

Static Force Characteristics of Electromagnetic Actuators for Braille Screen

Dedicated to Professor Slavoljub Aleksić on the occasion of his 60th birthday

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and Kristina Krasteva**

Abstract: Several constructions of electromagnetic actuators with moving permanent magnet for Braille screen are studied. All they are formed from a basic one that consists of two coils, core and moving permanent magnet. The finite element method is used for modelling of the magnetic field and for obtaining the electromagnetic force acting on the mover. The static force-stroke characteristics are obtained for four different constructions of the actuator. The constructions with ferromagnetic disc between the coils ensure greater force than the ones without disc and can reach the required minimum force.

Keywords: Linear actuators; permanent magnets; finite element method; Braille screen.

1 Introduction

THE DEVELOPMENT of electromagnetic actuators and the increasing demand for energy saving gave rise of intensive use of permanent magnets in different types of actuators. Design of new constructions is employed in wider areas. One such area is the facilitation of perception of images by visually impaired people using the so called Braille screens. In recent years, different approaches have been utilized for the actuators used to move Braille dots [1–9]. A linear magnetic actuator designed for a portable Braille display application is presented in [1]. Actuators based on piezoelectric linear motors are given in [2, 3]. A phase-change microactuator is presented in [4] for use in a dynamic Braille display. Similar principle

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is employed in [6], where actuation mechanism using metal with a low melting point is proposed. In [7], Braille code display device with a polydimethylsiloxane membrane and thermopneumatic actuator is presented. Braille sheet display is presented in [8] 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 [9].

In the present paper, several constructions of electromagnetic actuators with moving permanent magnet for Braille screen are studied using the finite element method and their force-stroke characteristics are obtained.

2 Studied Electromagnetic Actuators

The principal construction of the studied actuators consists of moving permanent magnet, two coils and ferromagnetic core. Two basic constructions of the actuators are studied - without and with ferromagnetic disc in the coil. They are denoted by variant 1 and variant 2. Each variant has two modifications - with outer yoke (a) and without outer yoke (b). Thus, four construction variants are formed. In Fig. 1 and Fig. 2, the principle constructions of the four variants are given.

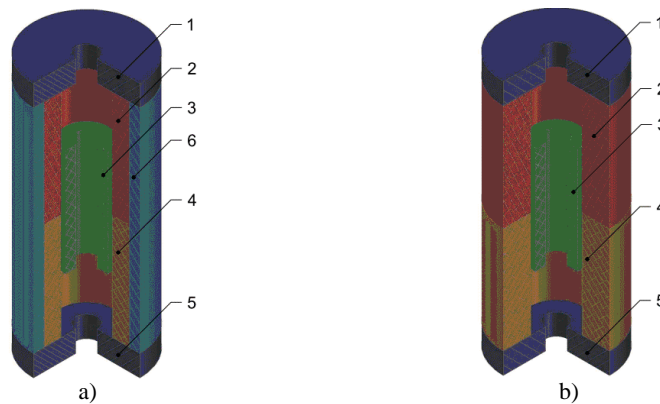


Fig. 1. Principal construction of variant 1: a) variant 1a; b) variant 1b. 1 - upper yoke; 2 - upper coil; 3 - moving magnet; 4 - lower coil; 5 - lower yoke; 6 - outer core.

The moving permanent magnet is NdFeB one and is magnetized axially. It is fixed on a driving nonmagnetic shaft, which is not shown in the figures.

The dimensions of the actuators are as follows: overall outer diameter: 5 mm; coil height: 5 mm; permanent magnet outer diameter: 2 mm; thickness of the upper and lower yoke: 2 mm; thickness of the outer core: 0.5 mm.

