Design of high power density electromagnetic actuators for a portable Braille display

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Abstract:
To enable the use of computers for visually impaired people refreshable Braille displays are used. In general, they are large and expensive. This paper presents the design of a small and inexpensive linear electromagnetic actuator, which allows a considerable reduction of size and cost of refreshable Braille displays. The refreshable Braille display design resembles a classic computer mouse. The actuator concept is optimised using electromagnetic finite element simulations, which are verified by means of measurements on a prototype.

Introduction

The Braille alphabet is a tactile representation of the regular alphabet. An example of the sentence 'hello world' is given in **Fig. 1**. The objective is to develop a portable and inexpensive refreshable Braille display to disclose computer use for visually impaired people.

Refreshable Braille displays have been developed before e.g. [1], but they are bulky and expensive. Existing refreshable Braille displays consist of 20 to 80 Braille cells allowing one line of text to be shown at a time. The fingertips slide over the pins of the Braille cells, just as in "paper Braille". Small displays contain only a single or a few Braille cells with pins that push into the fingertips. They are not as successful as larger displays, probably because the human skin is more sensitive to lateral movement than to orthogonal pressure [2].

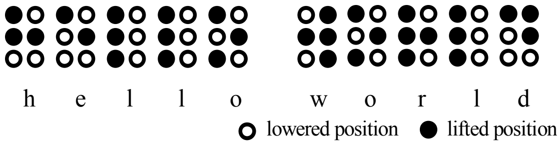

Fig. 1: *The Braille alphabet: example*

The refreshable Braille cell presented here consists of 8 pins in a 2 by 4 matrix, allowing eight-dot computer Braille (the lowest row are status pins). Each pin has two stable positions, a set or lifted position and a reset or lowered position and is actuated by a linear electromagnetic actuator.

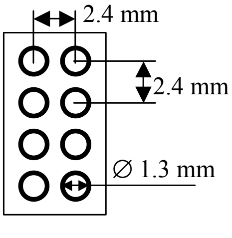

Fig. 2: *Dimensions of a computer Braille cell*

Design concept

The sensation of moving over a line of Braille characters without the need of a long and bulky linear display can be achieved with a rotating ring [3][4]. A ring on which Braille cells are located rotates inside a housing (**Fig. 3**). Only a single part of the ring can be 'read' in a window ('3 character display'), the remaining part of the ring is covered by the housing. The position of pins of the Braille cells that are covered by the housing is of no importance. But when the ring turns around, a new cell will enter the window. Just before this point, the Braille cells pins have to be set: all pins have to take a predetermined position according to a particular letter of the Braille alphabet (**Fig. 1**). Moreover, once a Braille cell is located in the window, pins should retain their position. After leaving the window, pins can be cleared. Their position is not important any more.

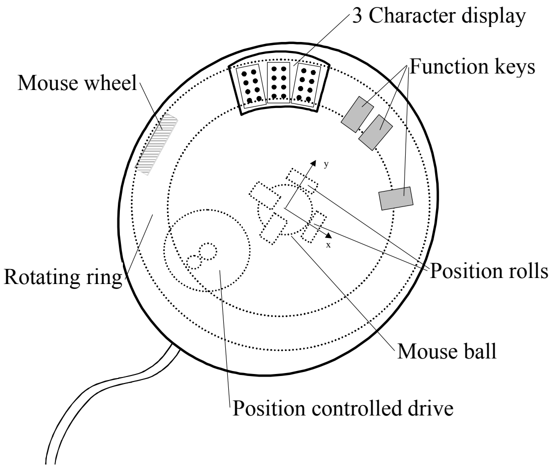

Fig. 3: *Design concept of a Braille mouse*

This design concept permits to split up functions: if every pin, attached to the rotating ring, can be made bi-stable, the actuation of the pins to change their position can be achieved separately from the rotating ring, i.e. fixed inside the housing. For this activation, less actuators are needed compared to classic refreshable Braille displays: eight actuators will be sufficient whereas about 600 actuators are required for a regular large display.

