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Operational Study and Fabrication of Flexible Miniature Gripper

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Abstract: This paper deals with the fabrication and operational study of an adjustable, two fingers flexible miniature gripper based on porous magnetorheological nanocomposites having the adjustability of pre-openings of the jaw's tips. The fabricated gripper grasps the small size and thin objects, maintain them and release them as required upon reducing the electrical current. The lead, package papers, wax, foams, silver film and silicon wafer sheets were used as under experiments materials and it has been noticed that it is working properly to grip the things which has rough surfaces at all. To grip the greater objects, it can be adjusted through its tips as well. This type of grippers includes the simple montage, lower fabrication prices and owns lower volume as well as weight, and there will be no need to apply the classic mechanical linkage inside. The results show that this type of grippers need less electrical energy to actuate and produce the lower forces in output. It is recommended to use the present gripper for the micro electromechanical systems, especially in the holding and transporting of sensitive work pieces against scratches, fingerprints and pressure.
Keywords: Flexible, Gripper, Magnetorheological, Miniature, Nanocomposites

I. INTRODUCTION

The flexible miniature gripper is known the category of grippers which can grasp and transfer the irregular objects. The literature and designing background of this type of grippers are returning to the two decades ago. Considering the importance of miniature grippers in the field of medicine, metrology, mechatronics and robotics industry; the laboratory researches has been conducted and reported. But so far, reports did not include the miniature gripper designing based on magnetorheological nanocomposites yet. Magnetorheological nanocomposites are a new category of flexible and light weight smart materials which is most sensitive against magnetic fields [1-5]. In the present research work, the porous samples of magnetorheological nanocomposites based on silicon rubber with Nano-sized carbonyl iron, silicon oil and ammonium bicarbonate powder; is used to design the miniature gripper jaws. The manner and fabrication detail of this type of magnetorheological nanocomposites along with its mechanical and magnetic properties have been reported in another [6] research study of author.

According to literature records, the first published research report on miniature gripper design is available in the field of endoscopic surgery [7]. This gripper was actuated using a vibrating mass and impact mechanism. The optimal force of gripper to grasp provide the objects is about 3N, the required voltage equal is 0.9 V and the maximum distance that gripper tip can open was 10 mm. This design scheme needs more space and its components must be adjusted together to maintain the proper balance.

The next design has been reported in the field of miniature gripper suitable for laparoscopic surgery [8], having the new features such as grip force of 40 N and the length of 25mm. Three types of actuators such as electric motors, hydraulic pistons and memory alloy has been used during the prototype development. However, the operation of the prototype using memory alloy wires having been approved, but, still it has not any physical place in industrial applications.

The Gassmann [9] engineering company built a miniature gripper named Model WPT / 6. this model is operated based on actuators made of shape memory alloy and was tested on working with microelectronics circuits and grasping of small objects such as electronic components, fibers, etc. The jaw's tip is made from tungsten carbide and the gripping force is configured in the range of 0.2 to 0.4 N. The working problem with this type of gripper is relating to its excess weight which it faces the operation with challenges.

The SCHUNK [10] sponsored industrial prototypes of miniature grippers with two fingers and multi fingers marketed successfully. The problem with this gripper are due to the existence of excess weights of connections, power supply and motor as excitation source as well. Some of this grippers has been used in the robot hands.

Some studies on the design of miniature gripper for grasping the biological cells [11] have been conducted. In the reported research studies, the force sensing was analyzed and steel spring along with PDMS has been used for fabrication. Because of the shape, sensitivity, accuracy and cost of the tip of the gripper, the gripper remained in laboratory-scale.

The miniature gripper with micro electrical-thermal excitation source, that their manufacturing process is simpler, requires a higher energy source [12], so as to move the tip of the gripper about 18 μm, there is required to apply 1.5 volts.

The miniature gripper made from magnetorheological elastomers containing micro-sized carbonyl iron [13] owns the lower magnetic permeability, needs the greater actuation coil. The jaws of this type of gripper are showing a higher stiffness as by applying a magnetic field, it becomes two to three times. In these grippers, there will be fewer points of contact between the object surface and the jaw's tip.