The two coils are connected in such way that they create opposite fluxes in

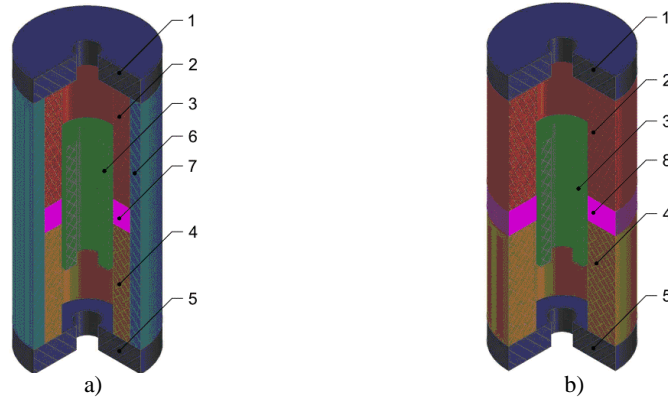


Fig. 2. Principal construction of variant 2: a) variant 2a; b) variant 2b. 1 - upper yoke; 2 - upper coil; 3 - moving magnet; 4 - lower coil; 5 - lower yoke; 6 - outer core; ; 7 - ferromagnetic disc.

their inner space. Thus, in both cases of power supply one of the coils creates flux coinciding with the magnet flux. We will consider the case, when the upper coil creates flux coinciding with the magnet flux, a case with positive coil current. The opposite supply will be a case of negative coil current.

3 Finite Element Modelling

For the magnetic field modelling of actuators, the finite element method and the program FEMM [10] are used. For speeding-up the computations, Lua Script is employed. Axisymmetric model is adopted as the actuators feature rotational symmetry. The electromagnetic force acting on the moving permanent magnet is obtained using the weighted stress tensor approach.

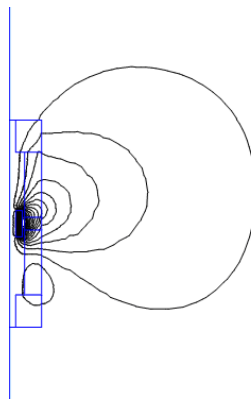


Fig. 3. Flux lines for variant 2b, symmetry position of the magnet and positive coil current.

An example of the flux lines distribution is given in Fig. 3. In this case, the force on the magnet is in upward direction.

4 Static Force Characteristics

The static force-stroke characteristics are obtained for the four construction variants. The results are obtained for different lengths of the permanent magnet and fixed apparent current density in the coils - 20 A/mm^2 .

The stroke is formed by taking minimal air gap of 0.1 mm and moving the magnet between the two yokes. The symmetry position (with equal air gaps on both sides of the magnet) is considered zero, thus the stroke is symmetrical about it. The stroke is thus different for the different magnet lengths but is always greater than the required minimum working stroke of 0.5-0.6 mm for actuators intended to move Braille dots. Thus the working stroke could be chosen appropriately within the whole possible stroke.

The force-stroke ($F - x$) characteristics for the four variants at positive coil current are given in Figs. 4-7.

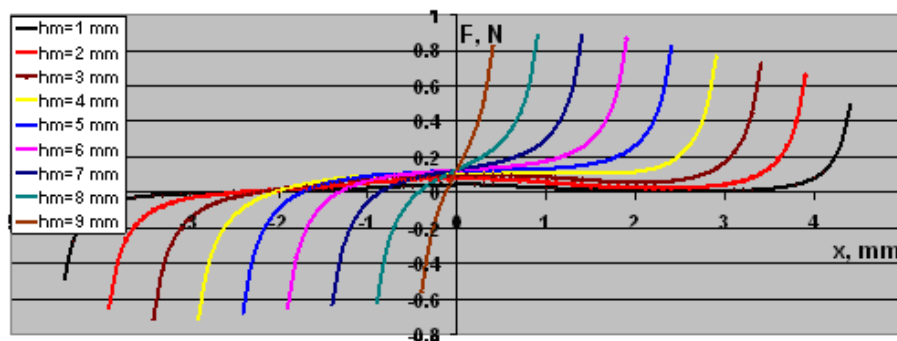


Fig. 4. Force-stroke characteristics of variant 1a at positive coil current and different magnet lengths.

The presence of outer core ("a" variants) does not influence significantly the force, in fact it leads to slightly smaller force than the variants without outer core ("b" variants) in the major part of the stroke. Outer core, though, could lower significantly the influence on neighbouring actuators - for a Braille screen there should be matrix of actuators.

In order to be able to estimate the actuator performance, also characteristics at negative coil current and without current are needed. In Figs. 8-11, the force-stroke characteristics without current in the coils (i.e. due only to the permanent magnet) are given.

