STRUCTURAL OPTIMIZATION OF TACTILE DISPLAY ACTIVATED BY MAGNETORHEOLOGICAL FLUID

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Abstract

A tactile display is a programmable device whose controllable surface is intended to be investigated by human touch. The main work in this paper is to use a commercial finite element software ANSYS to simulate, analyze and optimize the magnetic field of the prototype of display incorporating magnetorheological fluid. The purpose of this research is to know the magnetic field distribution in the area around every individual tactel. Parameters such as the size of the magnet, the distance between the solenoid and its neighbour and input current are the control variables in the simulation which aims to get a strong and steady magnetic field on the tactels of the display.

1 Introduction

Recent research in virtual reality has recognized the need for more realistic tactile displays. A tactile display is a programmable device whose controllable surface is intended to be investigated by human touch, as a finger is dragged over it [1-2]. It has a great number of potential applications in the field of virtual reality and elsewhere. Mechanical vibration is the most common stimulus for tactile display. The vibration stimulus can be encoded according the physical characteristics such as position, frequency, strength and lasting time. A typical tactile display is an array of independently controllable actuator elements that are able to exert (or resist) forces in the direction normal to the user's skin surface. By proper control of these actuators, an impression, similar to that when an actual object is touched by human's finger, can be generated artificially. Researchers have proposed a wide variety of pin or vibrator arrays to present the sensation of 3 dimensional local shapes, fine textures, and slippage of grasped objects. These tactile displays use many actuating techniques, ranging from shape memory alloy, piezoelectric ceramic, ionic conductive polymer gel film or a simple mechanical approach using miniature electric motors [3-7].

The previous research work on ER fluid based tactile displays highlights the possibility of constructing a tactile display in a very simple way - there are no moving components and few accessories for its operation [8]. Though the ER fluid tactile display has excellent performance, there are still some disadvantages to limit its application such as high driving voltage, lower yield stress and the requirement for the fluid and components to be strictly free from impurities. To overcome these problems, using MR fluid as an alternative actuating method was proposed.

Magnetorheological (MR) fluids are suspensions of micron sized ferromagnetic particles dispersed in varying proportions of a variety of non-ferromagnetic fluids. MR fluids exhibit rapid, reversible and significant changes in their rheological (mechanical) properties while subjected to an external magnetic field. Having similar properties as ER fluids, the MR fluids are also in liquid state without external stimuli. While MR fluids are subject to a magnetic field, they behave as solid gels. Recent MR fluids are becoming increasingly important in applications concerning active control of vibrations or switching/control of torque/force. Devices such as dampers, shock absorbers, isolators, clutches and brakes have all been designed [9,10]. In recent years, MR fluid based haptic interfaces have been investigated by some researchers. Carlson and his colleagues have designed a prototype of portable hand and wrist rehabilitation device based on MR fluid has been proposed. Some researchers used MR fluid to construct a haptic display to replicate perceived biological tissue compliance [11, 12].

Due to the outstanding properties of MR fluids, there are possibilities of constructing a tactile display in a very simple way -- there are no moving components and few accessories for its operation. As the applied magnetic field varied, the sensed surface profiles changed in synchronisation with the magnetic field strength, as shown in figure 1 [4].

In this paper, a commercial finite element software ANSYS has been used to simulate, analyze and optimize the magnetic field of the prototype of tactile display incorporating magnetorheological fluid.

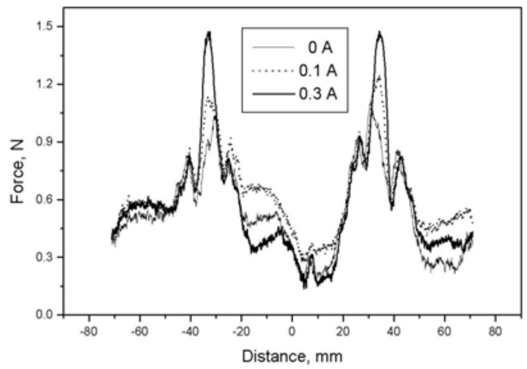


Fig. 1 The surface force response of MR tactile display with varied magnetic field strength

2 Design of MR tactile display

The designed MR tactile display consists in two components, the tactile display cell and magnetic field generator, as shown in the figure 2. The tactile display's frame is made of magnetic permeable material to ensure the magnetic flux can be directed into the MR fluid layer as much as possible. The frame's bottom is designed with a thickness of 1mm by considering the practical machining process. The upper surface of the tactile display is a layer of flexible membrane which can give the user the sensation of actual skin. It could be a very thin layer of rubber with a thickness less than 0.2mm. The thickness of MR fluid layer is set at 2.0mm for all simulations done in this paper. .