The objective is therefore to create a rotating ring with bistable pins. A holding force of 0.1 N was aimed at, as it is for piëzo-electric actuators in regular Braille displays [5]. The distance between two pins, which is 2.4 mm (**Fig. 2**), restricts the diameter of plungers. The vertical displacement of the pins should be at least 0.8 mm.

Creating stable positions

As the ‘holding’ does not need to be controllable, permanent magnets can be used to create the elevated and the lowered stable position. Different topologies of the ring acting as stator and the pins acting as plungers, are studied. **Fig. 4** and **Fig. 5** show two main designs.

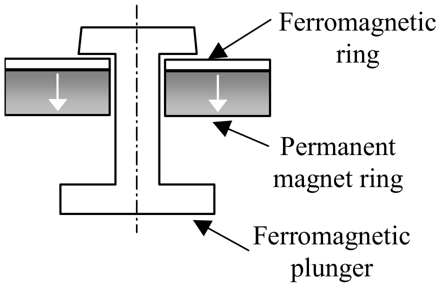

Fig. 4: *Design 1: holding mechanism with permanent magnet material attached to the stator*

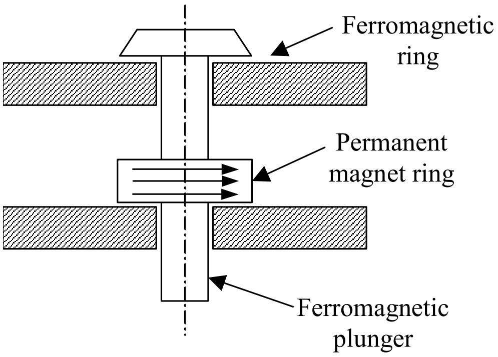

Fig. 5: *Design 2: holding mechanism with permanent magnet material attached to the plunger*

In the mechanism drawn in **Fig. 4**, the plungers and a top layer of the ring are constructed of soft magnetic material. The main part of the rotating ring consists of permanent magnet material. When a pin is in the elevated position, magnetic flux lines close through the pin and subsequent forces hold the pin in this position.

The mechanism of **Fig. 5** operates in a similar way. A small permanent magnet ring is associated to the pin. Both, the high and the low position are stable. Small, commercially available magnets – as used in watches – reduce material and production cost significantly. Therefore, this was the preferred design. The permanent magnet rings are glued to the pins, whereas the rotating ring consists of soft magnetic material.

Finite element simulations

The geometry of ring and plungers is optimised in order to achieve the specified holding force of 0.1 N. Simulations with static electromagnetic solvers based on the finite element method are performed to calculate the magnetic field and the resulting forces. Due to the cylindrical geometry of the pin, an axisymmetrical solver seemed preferable, but the transverse direction of magnetisation of the permanent magnets excluded this option. For this reason the geometry is modelled in two dimensions (**Fig. 6**).

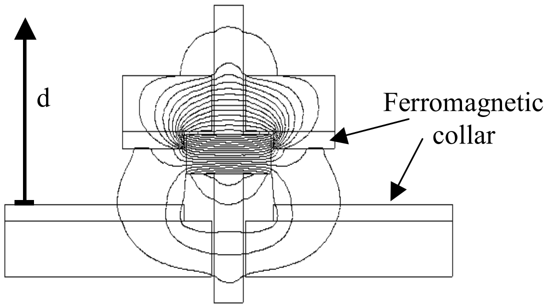

Fig. 6: *Magnetic flux lines in a 2D model of one pin*

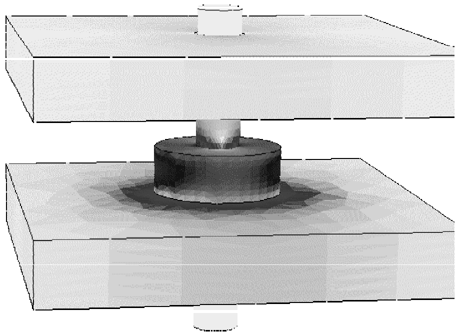

Fig. 7: *Flux density distribution in a 3D model of one pin*

The two-dimensional model of a single pin is simulated and optimised. The calculated results are based on unit problem depth. The solution of the optimised 2D model is compared with a threedimensional solution (**Fig. 7**) of the optimised geometry.

