Energy Efficient Electromagnetic Linear Drives for Braille Screen

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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. Within the European Union, the problem with the access of blind people to computer resources is quite pressing**.** A new type graphical Braiile sceen 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. Static force characteristics of recently developed permanent magnet linear actuator for driving a needle in Braille screen are presented.

Introduction

Within the European Union, the problem with the access of blind people to computer resources is quite pressing. Studies on European and world scale are carried out in many directions:

- A basic direction is the attempt for social integration of the visually impaired. Significant efforts are made in Germany. Since 2000, visually impaired students are tought in Informatics, Computer sciences and Computer systems. After 2007, students of other technical courses are also involved and even education in Architecture is planned;

- Development of Braille terminals and printers and adaptation to computer systems. Braille terminals and printers are produced by leading European and world companies in various sizes. The impediment here is the fact that there is no unified system for representation of graphical and mathematical elements. Braille terminals, however, are not widely used due to their high price and they are suitable only where there are mainly text interfaces – philology, judicial sciences, economics.;

- Since the communication man-computer was quite simple (mainly based on text instructions), solution of the problem was sought on the basis of voice synthesis or other forms of feedback [1]. These techniques have been developed before the graphical interfaces but they provide possibilities to form simple feedback to the user as voice commands. The existence of graphical interfaces and their establishment as standard made the interaction of visually impaired with computers very difficult.;

- Development of haptic interfaces based on electrically addressable and deforming polymer layer. Practically, the efforts are aimed at the manufacturing of a haptic dynamic input-output device allowing visually impaired people to obtain video information in other form. Technologically, the haptic devices provide great possibilities but the production of such terminal devices appears to be quite expensive at present. There are many problems with the 2D haptic representation of more complex geometrics models like images and space maps [2]. Generally, the haptic devices can apply force vector only at a single point of human body.

Special interfaces for the unsighted

The user interface should be regarded as part of the computer system through which the user comes into physical, conceptual contact on one hand and perceptive on the other hand. In computer sciences, the interface usually describes hardware and software components allowing the user to communicate with the computer system. The style of interaction with a computational system is a basic term describing the ways the user communicates and/or interacts with it. Generally, these are menus, direct manipulation of files and natural languages. The introduction of graphical user interfaces began as early as 1980 with the so called “pseudo-graphical representation” using auxiliary elements. After 1990, the graphical interfaces were introduced on a large scale not only for individual programs but also as means for effective management of the operation system resources. This refers not only for the massively adopted Windows OS but also for the intelligent interfaces of UNIX and Mac-OS.

From the point of view of the operation system, the interface is the highest level through which the communication man-computer is realized. The organization of the graphical operating structure of the interface, the positioning of the instructions, highlighted spaces, buttons, icons, etc. help the normally seeing users much more than before. The graphical structure of the interface is a powerful instrument. The computer mouse, as specialized input device, is the most helpful element for the use of this structure. As a result, the normally seeing people use much more often the mouse that the keyboard.

The introduction of the graphical interfaces, however, brought serious problems for the visually impaired people. The graphical interfaces based on the visual representation and direct manipulation with objects turned out to be a big obstacle for the unsighted people to effectively use computers. After 1990, the jobs of many visually impaired people were threatened with migration from textual to graphical interfaces in offices and companies. Actually, the investment in efforts the results of which will provide effective access to computers for people with reduced sight appears to be quite pertinent.

Permanent magnets

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 [3]. A linear magnetic actuator designed for a portable Braille display application is presented in [3]. Actuators based on piezoelectric linear motors are given in [4], [5]. A phase-change microactuator is presented in [6] for use in a dynamic Braille display. Similar principle is employed in [7], where actuation mechanism using metal with a low melting point is proposed. In [8], Braille code display device with a polydimethylsiloxane membrane and thermopneumatic actuator is presented. Braille sheet display is presented in [9] 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 [10].

Braille screen elements

We developed a matrix Braille screen with moving elements, giving graphical information for visually impaired people – fig. 1.
For each matrix element we have several variants, using the electromagnetic pole for moving elements.

