Electromagnetic Linear Micro Drives for Braille Screen: Characteristics, Control and Optimization

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Abstract: The graphical interfaces based on visual representation and direct manipulation of objects made the adequate use of computers quite difficult for people with reduced sight. A new type graphical Braille screen is developed. Permanent magnet linear actuator intended for driving a needle in Braille screen has been optimized. Finite element analysis, response surface methodology and design of experiments have been employed for the optimization. The influence of different parameters of the construction of a recently developed permanent magnet linear electromagnetic actuator for driving a needle in a Braille screen is discussed. The static force characteristics and magnetic field distribution is studied when varying the parameters.

1 INTRODUCTION

Permanent magnets have been intensively used in the constructions of different actuators in recent years. One of the reasons for their application is the possibility for development of energy efficient actuators. New constructions of permanent magnet actuators are employed for different purposes. One such purpose is the facilitation of perception of images by visually impaired people using the so called Braille screens.

Recently, different approaches have been utilized for the actuators used to move Braille dots (Nobels, et al., 2002; Cho, et al., 2006; Hernandez, et al., 2009; Green, et al., 2006; Chaves, et al., 2009; Kwon, et al., 2008; Kato, et al., 2005; Kawaguchi, et al., 2010). A linear magnetic actuator designed for a portable Braille display application is presented in (Nobels, et al., 2002). Actuators based on piezoelectric linear motors are given in (Cho, et al., 2006; Hernandez, et al., 2009). A phase-change microactuator is presented in (Green, et al., 2006) for use in a dynamic Braille display. Similar principle is employed in (Chaves, et al., 2009), where actuation mechanism using metal with a low melting point is proposed. In (Kwon, et al., 2008), Braille code display device with a poly-dimethylsiloxane membrane and thermopneumatic actuator is presented. Braille sheet display is presented in (Kato, et al., 2005) and has been successfully manufactured on a plastic film by integrating a plastic sheet actuator array with a high-quality organic transistor active matrix. A new mechanism of the Braille display unit based on the inverse principle of the tuned mass damper is presented in (Kawaguchi, et al., 2010).

Different electromagnetic actuators have been studied by the authors in (Yatchev, et al., 2011c; Karastoyanov, 2010; Karastoyanov, Simeonov, 2010; Karastoyanov, Simeonov, et al., 2010; Karastoyanov, Yatchev, et al., 2011).

In the present paper, recently developed permanent magnet linear actuator for driving a needle (dot) in Braille screen is studied and its magnetic field and static force-stroke characteristics have been obtained using the finite element method (Yatchev, et al., 2011a; Yatchev, et al., 2011b).

2 ACTUATOR CONSTRUCTION

The principal actuator construction is shown in Figure 1. The moving part is axially magnetized cylindrical permanent magnet.

The two coils are connected in series in such way that they create magnetic flux of opposite directions in

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the region of the permanent magnet. In this way, depending on the polarity of the power supply, the permanent magnet will move either up or down. When motion up is needed, the upper coil should create flux in the air gap coinciding with the flux of the permanent magnet. Lower coil at the same time will create opposite flux and the permanent magnet will move in upper direction. When motion down is needed, the polarity of the power supply is reversed. The motion is transferred to the Braille dot using non-magnetic shaft, not shown in Figure 1.

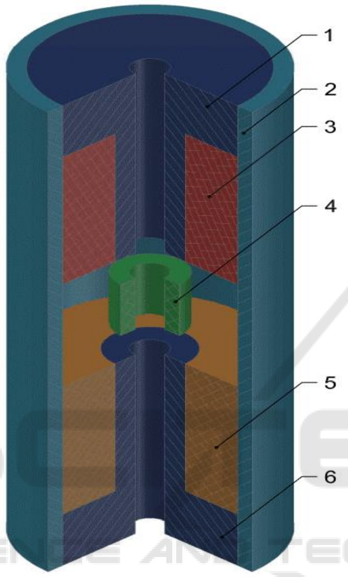

Figure 1: Principal construction of the studied actuator. 1 – upper core; 2 – outer core; 3 – upper coil; 4 – moving permanent magnet; 5 – lower coil; 6 – lower core.

