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# MECHATRONIC SYSTEM INTEGRATING AN ELECTROMAGNETIC ACTUATOR WITH THE POSSIBILITY OF MOVING THE WORKING MICROSCOPIC TOOL AT SUBMICROMETRIC RESOLUTIONS

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**Abstract.** *The possibility to work by using small objects, under the microscopic view, it is a challenge. The force's spectrum differs from that of the macroscopic scale, and many unexpected force vectors will appear. A sharp tip must be the ideal pressure vector on different microscopic small object to push, roll, and brake and so on. The positioning of this tip must be a very precise one, comparatively with the working area dimensions and we consider that 10 microns can be a reasonable measuring unit for these moves that are executed into a specific way in these kinds of cases. The mechatronic system designed to actuate the tip, becomes this paper subject. Indisputable we will talk about an actuator with one or more than one freedom degrees. Mechanical aspects are secondary, but necessary to understand the impact of electrical parameters on the minimum possible unit of movement. Electronic control refers to a switching and PWM signal, through a software that develops both the effective part of generating the control signal and the HMI interface through a touch-screen. The aim of this paper was to determine the minimum micrometric travel distance that can be obtained with a 12-bit PWM signal generated by a Raspberry mini-computer*

**Keywords:** mechatronic system, actuator, magnetic, PWM, HMI, Raspberry

## 1. INTRODUCTION

The manipulation of objects at the microscopic level is required in many areas. Regardless of the field of application, the tool is microscopic [1] and its movement is microscopic. Decreasing the values of the positioning resolution means quantitatively ensuring as little displacement as possible at a possible unit control signal.

Micromanipulation can be of many kinds, applying optical, magnetic, electrical, acoustic, aerodynamic or mechanical principles. Optical handling is applicable in certain cases where small organic objects are attracted to the spotlight which is a real tractor beam. The accuracy of this type of micromanipulation can reach a level of angstroms and can provide calculation information for forces at the level of femtonewton. These limits allow the biological study of biological macromolecules, especially molecular engines, such as the movement of kinesin on fixed microtubules, but the most important aspect is that of key DNA studies [2]. All this optical effect of manipulation has its roots in Kepler's old observations, about 400 years ago, about the mechanical effects that light can have on matter. The study of these effects observed by Kepler was deepened by Maxwell in the 19th century and by Lebedev, Nichols and Hull in the early 20th century, reaching the concept of light pressure on matter at a certain level [3,4].

Micromanipulation reaches unimaginable heights when magnetic fields are applied to the microscale, achieving atomic manipulation with trapping on magnetized surfaces [5]. Electrical micromanipulation involves electric fields and electrified microbodies that can be guided by electrically manipulable field lines, micromanipulation procedures already established being dielectrophoretic in direct current and electro hydrodynamics in alternating electric field [6]. The vibration generated by the acoustics of a device leads to the orientation of micro-objects, according to a deterministic that includes the frequency of the sound wave [7]. This type of micromanipulation is suitable for micro assembly operations, respectively the relative preorientation of objects. But the most used form of micromanipulation is the mechanical one, more precisely with mechanical contact between two objects, respectively the tool object and the manipulated object.

Contact problems at this level of mechanical operation are generated by specific forces at the micro-contact, such as cohesion, adhesion and other specific forces. In this paper is presented an electronic solution that allows the operation of an actuator operable at the microscopic level with micrometric precision, at very low costs. The positioning accuracy of a working tool object must be equal to the unit of measurement of the dimensions of the working frames. Under the microscope, a working frame with dimensions of 200-300 micrometers is a common one. A motion resolution of about 1-5 micrometers becomes adequate, depending on the size of the objects handled. In order to obtain such a resolution, precisely settable from unit to unit, it is necessary that the actuator

tip positioning reserve be submicrometric, so that the set nominal resolution is accurate and reproducible.

## 2. ACTUATOR DESCRIPTION

The actuator is an electro-mechanical one, with the use of the magnetic field to generate a pushing force of a permanent magnet attached to a mechanical elastic arm. By the magneto-mechanical balance maintained by the current in the coil, a certain position in space of the displaced peak is reached. This position is unique and depends on the electric power developed by the coil field.

The electric power is a product between the voltage applied to the coil terminals and the absorbed current, and the value of the electric power will be associated by a biunivocal connection with the value of the displacement of the actuator arm with respect to an equilibrium position. Figure 1 shows schematically the actuator system.