Variant 1: Electromagnetic driven balls (shots), [11].

a) The magnetic field pull up the balls (with a spring for neutral position) – fig. 2

b) The magnetic field beat off the balls – fig. 3

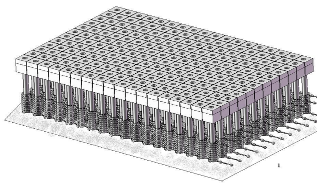

Fig. 1. Graphical Braille screen

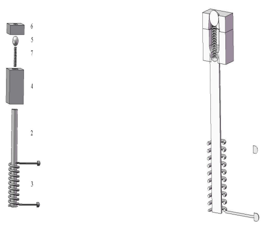

Fig 2. Actuators with springs

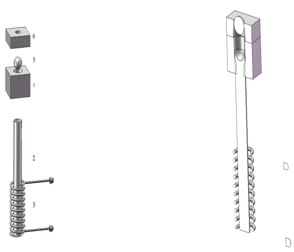

Fig. 3. The field beat off the balls

Variant 2: Rotating balls – each ball has North and South poles – fig. 4, [13].

Variant 3: Actuator with lifters and springs - fig. 5, [12].

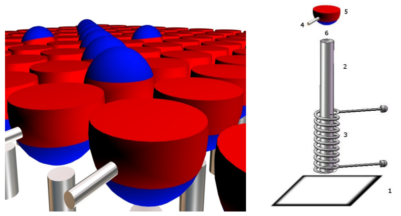

Fig. 4. The magnetic field rotates the balls

Fig.5. The pixel lifted and held by the spring

The finite element method for solving nonlinear magnetostatic problems with axial symmetry is employed. The computations are carried out using the program FEMM. The force on the mover is obtained using the weighted stress tensor approach. For automation of the computations, Lua Script® is employed, [15]. For cost, power and force reasons we developed a combined actuator construction, [14]. 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, [16]. The static force characteristics are obtained for different construction parameters of the actuator. The air gap between the upper and lower core, the length of the permanent magnet and the coils height have been varied, [16].

Actuator construction

The principal actuator construction is shown in Fig. 6. 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 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 Fig. 6

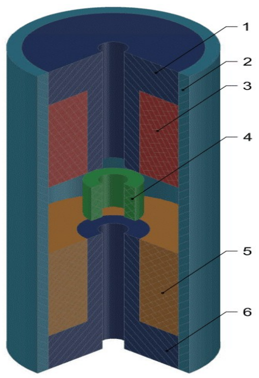

Fig. 6. Principal construction of the studied actuator
1 – upper core; 2 – outer core; 3 – upper coil; 4 – moving magnet; 5 – lower coil; 6 – lower core

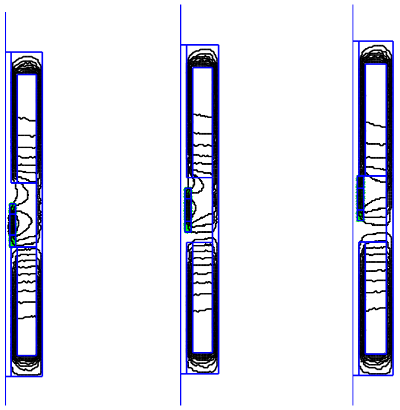

Figure 7. Typical flux lines distribution for three different mover positions

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

Finite element modelling

Magnetic field of the actuator is modelled using the finite element method and the program FEMM [16], [17]. For speeding-up the computations, Lua Script® is employed. Axisymmetric model is adopted as the actuator feature rotational symmetry. The electromagnetic force acting on the moving permanent magnet is obtained using the weighted stress tensor approach.

An example of the flux lines distribution is shown in Fig. 7. In this case, the force on the magnet is in upward direction

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 have been varied.

In Figs. 8 and 9, 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. “c1=-1, c2=1” means supply for motion up; “c1=1;c2=-1” – motion down, “c1=0, c2=0” – no current in the coil, i.e. this is the force due only to the permanent magnet.