An extra ferromagnetic layer ('collar' on **Fig. 6**) was introduced on the stator in order to improve the holding forces.

Postprocessing on the solution of the magnetic field is performed in order to obtain the forces acting on the plungers. The enhanced Maxwell stress tensor method [6] is used to calculate the vertical forces acting on a single pin.

Fig. 8 and **Fig. 9** display the upward force as a function of the vertical position of the pin for both geometries, with and without collar.

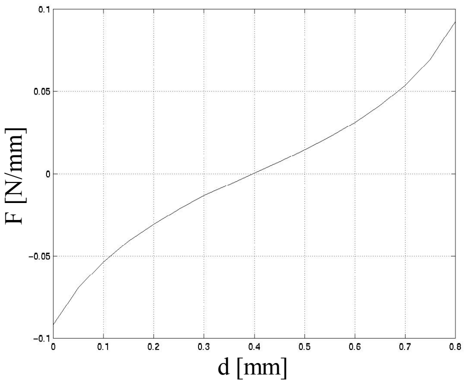

***Fig. 8:** Calculated force per problem depth F acting on a pin as a function of the position of the pin d without a collar (coordinate system see **Fig. 6**)*

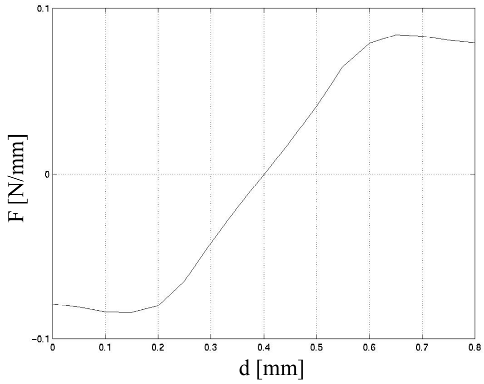

***Fig. 9:** Calculated force per problem depth F acting on a pin as a function of the position of the pin d with a collar(coordinate system see **Fig. 6**)*

As can be seen in the figures, the same maximum holding force is obtained in both cases. However, when a collar is present this force is reached at an earlier position, in both the lifted as well as in the lowered position. Moreover, for a slight movement of the plunger near the edge position, the second design offers an increased retaining force, as is revealed by **Fig. 9**.

Influence on neighbouring pins

Special attention is paid to the influence of a moving pin on its neighbours.

If one pin is moving, the pins closest to the moving pin may experience a force pulling them together with the moving pin. As a consequence, they might undesirably change their position.

A section (2D) of the real situation is simulated. **Fig. 10** shows the model, **Fig. 11** the calculated flux lines.

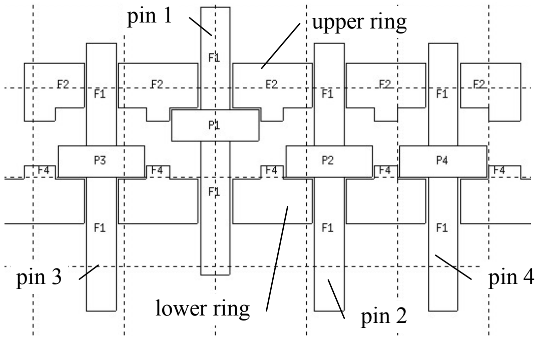

***Fig. 10:** Two-dimensional model of 4 Braille pins*

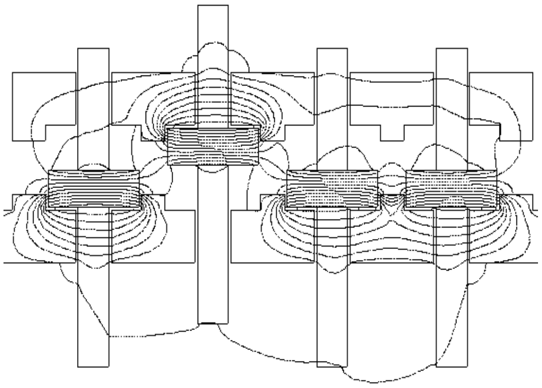

Fig. 11:** Magnetic flux lines in the model of **Fig. 10

This 2D simulation of a 3D problem is valid, because the 2D model covers the worst-case situation. Indeed, the attractive force between two neighbouring pins is at its maximum for the smallest distance between their magnets. However, this minimum distance between the two pins appears only at one point of the cylindrical magnet. In the 2D model on the other hand, this minimum distance is maintained over the whole unit depth the forces are calculated for.