To generate an MR effect, the design of the magnetic field generator is important. In this paper, electromagnets are used to provide the magnetic field for MR fluid. This type of magnet can be design according our demand and is small in size which gives the possibility of constructing a compact MR fluid based tactile display array. The core is made of low carbon steel which has high magnetic permeability and saturation. For each magnet, the core has a square cross-section no more than 1x1cm^2. To generate proper magnetic field to produce a satisfactory MR effect, the coil's turns number will be determined by theoretical modeling by considering such factors as the nonlinear magnetic properties of the MR fluid and core, fringing of magnetic flux and possible losses at junctions and boundaries.

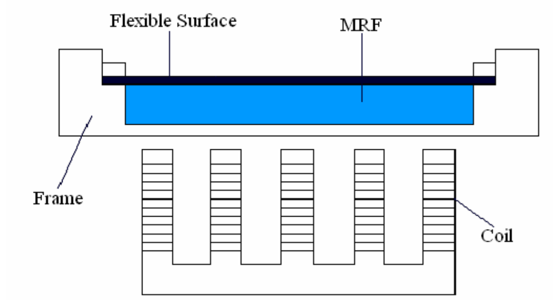


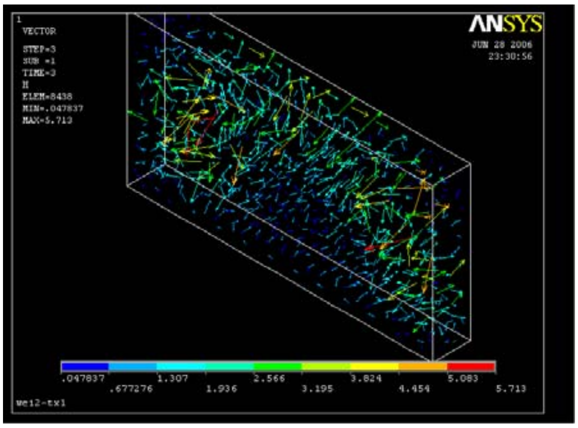
Fig. 2 Schematic diagram of the MR fluid based tactile display

3 Finite element analysis of electro-magnetic field

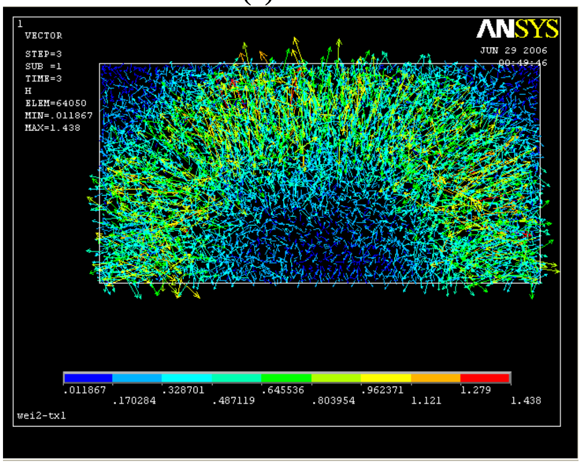
The strength and magnetic flux distribution of the magnetic field generated by the electromagnets have been simulated by FEM method. The purpose of this research is to know the magnetic field distribution in the area around every individual tactel. Parameters such as the size of the magnet, the distance between the solenoid and its neighbors and input current are the control variables in the simulation which aims to get a strong and steady magnetic field on the tactels of the display. ANSYS software has been used for this simulation.

