept (Fig. 5) and can be used to study the properties of this gripper design. The influence of parameters on the output quantity, i.e., the range of movement of the gripper arm y_2 was examined for different combinations of gripper geometry and the results are shown graphically in fig. 6. It follows from this simulation that the optimal combination of parameters is a_2 = 50 mm and b_2 = 30 mm, B_1 = 20 mm, angle α_1 = 80°, this value is represented in the graphical form by the extreme.

This variant solution also does not have a suitable kinematics for the realization of the gripper-end effector, because when moving the nitinol in the x_2 direction, the range of movement of the gripper arm y_2 is insufficient to grip the defined manipulation object. Therefore, it would be necessary to use nitinol with a longer length for the implementation, which is unsuitable in our case, due to the lack of space for nitinol placement.

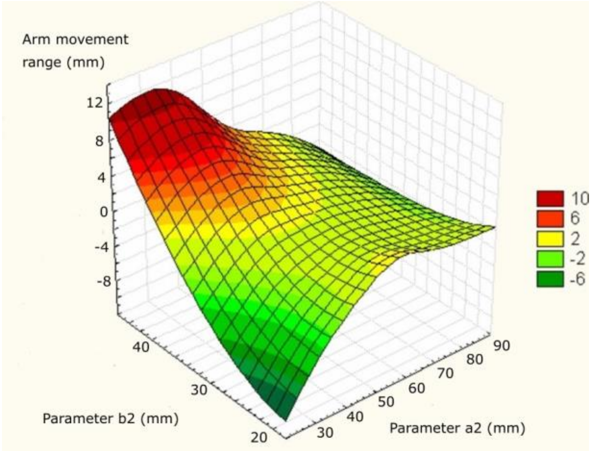

Figure 6. Range of movement of the gripper arm at different values of the arm parameters for variant solution 2

5 KINEMATICS OF THE THIRD VARIANT SOLUTION OF THE GRIPPER

The overall arrangement of the gripper consists of three arms rotated 120° about the axis of the gripper (Fig. 1), each arm being formed by a single component. All arms will be operated from a single point of contact located in the center of the gripper connected to the drawbar, where the end of the actuator performing the mechanical displacement will also be connected (Fig. 7).

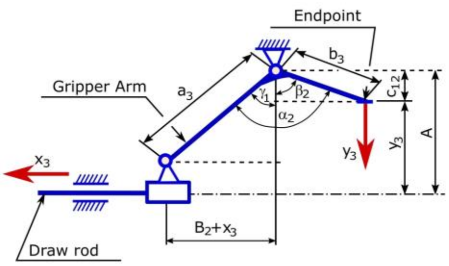

Figure 7. Kinematic scheme of the 3rd variant gripper solution

The gripper span can be described by:

$$y_3 = A - c_{12} \tag{14}$$

Where c_{12} we then determine:

$$c_{12} = b_3 \cdot cos\beta_2 \tag{15}$$

We determine the angle β_2 as follows:

$$\beta_2 = \alpha_2 - \gamma_1 \tag{16}$$

Where γ_1 is equal to:

$$\gamma_1 = arcsin\frac{B_2 + x_3}{a_3} \tag{17}$$

The resulting span can then be written as:

$$\gamma_1 = arcsin\frac{B_2 + x_3}{a_3} \tag{17}$$

The resulting span can then be written as:

$$y_3 = A - b_3 \cdot cos\left(\alpha_2 - arcsin\left(\frac{B_2 + x_3}{a_3}\right)\right) \tag{18}$$

This relationship represents a mathematical model of the proposed gripper concept and can be used to investigate the properties of this variant gripper solution. The influence of individual parameters on the output quantity, i.e., the range of movement of the gripper arm y_3 was examined for different combinations of gripper geometry and the results are shown in fig. 8. It follows from this simulation that the optimal combination of parameters is a_3 = 30 mm and b_3 = 60 mm, B_2 = 20 mm, angle α_2 = 130°, this value is represented in the graphical form by the extreme. Analogously, it is possible to express the dependence of the range of movement of the gripper arm y_3 even when changing the parameter B_2 = 30 mm and B_2 = 40 mm. These dependencies are shown in fig. 9 and fig. 10.