In the present paper, the flexible miniature gripper is fabricated and its operational performance is studied using magnetorheological nanocomposites as an actuator element. The overall dimensions of gripper is 3.5 x 5 x 3.5 cm, net weight (without actuation coil) is 7 grams, total weight (with an actuation coil and magnet) is 26 grams, the effective gripping force is observed between 0.0005 to 0.2 N, and a maximum opening distance of tip about 9 mm.

The target gripper is belonging to a movable jaw, radial operation, external contact, flexible type, Smart responsive to the magnetic field and miniature scale grippers family.

The new aspects of this fabricated flexible and miniature gripper based on magnetorheological nanocomposites consists of the following items:

a. Usage of magnetorheological nanocomposites as gripper jaws for first time

b. Because of jaw's flexibility which causes the more points of contact with the object surfaces, the possibility arises that the jaws match with irregular shaped objects and grasp and hold the objects having a large complexity and irregular geometric shapes.

c. Easy control of opening and closing of the gripper's tip is possible using modification in adjusting space, changes in the length of the jaw and applied current, and desired selection of location for actuation coil.

d. There is no need to use the mechanical hinges and the friction does not interfere with the function of the gripper without the mechanical hinges.

e. Because of being nontoxic, it can be used in medical applications.

f. It can be used in wet environments connected to electricity.

II. MATERIALS AND METHOD

To manufacture the flexible miniature gripper as shown in Fig.1, the material type of pieces has the great importance. The material for active pieces should be have the higher relative magnetic permeability in addition to the required strength and lower weight. The materials which were used for base support and magnet-jaw support are the PVC plastics and propylene respectively. Because, this type of plastics have the lower relative magnetic permeability with no interference properties towards loses in the magnetic flux density.

The required ingredients for fabrication of porous magnetorheological nanocomposites samples are Nano-sized carbonyl iron powder (23-35 nm), the silicone oil, ammonium bicarbonate powder (NH_4HCO_3) and silicone rubber.

Materials required to design of the actuation coil consists of winding copper wire (0.43 mm in diameter), cylindrical iron core with an inner diameter of 23 mm and outer diameter of 28 mm and the core open gap is 9 mm.

The used glue for montage, assembly and connection of supports to the actuator (jaw) is the Loctite 406 glue with a viscosity of 20 mPa-s.

The 50 mm in diameter and 0.80 mm thick of disk-shaped samples of porous magnetorheological are prepared in vacuum oven. Fabrication process of porous magnetorheological nanocomposites are consisted of three steps (mixing of ammonium bicarbonate (NH_4HCO_3) powder with carbonyl iron particles, silicone oil and silicone rubber, molding and sintering). By curing the samples, the NH_4HCO_3 can be decomposed into the NH_3, CO_2 and H_2O, thus the disk-shaped samples of porous magnetorheological nanocomposites are formed.