The actuator features increased energy efficiency, as the need of power supply is only during the switching between the two end positions of the mover. In each end position, the permanent magnet creates holding force, which keeps the mover in this position.

3 STATIC FORCE CHARACTERISTICS

The static force characteristics are obtained for different construction parameters of the actuator. The outer diameter of the core is 7 mm. The air gap between the upper and lower core, the length of the permanent magnet and the coils height has been varied.

In Figures 2–5, the force-stroke characteristics are given for different values of the permanent magnet height *hm*, coil height hw, magnetomotive force *Iw* and apparent current density in the coils *J*. With c1 and c2, supply of the coils is denoted. The notation “c1 = –1, c2 = 1” means supply for motion up; “c1 = 1; c2 = –1” means supply for motion down, while “c1 = 0, c2 = 0” means no current in the coil, i.e. this is the force due only to the permanent magnet.

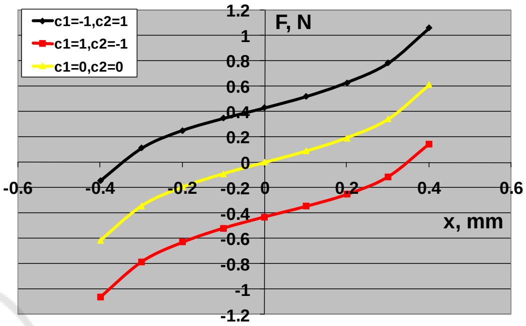

Figure 2: Force-stroke characteristics for *hm* = 2mm, δ = 3mm, *hw* = 5mm, *Iw* = 180A, *J* = 20A/mm^2.

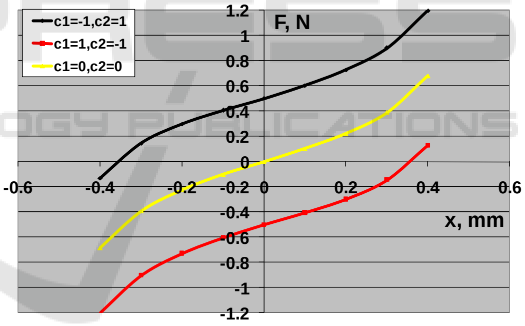

Figure 3: Force-stroke characteristics for *hm* = 3mm, δ = 4mm, *hw* = 5mm, *Iw* = 180A, *J* = 20A/mm^2.

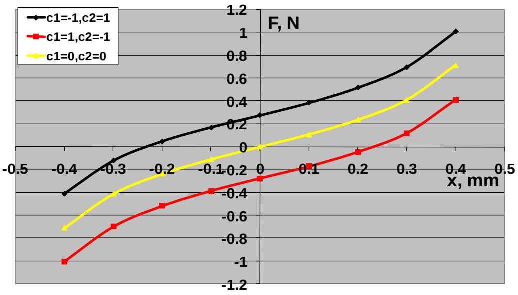

Figure 4: Force-stroke characteristics for *hm* = 4mm, δ = 5mm, *hw* = 5mm, *Iw* = 90A, *J* = 10A/mm^2.

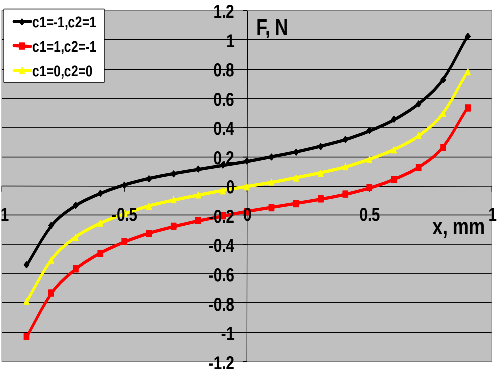

Figure 5: Force-stroke characteristics for *hm* = 2mm, δ = 5mm, *hw* = 10mm, *Iw* = 180A, *J* = 10A/mm^2.

