Conceptual Design of a Micro Gripper with Electrostatic Micro Stepper-Motor Actuation

Farshad Shadbakhsh[1,*], Mohammadali Shahriari[2], Abolghasem Zabihollah[3]

[1] Department of Mechanical Engineering, Sharif University of Technology International Campus Kish island
shadbakhsh@kish.sharif.edu

Abstract: Micro grippers are essential tools for manipulation of objects in micron size. An electrostatic micro stepper-motor is used for actuating a proposed gripper mechanism and performance of this gripper is compared with the previous ones. The characteristic of the proposed mechanism is analyzed by simulation and it is shown that the designed gripper has the capability of doing manipulation in micron dimension with an acceptable performance.
[Farshad Shadbakhsh, Mohammadali Shahriari, Abolghasem Zabihollah. **Conceptual Design of a Micro Gripperwith Electrostatic Micro Stepper-Motor Actuation**. Life Sci J 2013;10(8s): 290_293] (ISSN:1097-8135). http://www.lifesciencesite.com. 45

Keywords: MEMS, Micro gripper, Electrostatic actuation

1. Introduction

Precise micro and nano scale manipulation is one of the key technologies for micro robotics. Micro grippers are the tools for various micro operations, for example, assembly of micro parts, manipulation of biological cells, and handling of living bodies for micro surgeries [1].Micro-grippers can be classified into four types: thermal, electrostatic, pneumatic, and piezo actuation micro-grippers, depending on the type of actuation mechanism [4]. An electrostatic silicon micro-gripper was proposed by Kim et al. [5], and an electrostatic micro-gripper with embedded force senor was developed with MEMS technology [6]. Some micro-grippers are actuated by electro thermal actuators [7], while others are actuated by piezo actuators, as proposed by Carrozza et al. [8].

Electrostatic micro stepper-motors have been developed in many studies before. Trimmer et al. [9] and Xinli et al. [10] studied these motors and show that micro scale electrostatic motors are better than electromagnetic motors. Ghalichechian et al. [11] reported a variable capacitance micro motor supported on micro ball bearing. Sarajlic et al. [3] developed a rotary micro stepper motor with flexural suspension of the rotor to avoid any frictional effect during operation.

In this paper, performance of an electrostatic micro stepper-motor for actuating of a micro gripper has been studied.

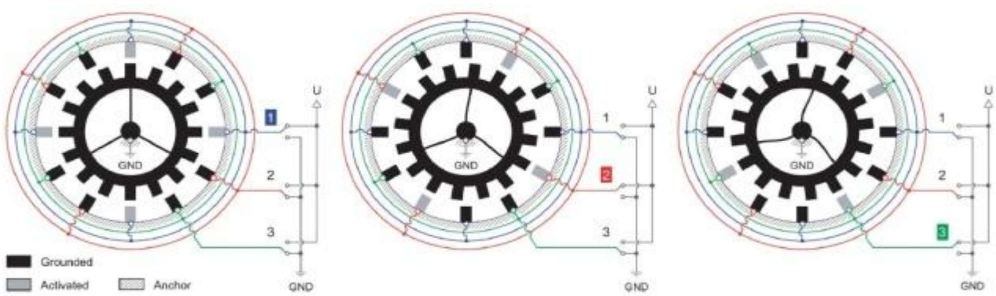

Figure 1. *Working principle of the three-phase electrostatic rotary stepper motor with a flexural mechanism. A stepwise motion of the rotor is achieved by applying the voltage on each phase successively. In these diagrams, only one phase is activated at a time. (From left to right) Phase 1, phase 2, and phase 3. [3]*

Working principle of the motor

The layout of the motor is shown in the figure 1. The motor consists of a rotor and stator both containing a large number of electrodes or poles where the electrodes are teeth like. The number of stator poles over rotor poles is 3/4; the reason is attributed to the fact that when a rotor pole aligned a stator pole, two another rotor electrodes are misaligned 1/3 and -1/3 of rotor pitch. In this way the motor can rotate clockwise or counterclockwise.[3]
As it is shown in the figure 1 this motor has 3 phases. The motor works by the applying pulses in the figure 2. The characteristics of the motor are shown in table 1.