Fig. 12 provides the results of this force calculation in the case that pin 1 moves, pin 2 occupies the elevated position while pin 3 and 4 are in the lowered position. The graph reveals that pins next to the moving pin experience a minor influence, but their position is not altered. Pins that are positioned further away do not undergo any influence.

The minor influence between neighbouring pins increases when the distance between upper and lower ring (**Fig. 10**) decreases. This effect is due to the height of the permanent magnets. When upper and lower ring come as close to each other in such a way that the PM overlap, influence between neighbouring pins will cause problems.

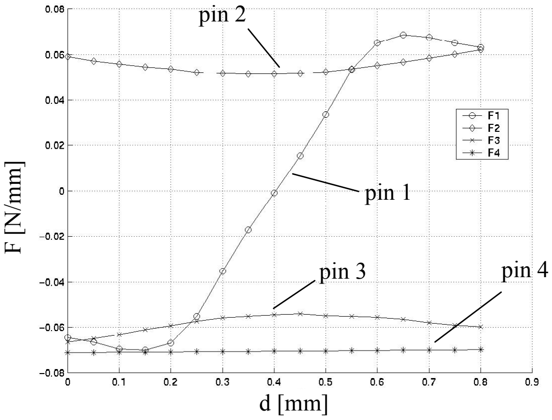

Fig. 12: *Force acting on the moving pin and the 'neighbour-pins' in lifted, respectively lowered position*

Verification

Based on the simulation results and the specifications of a Braille cell, all dimensions, e.g. the optimal height for the collar, are determined. A prototype for tests by visually impaired people is built (**Fig. 13**).

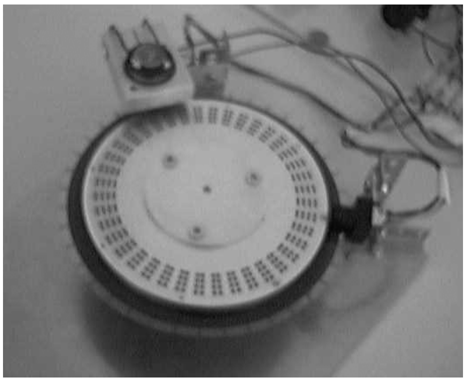

Fig. 13: *Prototype of the Braille ring (KULeuven)*

The measurements on this prototype are presented in **Fig. 14**. The upward force is measured as a function of the displacement of different pins starting from their top positions. Force measurements stop when the pin falls down. The graph proves that the specified holding force is obtained and that the simulation results are confirmed by the measurements.

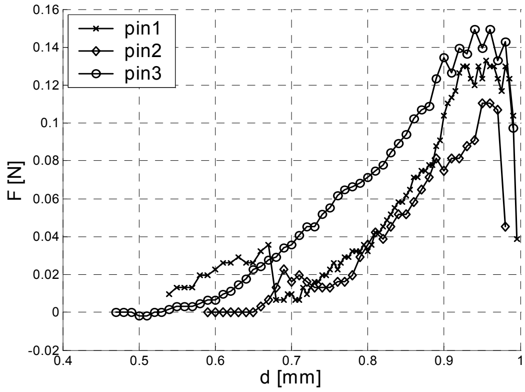

Fig. 14: *Force measurements*

Conclusions

A linear electromagnetic actuator has successfully been designed for a portable Braille display application. Holding forces in small linear actuators are limited by available energy density from permanent magnet materials. The paper illustrates the optimisation of high power density linear actuators in order to obtain maximum output forces by using the finite element models

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