For the last case, three different thicknesses of the ferromagnetic disc between

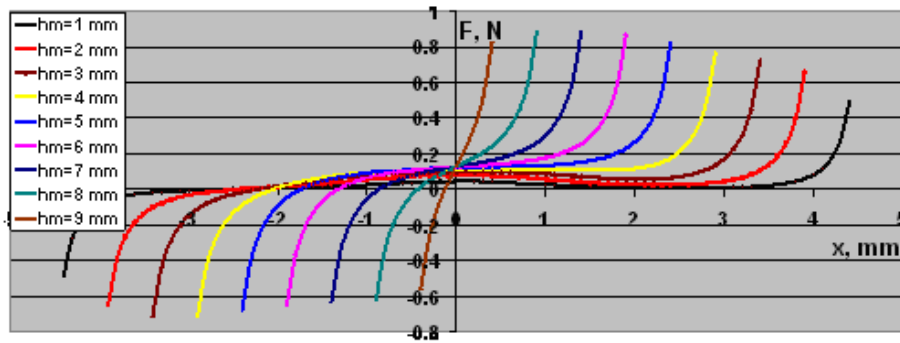


Fig. 5. Force-stroke characteristics of variant 1b at positive coil current and different magnet lengths.

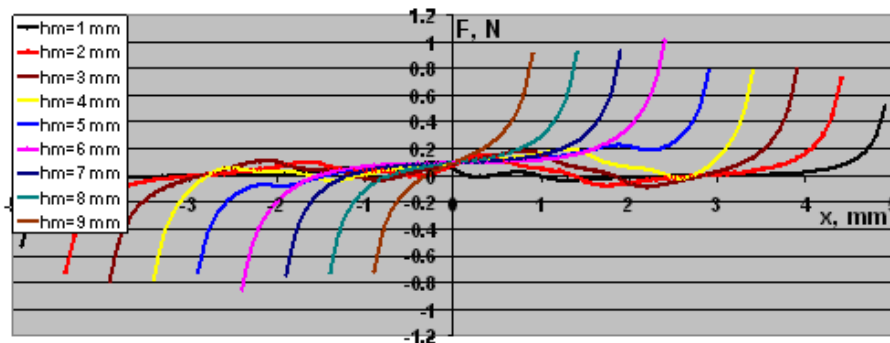


Fig. 6. Force-stroke characteristics of variant 2a at positive coil current and different magnet lengths.

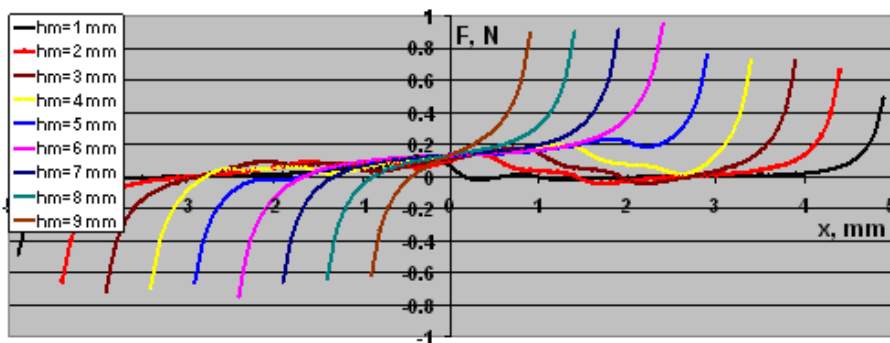


Fig. 7. Force-stroke characteristics of variant 2b at positive coil current and different magnet lengths.

the coils are studied (for all other cases, a thickness of 1 mm was used). The characteristics without current for three magnet lengths are shown in Figs. 12, 13 and 14.