Fig. 1 Image of assembled flexible miniature gripper

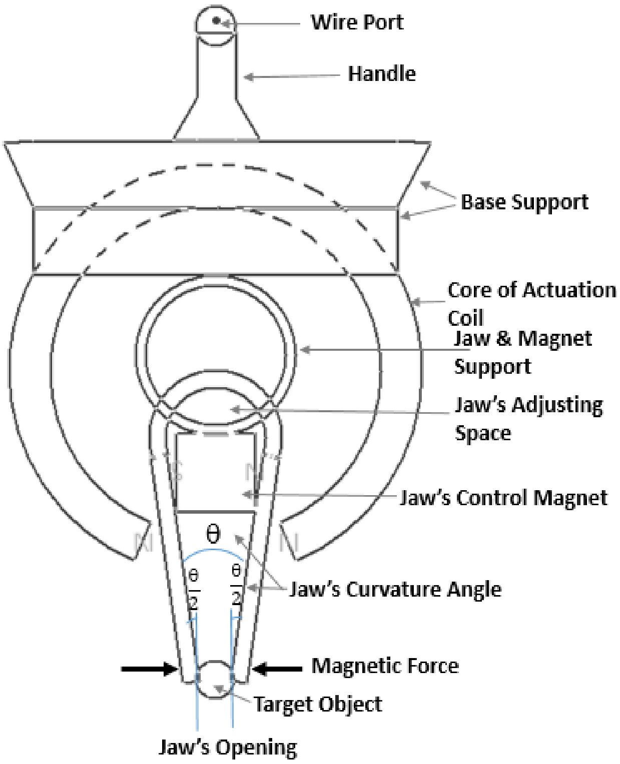

Fig. 2 Conceptual design of a flexible miniature gripper

The beams with a thickness of 0.8 mm, width of 3 mm and length of 50 mm are provided from disk-shaped samples of porous magnetorheological nanocomposites using a TROTEC Speedy 300 CO_2 Laser Cutter.

The actuation coil is designed from a two-layer dipole coil which included 240 windings.

Manufacturing of flexible miniature gripper in according to the conceptual design (Fig. 2) includes the following four basic steps:

1. Design, fabrication and testing of the actuation coil and its embedding in the base-support.
2. Selection, evaluation, design and testing of the geometric position of magnet-jaw support and its connection with the base-support.

3. Preparation of beams as gripper's jaw and its embedding in the magnet-jaw support.
4. Determination and selection of the bend radius of adjusting space considering the required length of jaw.

The highlights on design process and accurate manufacturing of this type of gripper includes the accuracy of the smaller size, appropriate force creation and actuation mechanism. The smaller size is depending on selection of materials in according to their magnetic properties. The appropriate holding force is depending to the physical structure of gripper and actuation mechanism. Actuation mechanism includes an electromagnetic dipole coil that apply the magnetic force to the end of gripper jaws and the jaws are forced to separate from the control magnet. So, it leads to make opening and closing the tip of the gripper jaws. By decreasing of the applied current, the tip of the jaws can be opened or closed.

In the current design scheme, the design variable parameters (Fig. 2) plays the key role in optimized performance of the gripper. The jaw's tip opening parameter along with jaw's curvature angle can be adjusted by the bend radius of jaw in adjusting space and accept the significant changes. Adjusting space of jaw can have the bend radius in the range of 800 μm to 6 mm. the arrangement of actuation coil causes the variation in magnetic force of gripper jaw's tip. Effective limits of length size of jaw and tip's opening according to the applied magnetic field are measured between 12 to 16 mm and 300 μm to 6 mm, respectively.

The physical structure of the gripper's actuator (jaw), is related to the shape of the jaw and the profile of jaw's tip. Shape of the jaws play the major role in determining of required force of gripper. In the present scheme, because of the flexibility of actuator material (magnetorheological nanocomposites); the frictional type of jaws have been used. In the frictional jaws [14], the maintaining factor for target objects is the applied force to the target objects by the jaw's tip.

Depending on the selected type of jaw and in order to better performance of jaws, the physical structure of the jaw should be reviewed and tested. Jaw profiles of the gripper should be evaluated experimentally. Because, tip profile influence on holding force and contact points between objects surfaces and tip surfaces to prevent the objects slippage. Some used types of jaw tip's profiles in this study are shown in Fig. 3.

Fig.3 Microscopic image of jaw's tip profiles of miniature gripper

III. OPERATIONAL TEST

The operational performance indicators for the flexible miniature gripper are the effective and precise action enumerated in the following cases:

a. Holding and maintaining of small and thin objects
b. No damage to the surface and tissue of objects during holding, maintaining and releasing
c. Jaw's tip opening in according to the applied current
d. Creation of curvature angle of jaws in according to the applied current
e. Achieving the forces varied in according to the time and applied current
f. Achieving the holding force based on the pre-opening space of jaw's tip

In all tests, the prototype gripper is shown in fig. 1, The direct current power supply, Dino Lite digital microscope (with a magnification of 4 to 140 times, product of AnMo Electronics Corporation, made in Taiwan) and objects in the range of 0.5 to 16 grams in weight; were used in the measurement cycle. The output data from microscope were recorded and analyzed using Dino Capture software on a Dell computer (Studio XPS with a processor of Intel® Core (TM) 2 Duo CPU 4.0 GHz).