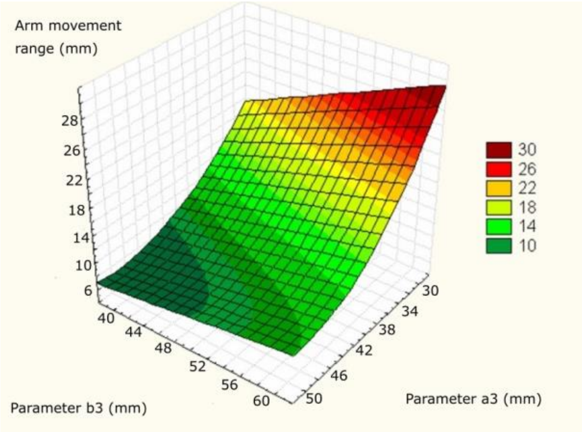

Figure 8. Range of movement of the gripper arm at different values of the arm parameters for the 3rd variant solution, B = 20 mm

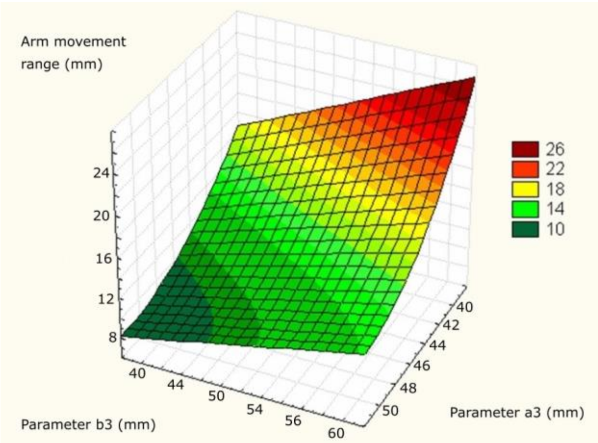

Figure 9. Range of movement of the gripper arm at different values of the arm parameters for the 3rd variant solution, B = 30 mm

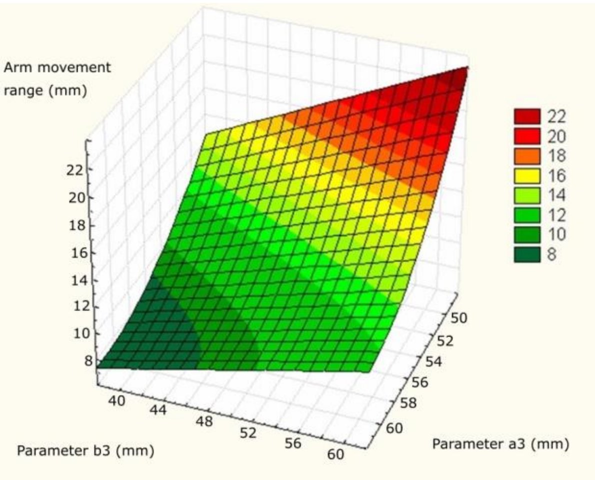

Figure 10. Range of movement of the gripper arm at different values of the arm parameters for the 3rd variant solution, B = 40 mm

Of the individual solutions, the most advantageous is the variant solution of the third kinematic set. Subsequently, a graphical dependence was compiled (Fig. 11), from which it can be seen how the value of y_3 (jaw clamping) changes when the nitinol is shortened in the direction of the x_3 axis.

The resulting gripper parameters are summarized in tab. 1 and are the basis for the implementation of the proposed gripper.

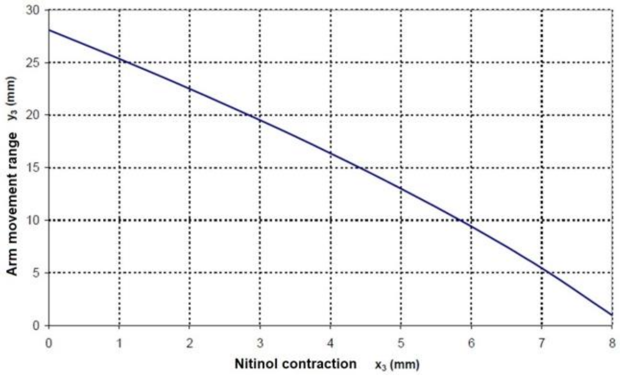

Figure 11. Gripper arm movement range y_3

a_3 (mm)	b_3 (mm)	α_2 (mm)	A (mm)	B_2 (mm)	y_3 (x_3=0) (mm)	y_3 (x_3=8) (mm)	Δy_3 (mm)
30	60	130	30	20	28.1	0.95	27.2