The disc thickness influences more significantly the magnet force for the first two magnet lengths - 2 and 4 mm, while for 6 mm magnet the influence is in the

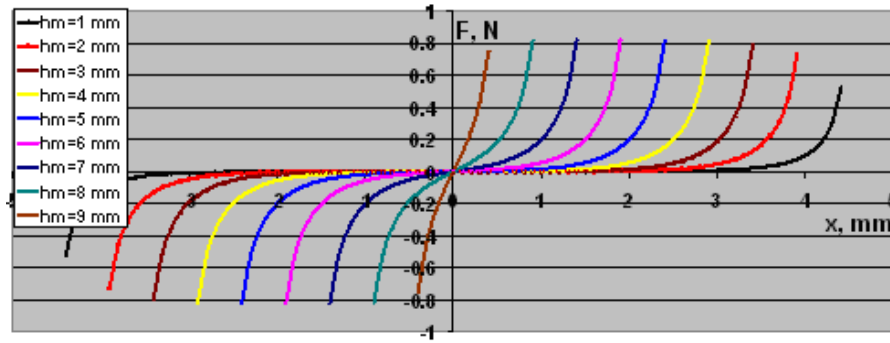


Fig. 8. Force-stroke characteristics of variant 1a without current for different magnet lengths.

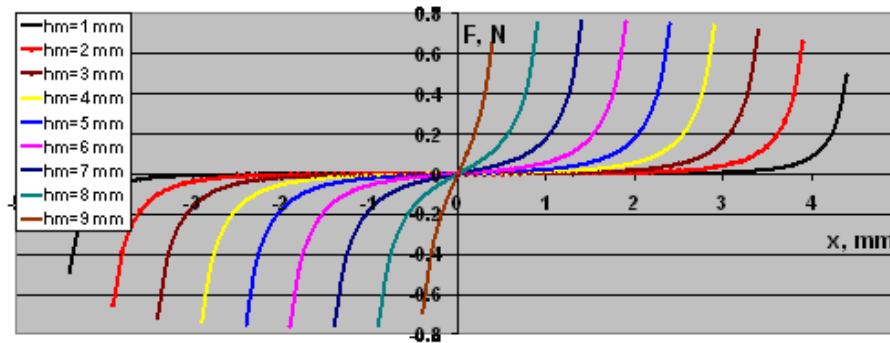


Fig. 9. Force-stroke characteristics of variant 1b without current for different magnet lengths.

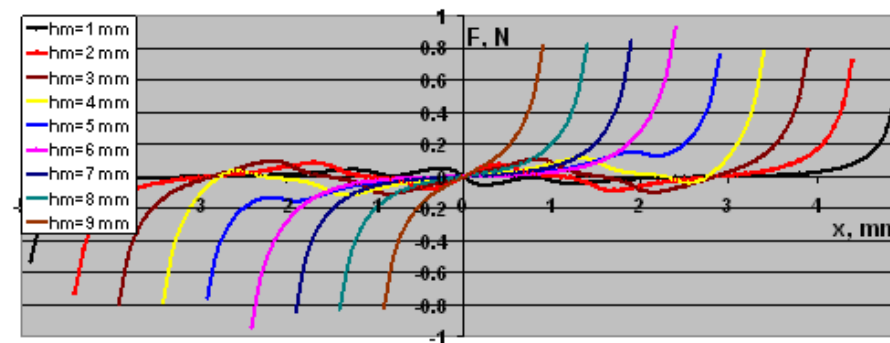


Fig. 10. Force-stroke characteristics of variant 2a without current for different magnet lengths.

end zones of the stroke. The characteristics with negative coil current (denoted by "c1=1,c2=-1" in the subsequent figures) are given together with these for positive current ("c1=-1,c2=1") for three magnet lengths for construction variants 1a and 2a in Figs. 15-20.

As pointed out before, the characteristics for "b" variants - without outer core

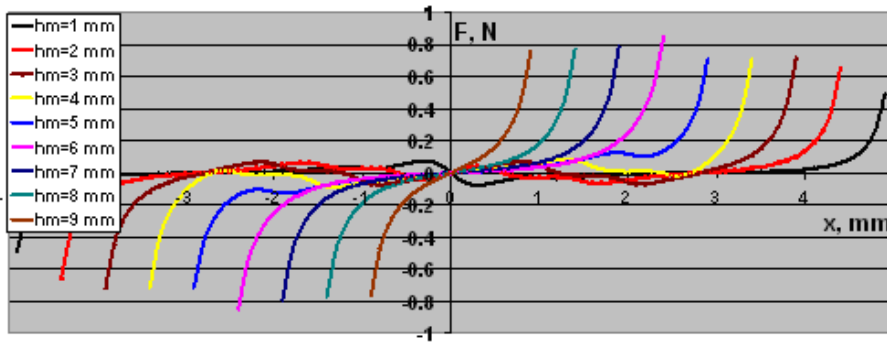


Fig. 11. Force-stroke characteristics of variant 2a without current for different magnet lengths.