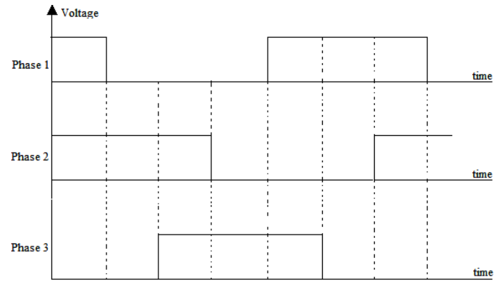

***Figure 2.** Driving pulse voltage of each phase*

Table 1. motor characteristics

Parameter	Amount	symbol
Rotor radius	200 µm	R
Air gap	1.5 µm	g
Number of Rotor electrodes	204	n
Number of active poles	68	N
Rotor thickness	30 µm	d
Pole width	3 µm	L

Theoretical modeling

Each rotor pole with its opposite stator pole creates a capacitor, according to the sizes of the rotor radius and poles width. It can be assumed that electrodes of the capacitors have rectangular shape. By applying voltage, two forces are exerted on the rotor electrodes. One is in the radial direction that has been canceled with its opposite electrode and the other one is in tangential direction that causes the rotor to rotate. The tangential force of each pair of electrodes is:

$$F = \frac{1}{2}\varepsilon_0 \frac{d}{g} V^2 \quad (1)$$

And the total torque of the rotor is:

$$T = NRF \quad (2)$$

(1) and (2) show that the torque of the motor varies with the amount of voltage which is applied to the electrodes.

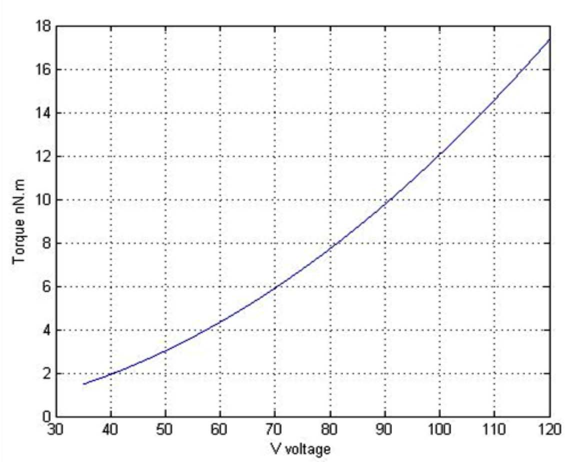

Figure 3. Driving voltage versus total rotor torque

According to the dimensions of the rotor and the numbers of rotor electrodes in each pulse, rotor rotates 0.0103 radians or 0.588 degrees.

Electrodes current

This motor is a variable capacitance motor and the current that flows in each electrodes of the motor varies because of the capacitance amount variation that has been made by two opposite electrodes. The capacitance can be shown by the equation (3).

The current of the motor phases with respect to the angular position of the arms can be driven by equations (3) to (10).

$$C = \varepsilon_0 \frac{d}{g} l \quad (3)$$

$$q = C\,V \quad (4)$$

$$i = \frac{dq}{dt} = \frac{dC}{dt} V \quad (5)$$

$$\frac{dC}{dt} = \varepsilon_0 \frac{d}{g} \frac{dl}{dt} \quad , l = R\theta \quad (6)$$

$$i = \varepsilon_0 \frac{d}{g} \frac{d\theta}{dt} \quad (7)$$

$$T = (I_{rotor} + I_{load})\alpha \quad (8)$$

$$\theta = \frac{1}{2}\alpha t^2 \quad (9)$$

$$i(\theta) = \varepsilon_0 \frac{dRV\sqrt{\alpha}}{g} \sqrt{\theta} \quad (10)$$

By measuring the variation of the current for one pulse and knowing that the rotor rotates 0.0103 radians, in the case when the gripper arms touch the object, variation of the current will be different with the other times. As a consequence the position of gripper arms can be detected.

As it is mentioned before, in each step 68 poles of the motor are activated and so it is obvious that in each step there exist 68 parallel capacitances and the total current of each phase of the motor is 68 times of the current of each pair of electrodes. Figure 4 shows the variation of the current of each phase of the motor for different amounts of voltages.

Mechanism analysis of the gripper

The mechanism consists of two arms with two revolute joints which are shown in the figure 5. Each arm has 1 mm length with rectangular cross section. It is assumed that the gripper arms are made of silicon. Each motor is located in upper and lower plates in order to actuate each arm.