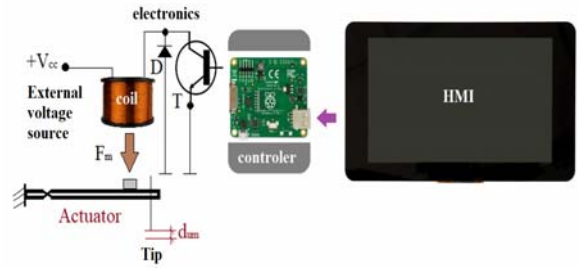



**Figure 1. Mechatronic system**

As can be seen, the magnetic field generator coil is powered by an external voltage source, but its amplitude, although fixed, will be modulated by a switching transistor. The switching transistor is controlled by PWM (Pulse Width Modulation) signal, a signal generated by the Raspberry mini-computer, with a resolution corresponding to a 12-bit register, with 4096 sampling intervals. Thus, it became possible to discretize the maximum stroke in a number of 4096 quasi-equal displacements. The actuator has a series of mechanical constants that depend on the geometric construction of the arm and the material from which it is made. The magnetic field generated by the coil is dimensioned so as to allow sufficient deformation power of the arm (Figure 2), over an interval of approximately 200 micrometers, as the maximum bending arrow. The goal is to obtain a displacement of the tip of the submicrometric actuator.



**Figure 2. Actuator arm**

As shown in Figure 2, the actuator arm has a section reduction in the vicinity of the fixing / embedding area, the size of which adjusts its elasticity as a whole. The material of the arm used is metallic, the arm being obtained by rapid prototyping on a titanium oxide bed.

The permanent magnet is placed in the circular slot, which is secured to the actuator arm. The place where the magnet is placed determines the bending moment arm, whose actuating force is the magnetic force generated by the coil. Thus, the actuator becomes the subject of a bending process of a metallic element with constant elasticity, by means of a variable bending moment, variability conferred exclusively by the size of the magnetic force of the coil, because the arm of the mentioned moment is constant

## 3. EXPERIMENTAL SET-UP AND WORKING MODE

In Figure 3. the elements of the experimental set-up are presented: (1) The actuator used is also shown in Figure 4 in detail; (2) External DC voltage source; (3) Digital microscope with measurement software at a resolution of 0.44 micrometers / pixel; (4) Oscilloscope for accurate determination of PWM signal frequency and fill factor; (5) User interface with the possibility to set the signal frequency and the filling factor; 6) PC; 7) High diagonal and high-resolution monitor.

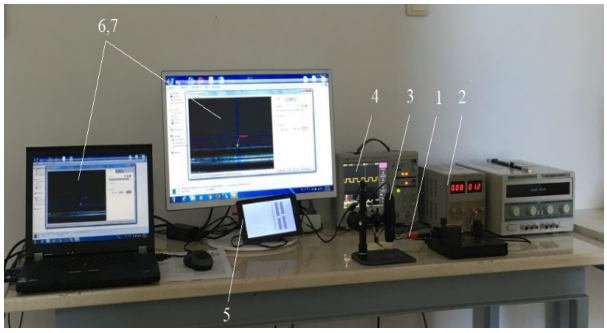



**Figure 3. Experimental set-up**

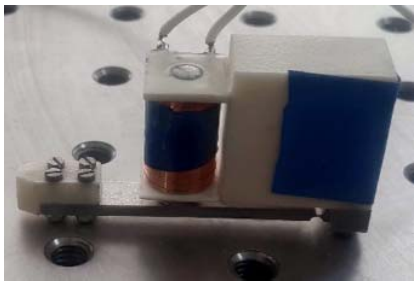


**Figure 4. Actuator used**

The tip positioned by the microscope is a glass tube with a precise size of the diameter, respectively 420 micrometers. Why glass? Because at a certain illumination of the scene, due to the translucency, a thin, fine and easily detectable edge is obtained, with a representation of few pixels, which immediately allows any movement from one position to another.

The measurement software allows the precise calibration of the optical scene to determine the distance between two points of the screen. For the present case, the calibration of the working space is 0.44 micrometers / pixel, a value that theoretically ensures the measurement of submicrometric displacements. The uncertainty of the determinations was of maximum 2 pixels, which allowed the detection of submicrometric displacements. The measurement of a displacement is done with the help of

successive sliders that allow the edge to be scored before and after the movement, the distance between the sliders resulting directly in micrometers. The thickness of the cursor line is reduced to 3 pixels and is very visible on the black background of the scene, next to the translucent edge of the glass tube that represents the microscopic object moved by the actuator.