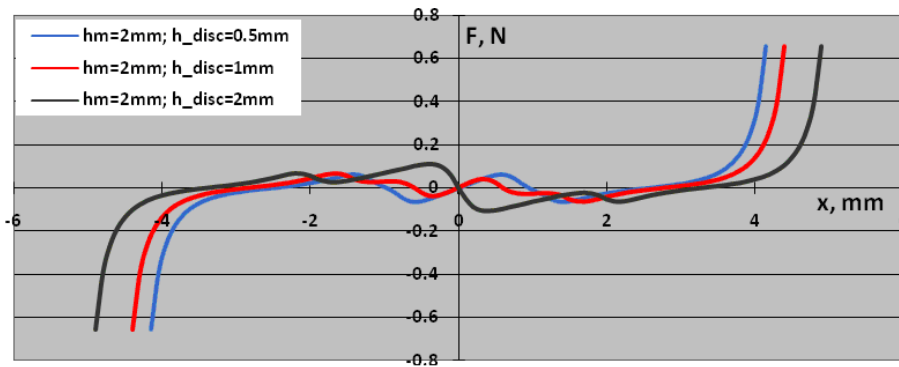


Fig. 12. Force-stroke characteristics of variant 2b, 2 mm magnet, without current, for different disc thickness.

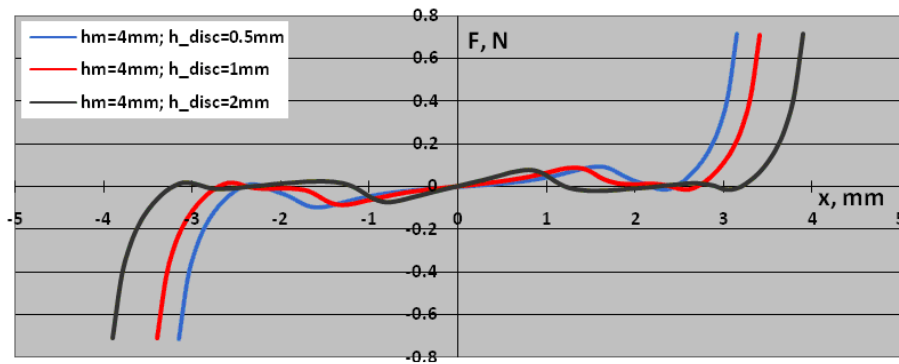


Fig. 13. Force-stroke characteristics of variant 2b, 4 mm magnet, without current, for different disc thickness.

- are very close the ones with outer core. In the characteristics for variant 2b for 2 and 4 mm magnet (Fig. 18 and Fig. 19), the influence of the ferromagnetic disc in

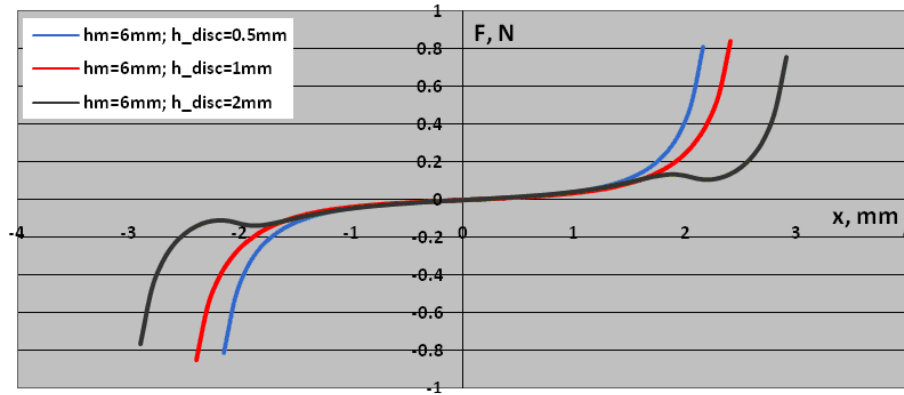


Fig. 14. Force-stroke characteristics of variant 2b, 6 mm magnet, without current, for different disc thickness.