In order to observe the maintaining and holding abilities of jaw's tip, different small and thin objects with different appearance were griped, maintained and transferred.

The observation findings show that the holding of target objects are possible without any slippage and the maintaining of objects through jaw's tips are stable until reduction of current and its time is adjustable for a desired range.

The microscopic image of gripper's jaws during the holding and maintaining of target objects is reported in Fig. 4.

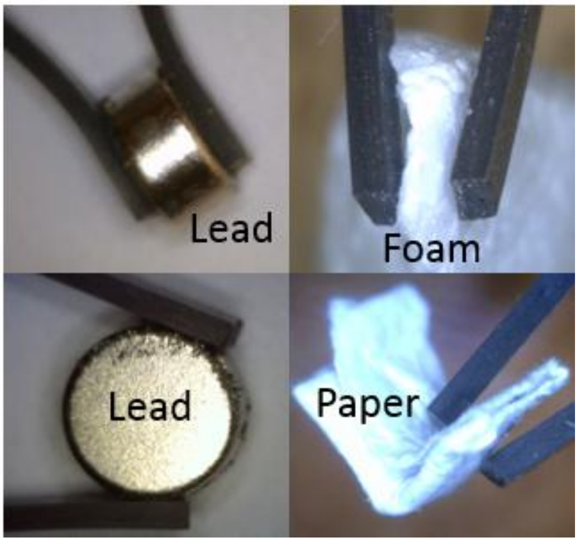

Fig. 4. Microscopic image of gripper's jaws during the holding and maintaining of objects.

This test examined the lack of damage to the surface and tissue of objects such as synthetic wax, silver film and the silicon wafer pieces during holding, maintaining and releasing (Fig. 5).

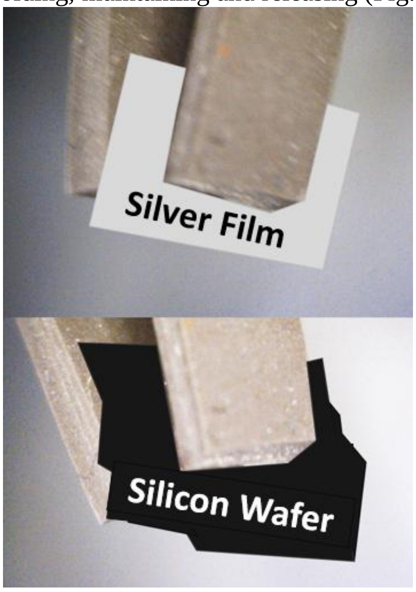

Fig.5 Microscopic image of gripper jaws during holding & maintaining of silicon wafer and silver film

In order to study the operational performance of gripper, the target objects was holding and releasing by jaw's tip. After objects releasing, the surfaces of objects were observed using digital microscope. There was no signs of changing in shape, size and scratches at all.

Based on this test, there is a need to have greater force to maintain the objects and bodies with perfectly smooth and polished surfaces to prevent them from sliding. Also, the roughness of tip's contact will help the stability of object maintaining.

The maintaining stability of objects with smooth surfaces establish a functional challenge for gripper.

Jaw's tip opening in according to the applied current has been tested. In this test, the overall goal is to assess the opening size of jaw's tip in according to the applied current. The pre-opening space of tip was adjusted in three different sizes (282, 632, and 902 μm) and the opening of jaw's tip was measured per unit of applied current using digital microscope. The data analysis results was graphed and displayed in fig. 6.

In this case, it was cleared that the pre-opening space has an important role for opening of jaw's tip. As the size of pre-opening is selected larger, the tip can be opened larger and will be able to grasp the larger objects with easily.