The oscilloscope allowed the precise passage of the modulation interval.

The external source of direct voltage allowed the visualization of the current absorbed only at the level of tens of milliamperes. In order to arrive at milliampere units or hundreds / tens / units of microamperes where appropriate, a precise multimeter not shown in the figure in Figure 3 was used. A second multimeter, equally accurate, was used to determine the voltage of at the coil terminals at the tenth volt level.

## 4. RESULTS

Table 1 shows selected experimental values, obtained after the 0-5V D.C. interval, by applying a frequency of 5 kHz and a series of filling factors between 0 and 100%.

**Table 1. Selected experimental values**

| Nr. Crt. | $U_{IN}$ [V] | $I_{IN}$ [mA] | Displacement [µm] | $P_e$ [mW] |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |
| 1 | 0,1 | 5 | 13 | 0,5 |
| 2 | 0,6 | 30 | 29 | 18 |
| 3 | 1 | 50 | 41 | 50 |
| 4 | 1,4 | 70 | 62 | 98 |
| 5 | 2 | 100 | 79 | 200 |
| 6 | 2,5 | 125 | 104 | 312,5 |
| 7 | 3 | 150 | 123 | 450 |
| 8 | 3,4 | 175 | 139 | 595 |
| 9 | 4 | 200 | 165 | 800 |
| 10 | 4,6 | 230 | 184 | 1058 |
| 11 | 5 | 250 | 215 | 1250 |

Figure 5 shows the graph of the Current-Displacement function with the data from Table 1. The linear regression function was also extracted, which allows the analytical approximation of the dependence between the two mentioned quantities.

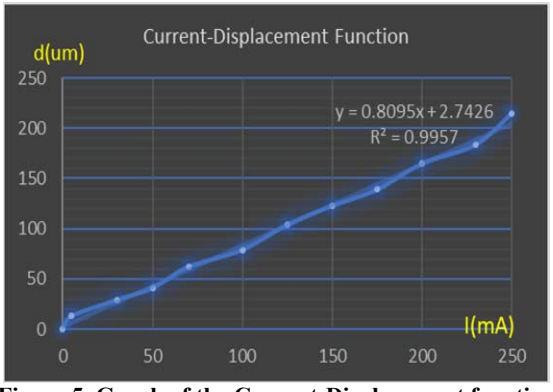



**Figure 5. Graph of the Current-Displacement function**

The lowest displacement detected was 1.32 um according to the deductive calculations of the measurement software, at a filling factor of 19 out of 4096, with an absorbed current of 60 µA and a voltage of 1.2 mV.

## 5. CONCLUSIONS

The goal proposed at the beginning of this work was achieved, that of determining the smallest possible displacement, detectable and submicrometric. The submicrometric displacement reserve exists, because 18 distinct values are also applicable to the filling factor, compared to the reference value 19 at which a smaller displacement was detected at this optics. Thus, an electronically assisted machine was created for the generation of movements around 1 micrometer, with possibilities to cover and some submicrometric distances, through the numerical reserve of the system.

The device is useful for working under a microscope for various categories of biomedical researchers or in micro assembly. From an economic point of view, after the stage of development of the industrial product, the system would not exceed estimated material costs higher than 500 euros, which can place this type of device among the equipment where the price-quality ratio is very high.

## REFERENCES

[1] Dholakia, Kishan, Peter Reece, and Min Gu. "Optical micromanipulation." *Chemical Society Reviews* 37.1 (2008): 42-55.

[2] Dholakia, Kishan, and Peter Reece. "Optical micromanipulation takes hold." Nano today 1.1 (2006): 18-27.

[3] P.N. Lebedev, Ann. Phys., 6 (1901), p. 433.

[4] E.F. Nichols, G.F. Hull Phys. Rev., 13 (1901), p. 301.

[5] Reichel, J., W. Hänsel, and T. W. Hänsch. "Atomic micromanipulation with magnetic surface traps." *Physical Review Letters* 83.17 (1999): 3398.

[6] Velev, Orlin D., and Ketan H. Bhatt. "On-chip micromanipulation and assembly of colloidal particles by electric fields." *Soft Matter* 2.9 (2006): 738-750.

[7] Baudoin, Michaël, and J-L. Thomas. "Acoustic tweezers for particle and fluid micromanipulation." *Annual Review of Fluid Mechanics* 52 (2020): 205-234.