As seen, the major part of the characteristics is suitable for Braille screen application.

4 OPTIMIZATION

The objective function is minimal magneto motive force of the coils. The optimization parameters are dimensions of the permanent magnet, ferromagnetic discs and the cores. As constraints, minimal electromagnetic force acting on the mover, minimal starting force and overall outer diameter of the actuator have been set. The optimization is carried out using sequential quadratic programming, (Yatchev, Karastoyanov, 2012).

The canonic form of the optimization problem is:

$$\min\{NI\}$$

$$\left|\begin{array}{c} 5 \le hw \\ 0.5 \le hm \\ 0.3 \le hd \\ 0 \le J \le 25A/mm2 \\ Fh \ge 0.3N \\ Fs \ge 0.05N \end{array}\right.$$

where:

- *NI* — ampere-turns — minimizing energy consumption with satisfied force requirements;
- *Fh* — holding force — mover (shaft) in upper position, no current in the coils;
- *Fs* — starting force — mover (shaft) in upper or lower position and energized coils;
- *J* — coils current density;
- *hw*, *hm*, *hd* — geometric dimensions.

Minimization of magneto-motive force *NI* is direct subsequence of the requirement for minimum energy consumption.

Constraints for *Fs* and *Fh* have already been discussed. The lower bounds for the dimensions are imposed by the manufacturing limits and the upper bound for the current density is determined by the thermal balance of the actuator.

The radial dimensions of the construction are directly dependent by the outer diameter of the core – D which fixed value was discussed earlier. The influence of those parameters on the behavior of the construction have been studied in previous works, that make clear that there is no need radial dimensions to be included in the set of optimization parameters.

The optimization is carried out by sequential quadratic programming. The optimization results are as follows:

$$NI_{opt} = 79.28\text{ A},$$
$$hw_{opt} = 5\text{ mm},$$
$$hm_{opt} = 2.51\text{ mm},$$
$$hd_{opt} = 1.44\text{ mm},$$
$$J_{opt} = 19.8\text{ A}$$

The optimal parameters were set as input values to the FEM model. The force-stroke characteristics of the optimal actuator are shown in Figures 6 and 7.

In Figures 8 and 9, the magnetic field of the optimal actuator is plotted for two cases.

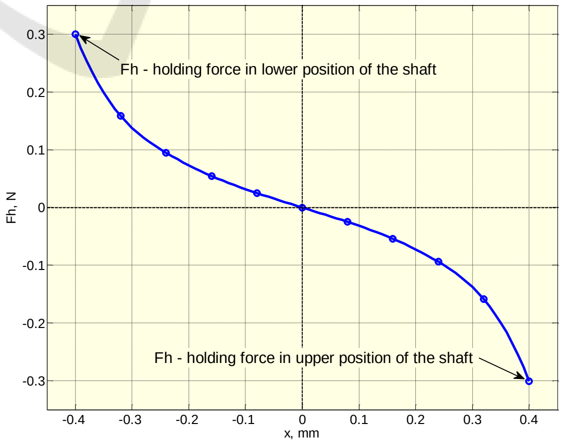

Figure 6: Force-stroke characteristic of the optimal actuator. The force is created by the permanent magnet only (no current in the coils).