4 Results and discussion

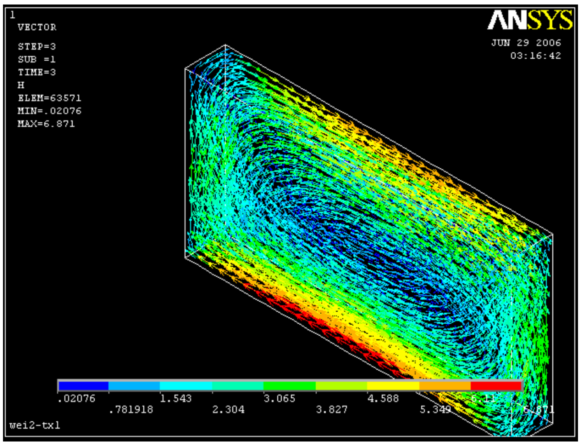
Figure 3 is the magnetic flux in the MR fluid layer where there is a single magnet being input various current 0.3A, 1.0A and 2.5A respectively. It need to be indicated that only half of the magnet and display cell are considered as the model's symmetrical structure.



(a) 0.3A



(b) 1.0A

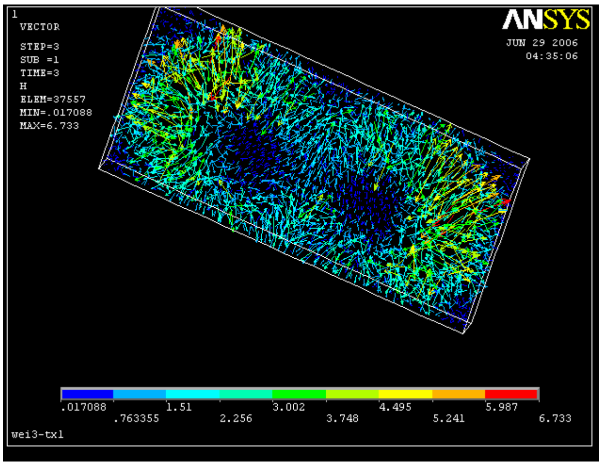


(c) 2.5A

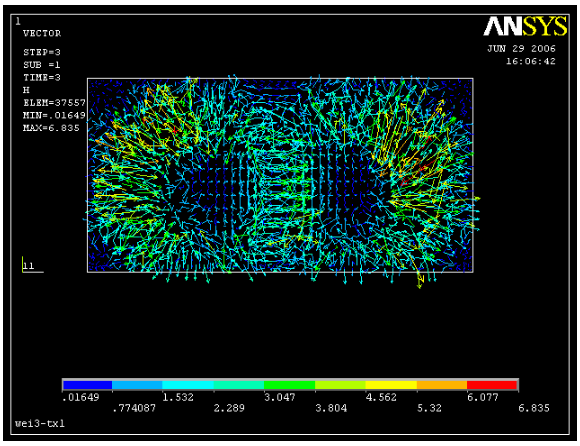
Fig. 3 Magnetic flux in MRF layer

From these figures, it is clear that with the increased input current into the coils, the magnetic flux density in MR fluid layer will increase. In figure 3 (c), the magnetic flux reaches to the saturated state. It means that the magnetic field will not increase with any further increasing input current. At the same time, the higher input current will bring more heat. This will be a serious problem if the tactile display designed to work continuously over a wide time range.

Figure 4 shows the magnetic flux in MRF layer when the two neighboring magnets are input current in different flowing direction. It is can be seen that if both the magnets are input current in clockwise direction, then in the area between the two magnets very weak magnetic flux will pass through the MRF layer. While one coil is with a clockwise input current and the other is with an anticlockwise input current, the magnetic flux pass through the area between two magnets will be stronger.