Table 1. Table of result parameters for gripper design according to the third variant solution

6 STATIC ANALYSIS OF THE GRIPPER ARM

Stress and displacement analysis was performed during the static analysis of the gripper arm. The gripper arm is designed from a material - aluminium (Al) 1060 Alloy. The gripper arm was loaded with a force of F = 5N. The course of tension and displacement in the gripper arm are shown in fig. 12 As can be seen from fig. 12 the largest displacements are at the end point of the gripper arm.

Stress analysis was performed during the static analysis of the frame. The frame is designed from the material - aluminium (Al) 1060 Alloy. The frame was loaded with a force of F = 5N. The voltage and displacement waveforms are shown in fig. 13.

As can be seen from fig. 13 is the largest displacement at the point of attachment of the frame to the gripper arm. The overall arrangement of the gripper is shown in fig. 14. A pulley is located at the point that controls the opening of the gripper jaws. Nitinol will rest on this pulley, which will change its length upon activation. The ends of the nitinol are attached to the upper part of the gripper on an insulating pad, which at the same time forms a terminal for connecting an electric current.

Activation of nitinol is visible as a change in its length and will be created by heating the nitinol with Joule heat, which is generated when an electric current passes through this nitinol in the form of a wire. The place where the nitinol is located is closed by a cover (Fig. 15).

A flange is located in the upper part of the gripper, which can also be used to attach the gripper to the manipulator (Fig. 15). The coil spring, which is located between the sliding parts of the gripper, is used to create the nitinol preload that is necessary for the proper operation of this actuator.

to be gripped, it is possible to replace the gripping fingers of the gripper with another.

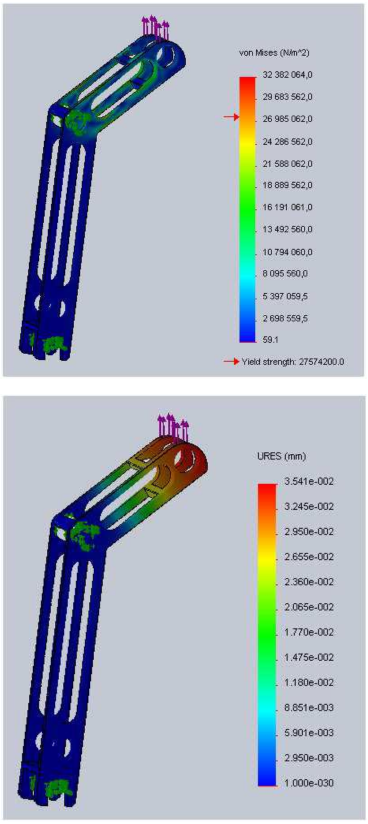

Figure 12. Static analysis of the gripper arm - the course of tension and the course of displacement

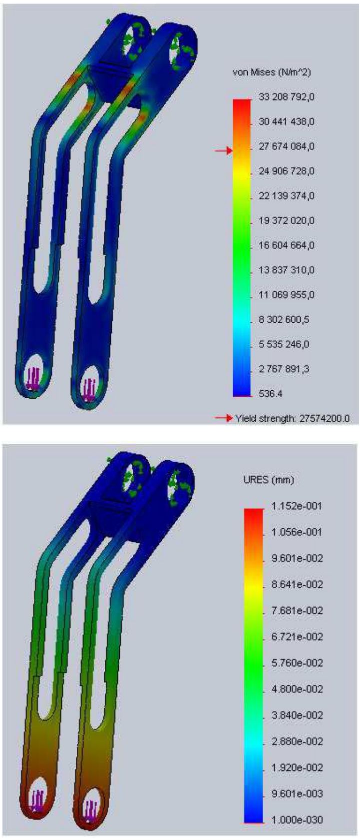

Figure 13. Static frame analysis - stress and displacement

The gripping of the object can thus be carried out by activating the nitinol and deactivating it will release the jaws of the gripper (Fig. 16). When changing the shape or size of the object