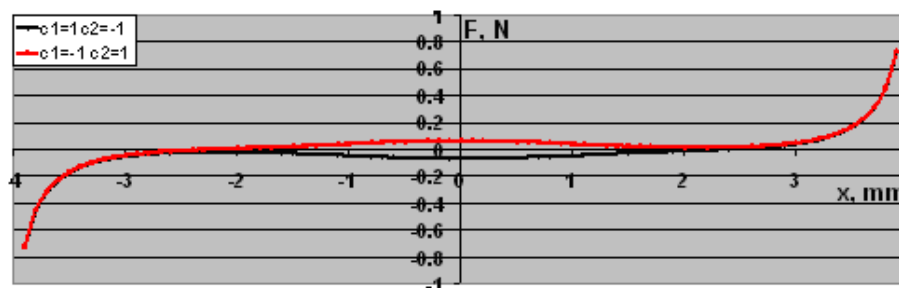


Fig. 15. Force-stroke characteristics of variant 1a, 2 mm magnet, for positive and negative current.

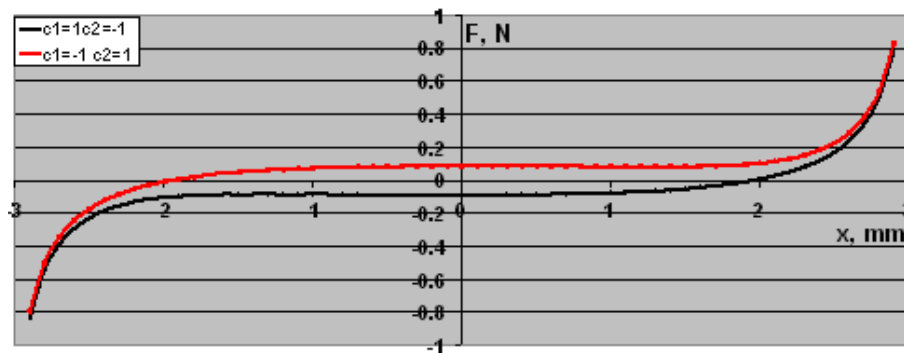


Fig. 16. Force-stroke characteristics of variant 1a, 4 mm magnet, for positive and negative current.

the coil is seen clearly, while for the 6 mm magnet (Fig. 20) the characteristic is similar to the one without disc in the coil (i.e. variant 1).

The working stroke of the actuator should be defined in such way that at each end position the permanent magnet to be able to create enough holding force and by

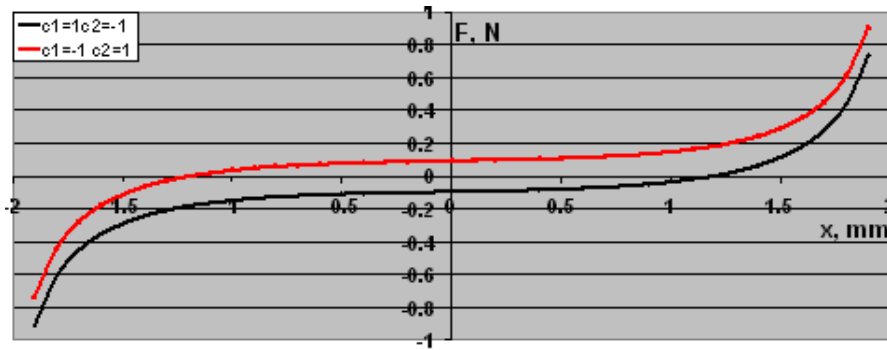


Fig. 17. Force-stroke characteristics of variant 1a, 6 mm magnet, for positive and negative current.