(a) Both the magnets' input current into the coils are clockwise



(b) One coil with a clockwise input current and the other with an anticlockwise input current

Fig. 4 The magnetic flux in MRF layer when the gap between two magnet core is 4mm

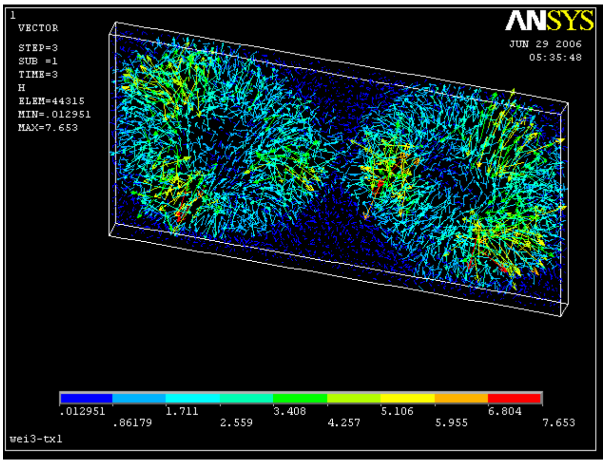


Fig. 5 The magnetic flux in MRF layer when the gap between two magnet core is 10mm

Actually, if the two magnets are too close to each other, the magnetic fields generated by them will be disturbed each other, as shown in figure 4. With the same conditions as fig.4 (a), when the gap between the two neighboring magnets is set longer (10mm), the disturbance between them will be weaker. However, in this situation, the resolution of the display will decrease. Furthermore, if the magnets are too close, the generated heat can not be dissipated quickly. This will affect the whole performance of the tactile display. For this design, a gap between 5 ~10mm would be suitable.

5 Conclusions

Through the finite element analysis results several conclusions have been obtained. The dimension of the magnet, the distance between magnets and the input current's level are the main factors which can affect the magnetic filed in the MRF layer of the display. The neighboring magnets should be kept at a distance at least larger than 5mm or they will affect the other's magnetic flux. On the other hand, this can also ensure the displayed information can be felt by human finger's touch.
The direction of current input can also affect the magnetic flux distribution. If the currents flowing through the two magnets' coil are in different direction, a better magnetic flux distribution could be generated especially when the two magnets are closer.

References

[1] R. A. Russel and S. Parlinson, Sensing surface shape by touch, in: Proc. Of IEEE International Conference on Robotics and Automation, pp 423-428, 1993.

[2] Hardwick, S. Furner et al, Tactile display of virtual reality from the World Wide Web—a potential access method for blind people, Displays, vol. 18, pp153-161, 1998.

[3] P. M. Taylor, A. Moser et al, A sixty-four element tactile display using shape memory alloy wires, Displays, vol. 18, pp163-168, 1998.

[4] Y. Liu, R. Davidson and P. Taylor et al, Single cell magnetorheological fluid based tactile display, Displays, vol. 26, pp29-35, 2004.

[5] Y. Liu, J. Ngu and R. Davidson et al, Tactile display array based on magnetorheological fluid, SPIE-13th Annual International Symposium on Smart Structures and Materials, USA, 2006

[6] M. Konyo and S. Tadokoro et al, Artificial tactile feel display using soft gel actuators, in: Proceedings of the IEEE International Conference on Robotics and Automation, pp 3416-3421, 2000.

[7] T. Maucher and K. Meier et al, An interactive tactile graphic display, in: Proceedings of Sixth International Symposium on Signal Processing and its Applications, pp190-193, 2001.

[8] Y. Liu, R. Davidson and P. Taylor, Touch sensitive electrorheological fluid based tactile display, Smart Materials and Structures, vol. 14, pp1563-1568, 2005.

[9] Mark R. Jolly, J. David Carlson and Beth C. Muñoz, Smart Materials and Structures, vol. 5 , pp607-614, 1996.

[10] J. D. Carlson and M. R. Jolly, MR fluids, foam and elastomer devices, Mechantronics, vol. 10 pp 555-569, 2000.

[11] J. D. Carlson and S. P. Koester, Magnetically-controllable active haptic interface system and apparatus, US Patent No. 6,283,859 B1.

[12] E. Z. Scilingo, A. Bicchi et al, A magnetorheological fluid as a haptic display to replace perceived biological tissue compliance, in: 1st Annual International IEEE-EMBS Special Topic Conference on Microtechnologies in Medicine and Biology, vol. pp 229-233, 2000.