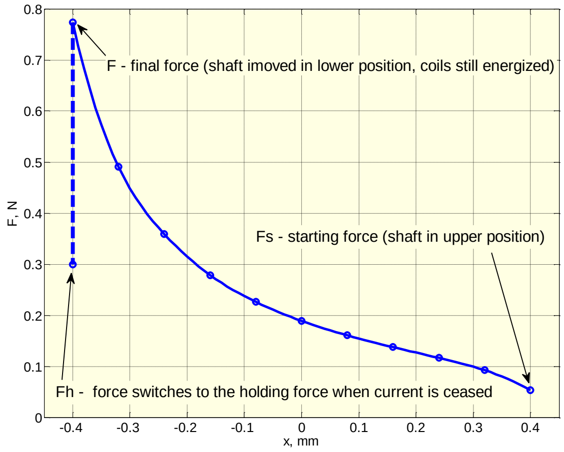

Figure 7: Force-stroke characteristic of the optimal actuator. Coils are energized. The shaft is displaced from final upper to final lower position.

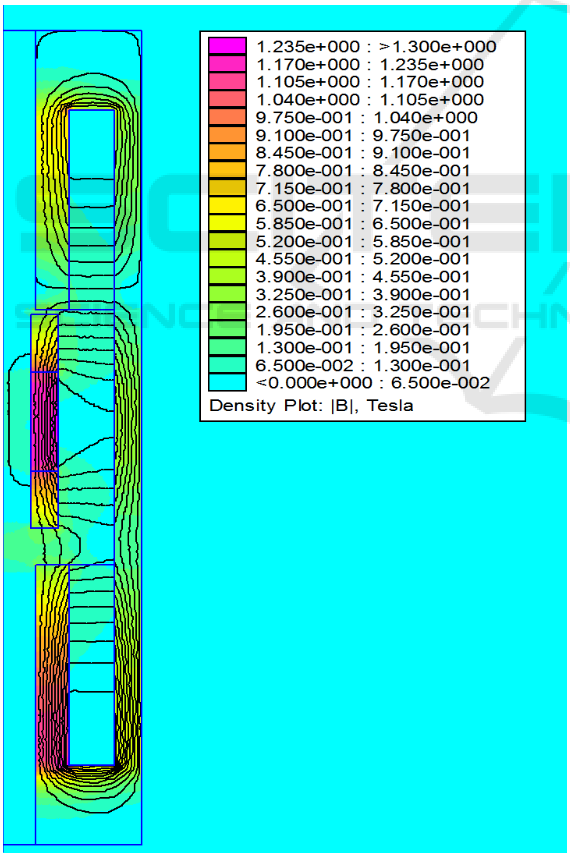

Figure 8: Magnetic field of the optimal actuator with shaft in upper position and coils energized to create downward force.

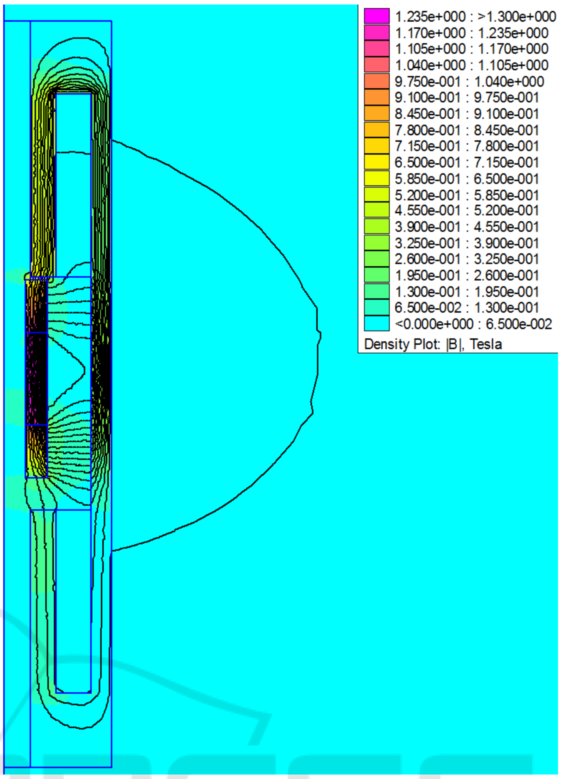

Figure 9: Magnetic field of the optimal actuator with no current in the coils.