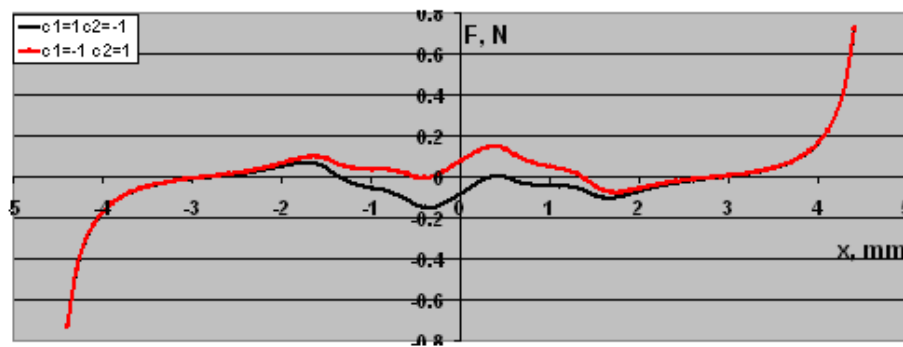


Fig. 18. Force-stroke characteristics of variant 2a, 2 mm magnet, for positive and negative current.

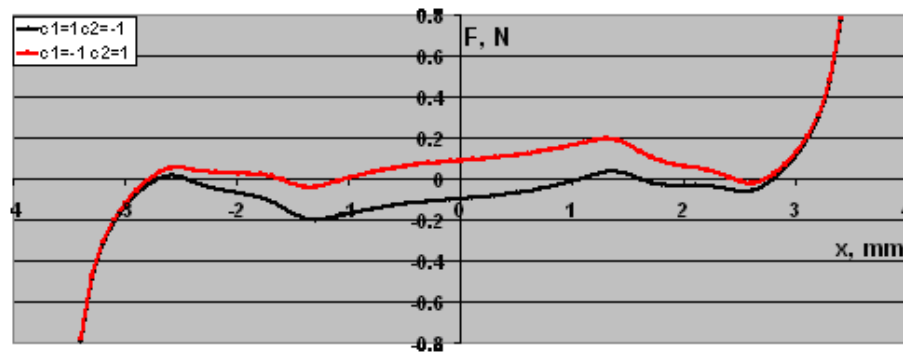


Fig. 19. Force-stroke characteristics of variant 2a, 4 mm magnet, for positive and negative current.

supplying the coils with the proper current, the magnet to move to the other end position. In most of the construction variants it is possible to find a stroke that fulfills these requirements. The value of the holding force for the suitable strokes, though, is below the recommended limit of 0.1 N, although there are variants, where its

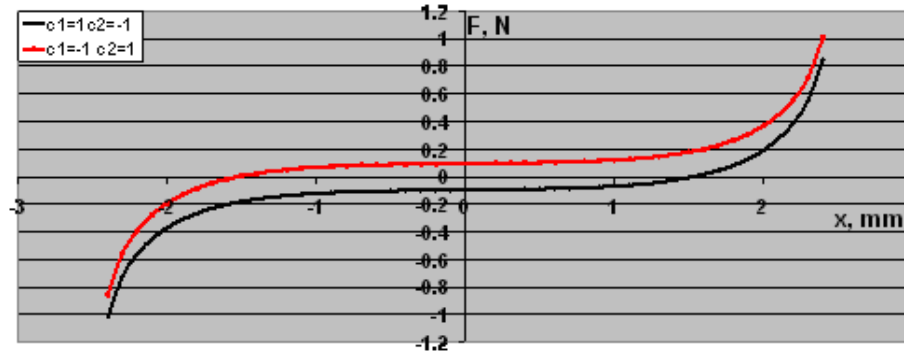


Fig. 20. Force-stroke characteristics of variant 2a, 6 mm magnet, for positive and negative current.

value is close to the limit. That is why further research could include optimization, with employing other geometric factors in addition to the magnet length and disc thickness.

5 Conclusion

Static force characteristics have been obtained for the different constructions of permanent magnet linear actuator for moving Braille dot in a Braille screen. The obtained results show that different characteristics could be obtained due to different magnet lengths, presence of ferromagnetic disc between the coils and its thickness. The presence of outer core does not influence significantly the characteristics of the actuator. It could be of help to avoid undesired magnetic field interfacing between adjacent actuators. Further research could include optimization with more geometric factors.

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