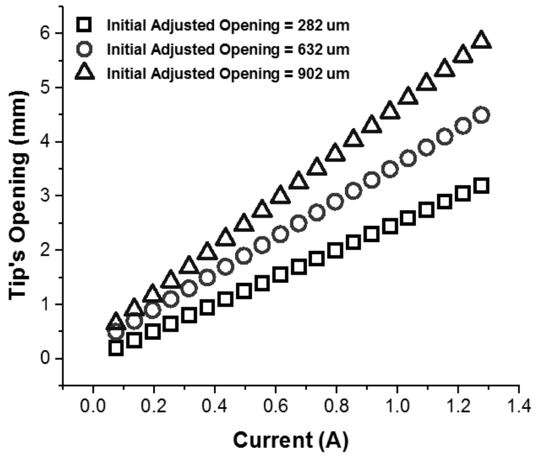

Fig.6 Jaw's tip opening based on applied current

Fig. 7 Microscopic measurement setup of jaw's curvature angle of miniature gripper

Creation of curvature angle of jaws in according to the applied current has been observed. In this test, the only measurable parameter is the jaw's curvature angle which is measured through the digital microscope. Using fig.2, θshows the jaw's curvature angle which includes the curvature ranges from a closed mode (Maximum curvature angle) to an open mode (Minimum curvature angle).

Review on output data show that there is a nonlinear relationship between applied current and curvature angle of jaws, and the curvature angle will be increased with increasing of applied current.

Fig. 7 reports the measurement system of curvature angle and fig. 8 describes the curvature angle changes depending on the applied current.

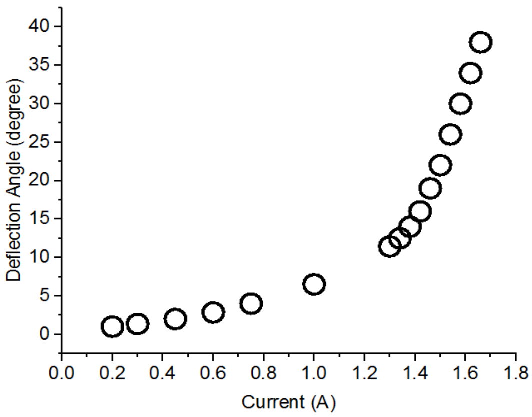

Fig. 8 Jaw's curvature angle changes depending on applied current

The forces varied in according to the time and applied current has been studied. In this situation, the sensitivity of holding force was tested on two objects made of two different materials. The applied electrical current was selected between 0.1 to 1.6 ampere and the pre-opening space was determined from 282 to 902 μm to investigate the variation of holding force relating to the time.

Fig. 9 and 10 shows the force changes in term of operational performance time of gripper for lead and foam piece holding.

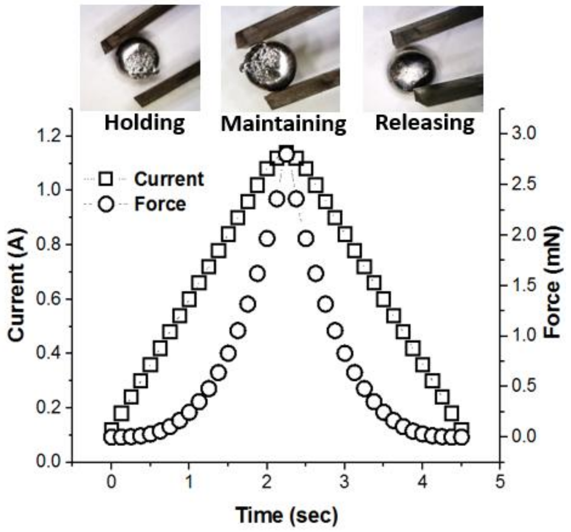

Fig. 9 holding force changes in a range of applied electrical current for a lead piece weighting 3.75 gr

In the test, the force is calculated per each unit of jaw's curvature angle using relation (1) as

$$F = {}^{2EI\theta}/_{L^2} \quad (1)$$

Where, E, I and L denote the young's modulus, moment of inertia and length of jaw respectively.