The force constraints for *Fs* and *Fh* are active which can be expected when minimum energy consumption is required. The active constraint for *hw* is also expected because longer upper and lower cores size which respectively means longer coils will increase the leakage coil flux and corrupted coil efficiency.

5 CONTROL

The developed actuator has static force characteristics which are suitable for Braille screen application, as illustrated on Figure 10.

The employed approach has confirmed its robustness for solution to the optimization problem for the actuator. The obtained optimal solution satisfies the requirements for actuators for Braille screen. The presented variant of the linear electromagnetic actuator is energy efficient because of the impulse way of its work, (Balabozov, et al., 2012). All the three varied parameters influence the characteristics and especially the initial force, which is significant for these actuators.

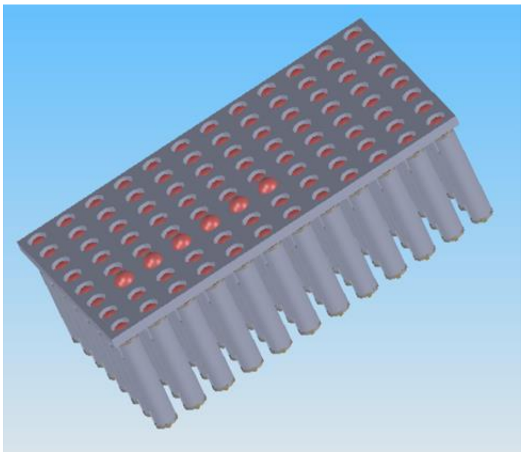

Figure 10: Braille screen with needles (dots) driven by linear actuators.

For better resolution of the graphical images the Braille screen must be larger, for example 96×64 linear micro drives (pixels). It is more than 6000 elements in human hand size with 4 coil connectors for each. In this case we need a strong electro-mechanical test of the entire circuit. We plan to use micro robots for positioning and testing, (Georgiev, et al., 2010; Genova, et al., 2010; Kotev, et al., 2011). We develop a smart micro robot with 3 DOF and piezo effectors, shown on Figure 11.

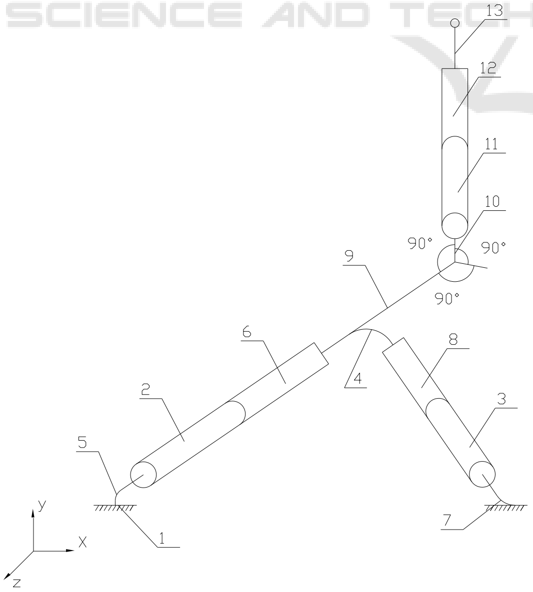

Figure 11: Micro manipulator with 3 degree of freedom and piezo effectors, where: 1 – base; 2, 3, 11 – mobile links; 4, 5, 7 – elastic connections; 6, 8, 12 – piezo actuators; 9, 10 – hard connections; 13 – sensing element.

6 CONCLUSION

Based on the results obtained the following conclusions can be drawn:

- The developed actuator has static force characteristics which are suitable for Braille screen application;
- Increasing the height of the coil has important influence on the force-displacement characteristics and the holding force. Above a certain value, thought, further increase does not lead to significant change;
- The maximal stroke influences more significantly the initial force than the holding one and its minimal value could be recommended;
- Higher outer diameter of the actuator leads to significant increase of both holding and initial force;
- Current density of 15 A/mm2 could ensure enough initial force at lower starting position of the mover.

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