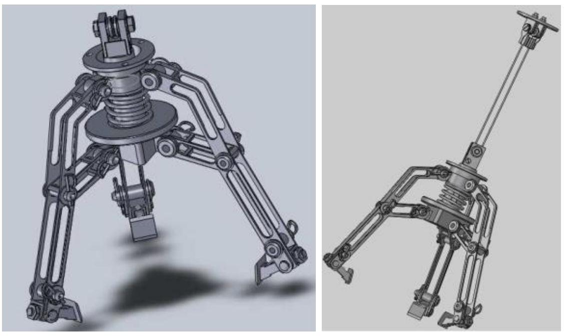

Figure 14. Designed gripper and illustration of SMA attachment to the gripper pulley

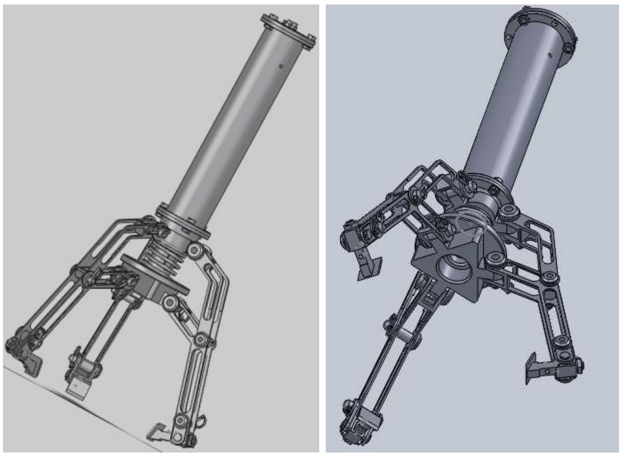

Figure 15. Cover for SMA and attachment of the gripper to the manipulator

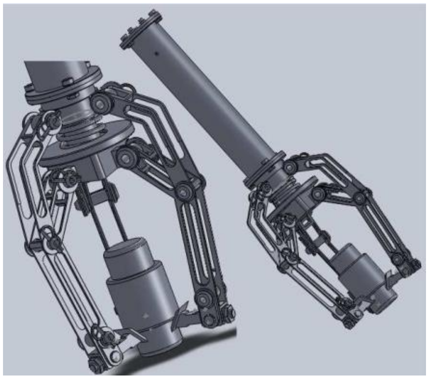

Figure 16. Illustration of gripping an object with a manipulator

7 CONCLUSIONS

The final gripper solution is an unconventional solution that can be implemented at low cost and allows easy gripping of objects. The undeniable advantage of the application of Nitinol is that it is a noiseless actuator without the need for a gearbox and with the possibility of application even in a dusty industrial environment. Probably the only disadvantage is the slower response of the actuator, which in some applications would not be a problem. The development of similar applications can mean advantageous alternative economic solutions [Bezak 2014, Semjon 2016, Hajduk 2018, Liptak 2018, Lumnitzer 2015, Lumnitzer 2016, Pavlenko 2020, Zidek 2018, Virgala 2021]. In combination with suitable sensor equipment, it provides the possibility to create intelligent gripping system solutions

[Hajduk 2009, Virgala 2012, Krenicky 2013, Mikova 2014, Bozek 2016 and 2021, Pinosova 2018, Galajda 2018, Oscadal 2020, Saga 2020, Pastor 2020, Kelemen 2021, Kelemenova 2021, Trojanova 2021]. The actuator used provides a relatively wide range of applications in various other gripping or motion creation systems [Kelemen 2012, Murcinkova 2013, Ostertag 2014, Virgala 2014a and b, Panda 2016, Hlavac 2018, Pavlasek 2018, Kelemen 2018, Olejarova 2021]. To control this actuator, it is necessary to create a control unit with a microcontroller to effectively use the capabilities of this actuator [Kelemen 2014].

ACKNOWLEDGMENTS

The authors would like to thank the Slovak Grant Agency—project 004TUKE-4/2021, VEGA 1/0201/21 and VEGA 1/0436/22.

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