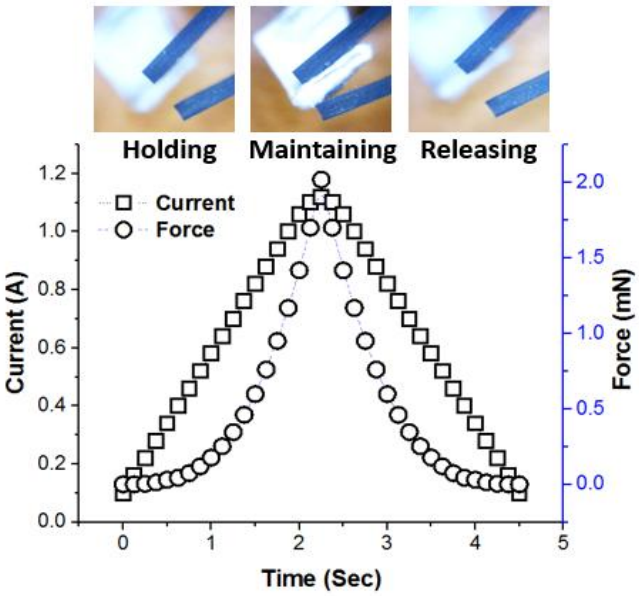

Fig.10 holding force changes in a range of applied electrical current for a foam piece weighting 2.85 gr.

The time is measured experimentally per each unit of changes in curvature angle using chronometer.

The change in forces is recorded experimentally in terms of time and the most maximum required force is noted during the maintaining position of objects. Based on plotted diagram, it is inference that the heavy objects required the higher force to grasp (Fig. 9).

The comparative accuracy of value obtained from equation (1) has been evaluated by mathematical relations discussed in [15-16].

The test time intervals was selected appropriate to the pre-opening space and applied electrical current.

Achieving the holding force based on the pre-opening space of jaw's tip

Finally, in order to review the variation of holding force considering the pre-opening space of jaw's tip; the holding test conducted on target objects. In this case, the applied electrical current was selected between 0.1 to 1.6 ampere and the pre-opening space was determined between 0.25 to 3 mm to investigate the variation of holding force relating to the different pre-opening spaces.

Fig. 11 shows the variation of holding force of miniature flexible gripper for a lead piece of weighting 6 gr.

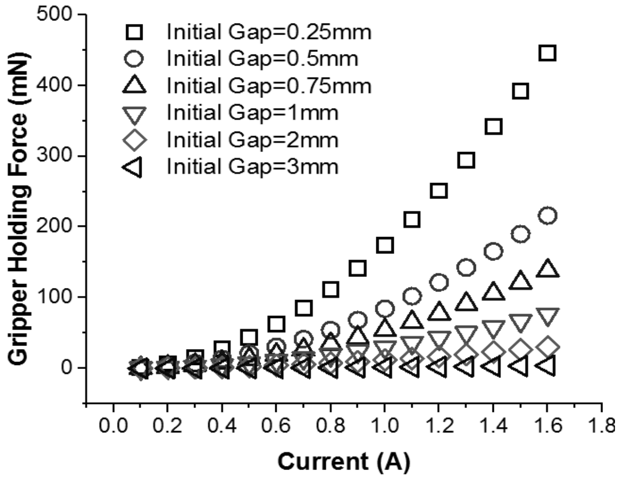

Fig. 11. Variation of holding force of miniature flexible gripper for a lead piece

Analysis of the data which obtained from the test show that the larger pre-openings(initial gap) creates lower output forces, and the best option to create the maximum force is to have a smaller pre-opening spaces in the tip.

Fig. 12 shows the magnetic circuit diagram when the miniature flexible gripper is going to be closed as well as holding the sample pieces.