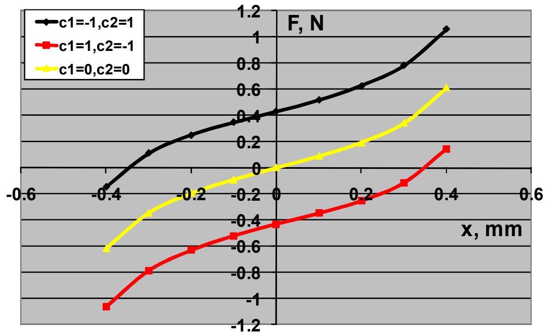

Fig. 8. Force-stroke characteristics for hm=2mm, δ=3mm, hw=5mm, Iw=180A, J=20A/mm^2

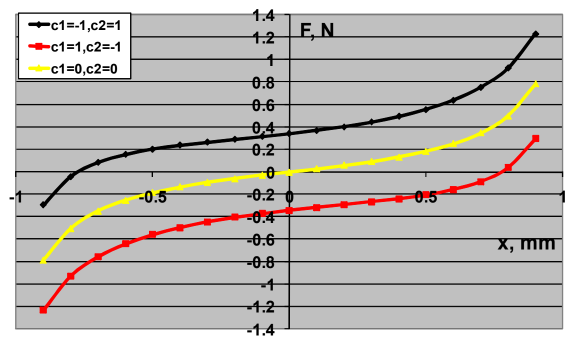

Fig. 9. Force-stroke characteristics for hm=4mm, δ=6mm, hw=5mm, Iw=180A, J=20A/mm^2

Optimization

The objective function is minimal magnetomotive 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.

The canonic form of the optimization problem is:

$\min \{NI\}$ $5 \le hw$, $0.5 \le hm$, $0.3 \le 0 \le J \le A/mm^2$, $Fh \ge 0.3$ N, $Fs \ge 0.05$ N , 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 work [17] 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 A, hw_{opt}=5 mm, hm_{opt}=2.51 mm, hd_{opt}=1.44 mm, J_{opt}=19.8 A

The optimal parameters were set as input values to the FEM model. The force-stroke characteristics of the optimal actuator is shown in fig. 10 and fig. 11.

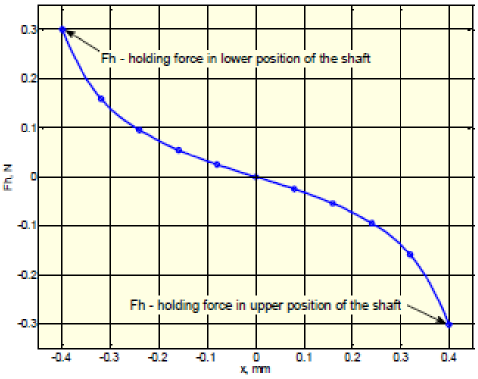

Fig 10: Force-stroke characteristic of the optimal actuator. The force is created by the permanent magnet only (no current in the coils).

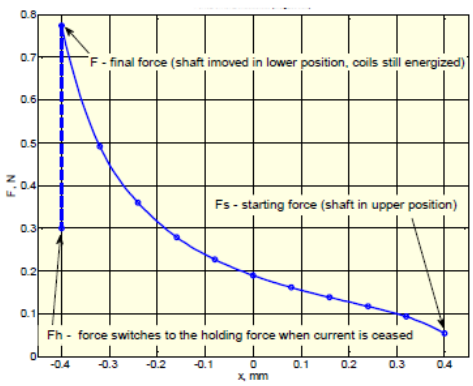

Fig 11. Force-stroke characteristic of the optimal actuator. Coils are energized. The shaft is displaced from final upper to final lower position.

In Figs. 12 and 13, the magnetic field of the optimal actuator is plotted for two cases. 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.

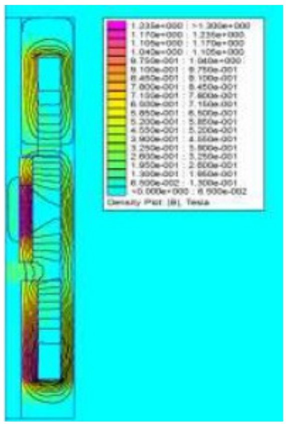

Fig 12: Magnetic field of the optimal actuator with shaft in upper position and coils energized

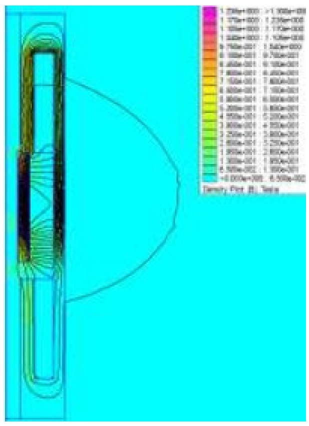

Fig 13: Magnetic field of the optimal actuator with no current in the coils.

Conclusion

The developed actuator has static force characteristics which are suitable for Braille screen application. 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.

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