Each voltage pulse moves the gripper arm approximately 10µm, the gripping forces have been shown in the figure 6.

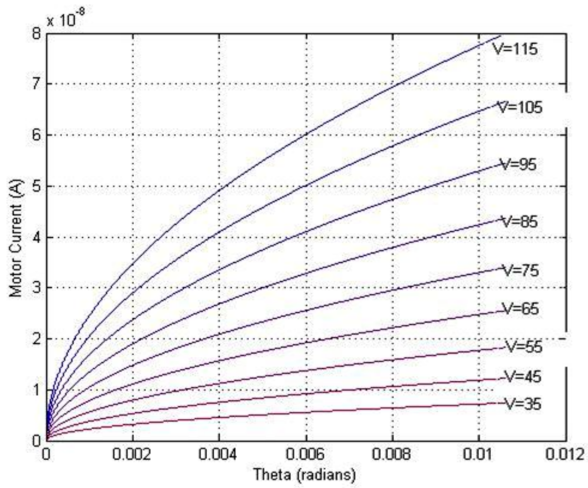

Figure 4. Phase current versus angular position

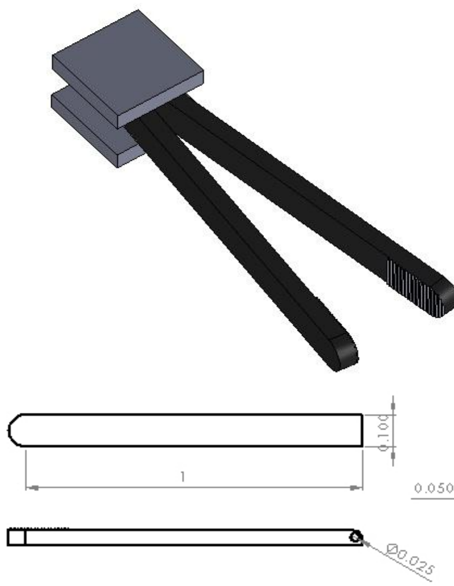

Figure 5 . Schematic of the gripper (dimensions are in mm).

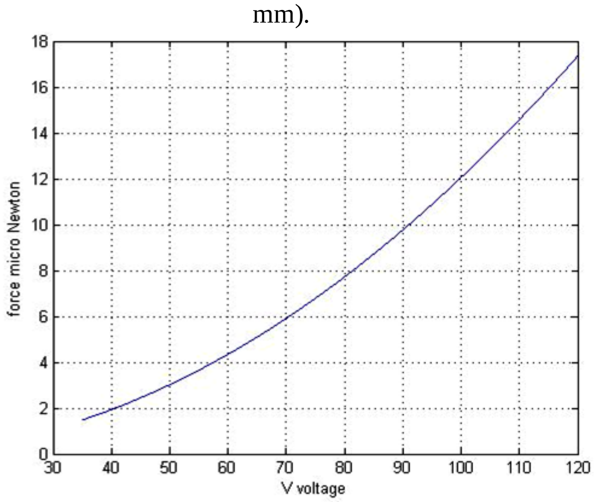

Figure 6. Gripping force versus voltage

A comparison with other types of micro grippers

In this section some different kinds of micro grippers have been compared with the proposed one in this study.

Micro grippers with flexure mechanism which use piezoelectric or electrostatic comb drive for their actuation do not have large range of maneuverability in comparison with the proposed mechanism. The mechanism which has been analyzed in this study uses revolute joint that it can grasp micro objects in large ranges of size. Table 2 shows the maximum tip displacement of other grippers in comparison with the proposed one. Also in flexure based mechanisms displacement of the gripper tip depend on the gripper force. It means that for grasping smaller objects, actuator must exert larger force to the gripper arms and this causes larger amount of gripping force. In the case of grasping sensitive objects, for instance in micro surgery, this is not desired. The proposed gripper in this study according to the numerical simulations and the type of its actuator, displacement of the gripper arm is independent of the gripping force. Displacement of this gripper depends on the numbers of pulses that exert to the motors and the gripping forces depend on the amplitude of the pulses. Figures 7 and Figure 8 show the relationship between driving voltage and displacement and displacement versus grip force respectively. The results show that griping force is linearly proportional to the displacement and displacement is also proportional to the driving voltage, it means that the grip force is linearly proportional to the driving voltage.