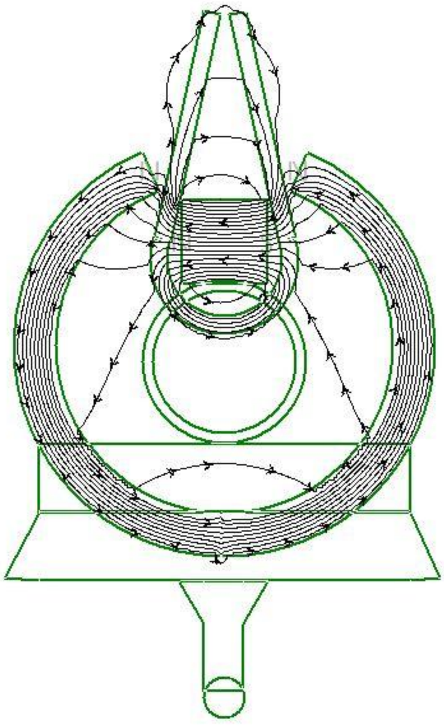

Fig. 12. Magnetic circuit diagram miniature flexible gripper

IV. RESULTS AND DISCUSSION

The flexible miniature gripper is able for holding and transferring the thin objects with irregular geometric shapes. This gripper is functioning well during the holding, maintaining and releasing of target objects. It was found from the operational performance tests on the objects like lead, compressed paper, foam and silicon wafer sheets that although the gripper is able to grasp the objects without producing any damage and scrapes on their surfaces, but still there is the stability problem during the holding, maintaining and releasing of polished and very smooth surfaces such as thin silicon wafer sheets. By applying the changes in the radius of curved part of jaw (Adjusting space), and adjustment the space, the jaw's length is decreased and the above mentioned problem will be solved.

The porous magnetorheological nanocomposites is a desired candidate for manufacturing of lightweight and flexible jaws. The experiment shows that this porous nanocomposite should be trained before final montage of gripper. Conducting the magnetic behavior training for jaws are considered to be a necessity to ensure the consistency, effective operation, and optimized performance of jaws to avoid for unexpected jumps of jaws during the application of magnetic field.

Pre-opening spaces are helping the favorable tip's opening sizes and enhancing the holding of objects. Of course, increase in the applied current excesses the tip's opening sizes.

The curvature angle of the jaw is measurable in the range of 2.52 to 38.6o due to the applied magnetic field, and the change in the curvature angle is counted practically by a digital microscope.

The force required to grasp a metallic object (i.e. lead) is greater than a nonmetallic objects (i.e. foam, wax, paper, plastic and etc.). Opening of the tips by a few micrometers will causes the releasing of the objects.

Repeated experiments at different operational performance levels of gripper show that there will be no problems such as unexpected imbalance and slippage of objects during the gripper functioning, and the performance and behavior stability is visible for the target objects within the weight range (0.5 to 14 gr).

Extra studies on holding force of miniature gripper proves whatever the pre-opening space is being greater, the lower output force will be achieved and the best condition to have the maximum force is depending to have smaller pre-opening spaces. The larger pre-opening space in alignment with the air interaction; harming the magnetic flux density lines, weakens the magnetic force and causes the delays during the closing and opening of jaws.

V. CONCLUSION

In this paper, a flexible miniature gripper was fabricated based on magnetorheological nanocomposites and its operational performances were investigated. In the investigations, the effects of pre-opening space of gripper's tip on opening size of tip and role of applied electrical current on curvature angle of the jaw has been reviewed experimentally. The main focus was concerned to the easy control of opening and closing of the jaw's tip by adjusting the length of the jaw, applied electrical current and location of actuation coil, respectively. With the expectation to the fabrication and performance parameters of such type of gripper, it is necessary to use a mixed method of analytical - experimental to study the performance of the designed miniature gripper. Considering the applied weight and magnetic field on jaws, the functional optimization will get possible and two-finger flexible miniature gripper can be manufactured to grasp the complex and irregular objects.

More researches are required on proper geometry design of jaw's tip, positioning of the actuation coil, magnetic behavior training of magnetorheological nanocomposites, and speedup the closing and opening of jaw's tip.

Two important factors on gripper performance are air interaction and friction between jaw's tip and object surfaces. To decrease the effects of these factors, the friction and air interaction should be minimized.

A research is proposed to design and find the proper location of actuation coil, and creation of control system to establish the flexibility of the gripper jaws.

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