Table 2.

gripper	Maximum tip displacement
C. Moon et al. [2]	0 – 80 µm
J. –S. Park et. al. [1]	0 – 60 µm
Proposed gripper	0 – 500 µm

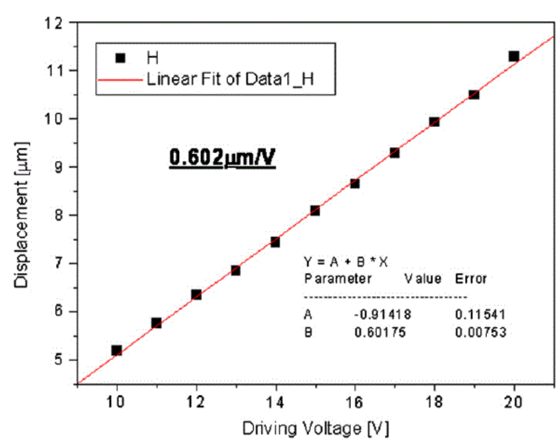

Figure 7. Driving voltage versus displacement[2]

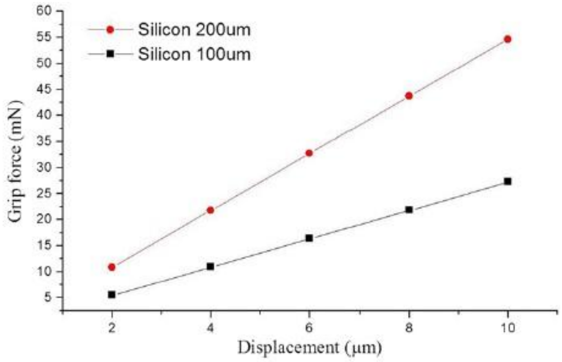

Figure 8. Displacement versus griping force[2]

Conclusion

A micro gripper design using electrostatic micro stepper-motor has been studied in this paper and it has been shown that this design has the capability of both providing sufficient torque and maneuverability for gripping diverse kind of objects in micron dimension.

References

1. Chang-Seong Jeon, Joon-Shik Park, Sang-Yeol Lee, Chan-Woo Moon, Thin Solid Films 515 (2007) 4901–4904.
2. Bong-Seok Kim, Joon-ShikPark, ByoungHun Kang, ChanwooMoond,Robotics and Computer-Integrated Manufacturing 28 (2012) 50–56.
3. Edin Sarajlic, Christophe Yamahata, Mauricio Cordero, and Hiroyuki Fujita. JOURNAL OF MICROELECTROMECHANICAL SYSTEMS, VOL. 19, NO. 2, APRIL 2010.
4. Kim Won-Hyo, Park Joon-Shik, Shin Kyu-Shik, Park Kwang-Bum, Seong Woo-Kyeong, Moon Chanwoo. Simulation and fabrication of silicon micro-grippers actuated by piezoelectric actuator. Materials Science Forum 2005;475- 479:1885-8.
5. Kim CJ, Pisano AP, Muller RS. Silicon-processed overhanging microgripper. Journal of Microelectromechanical Systems 1992;1(1):31–6.
6. Beyeler F, Bell DJ, Nelson BJ, Sun Y, Neild A., Oberti S., et al., Design of a micro-gripper and an ultrasonic manipulator for handling micron sized objects. In: Proceedings of the 2006 IEEE/RSJ international conference on intelligent robots and systems; 2006. p. 772–7.
7. Kim Keekyoung, Liu Xinyu, Zhang Yong, Cheng Ji, Yu Wu Xiao, Sun Yu. Mechanical characterization of polymeric microcapsules using a force-feed- back MEMS microgripper. In: Proceedings of the International IEEE EMBS conference; 2008. p. 2845–8.
8. Carrozza MC, Menciassi A, Dario P. The development of a LIGA-microfabri- cated gripper for micromanipulation tasks. Journal of Micromechanics and Microengineering 1998:141.
9. W. S. N. TRIMMER and K. J. GABRIEL. Sensors and Actuators, 11 (1987) 189 – 206.
10. Wang Xinli et. al. 0-7803-7420-7/02/$17.00 © 2002 IEEE.
11. Nima Ghalichechian et. al. JOURNAL OF MICROELECTROMECHANICAL SYSTEMS, VOL. 17, NO. 3, JUNE 2008.

4/2/2013