A Study on Circular-coil Characteristics for Displaying Non-contact Tactile Sensation based on Magnetic Field.

Hyung-Sik Kim
Department of Mechatronics Engineering
School of ICT Convergence Engineering, College of Science & Technology, Konkuk University
Chungju, Republic of Korea
email: hskim98@kku.ac.kr

Kyu-Beom Kim, Ji-Su Kim, Soon-Cheol Chung*
Department of Biomedical Engineering
School of ICT Convergence Engineering, College of Science & Technology, Konkuk University
Chungju, Republic of Korea
email: rlarbqja0507@kku.ac.kr; roseee517@kku.ac.kr; scchung@kku.ac.kr*

***Abstract*—In this study, characteristics of coil, which is an actuator of magnetic field-based non-contact tactile presentation technology, were simulated. To induce a sense of touch using a magnetic field without wearing any devices on hand, a high-power power supply device, a power semiconductor switch, and a coil for generating a magnetic field are required. Because of the high power used, the power supply and coil require a separate heat sink device. Therefore, a simulation study was conducted on the characteristics of coils in order not to use a heat dissipation device. Simulations were conducted for the strength and field pattern of the magnetic field for each experimental frequency, the density of the magnetic field, and the generated heat for the circular coil. From the results, the magnetic field density and distribution were the same at all frequencies. In the analysis of the change in magnetic field density according to the frequency, the difference in the density of the magnetic field calculated at 5 Hz and 250 Hz was only about 2.03%. In the case of heat analysis, the time required to recover to the ambient temperature of 25 °C is less than 10 seconds in the case of 5 Hz condition, but the time required to return to the ambient temperature is more than 3.6 minutes at 250 Hz. Through this study, it was confirmed that a circular coil with a diameter of about 28 cm made of copper can operate for a long time without a cooling system under natural convection conditions.**

Keywords-Non-conctact tactile stimulator; Circular-coil; Magnetic field strength; Density; Heat, Heat-sink.

I. INTRODUCTION

As IT technology develops, research for interaction between devices and humans is also being actively conducted [1]. These studies stimulate sight and hearing among the human senses and exchange information through the process of perception and cognition. Recently, studies to present tactile sensation for more realistic interaction are also being conducted. Until now, most of the devices for presenting the tactile sensation are of a contact type and mainly induce a sense of vibration [2]. An actuator to generate a sense of vibration mainly uses a motor. This is because it is easy to control the magnitude of vibration and the frequency of vibration using electric signals, and it is possible to manufacture in a small size and is inexpensive. However, in the tactile presentation method, the tactile sensation can be evoked only when the person and the device must maintain a contact state. In addition, even if the contact state is maintained, the shape of the tactile sensation caused by changing the area, size, and time of contact is not consistent. Therefore, a technique for presenting a sense of touch in a non-contact method is also being studied. Representatively, a method using focused-ultrasound and a method using compressed-air are being tried [3]. However, these methods always have additional noise, have a short stimulus presentation distance, and complicate the configuration of the control system.

Recently, a method using a pulsed laser has also been introduced. This method has the advantage of a very long stimulus presentation distance, but the price of the laser system for tactile presentation is very expensive and requires a delicate setup using optics. Since the above three methods transmit energy for inducing a tactile sensation to the skin through space, it is impossible to transmit the tactile sensation when there is an object between the actuation source and the skin. Recently, a method using magnetic field induction has been developed [4]. Since this method uses an electromagnetic field, it has the advantage of presenting a sense of touch even when an arbitrary object exists.

However, high power is required to generate a magnetic field. In addition, since high heat is generated in a coil that generates a magnetic field, an additional device for heat dissipation is required when a continuous tactile sensation is generated. The cooling system also has the disadvantage that it is generally large and requires separate operating power. Therefore, in this study, a study on the characteristics to minimize heat generation of the coil, which is an actuator for presenting a magnetic field-based tactile sensation, was conducted through simulation analysis.

II. MATERIALS AND METHODS

A. *Setting up the Simulation Environment for the Stimulation Coil*

The analysis of the coil was performed through theoretical analysis and simulation of the magnetic field distribution. ANSYS (ANSYS Inc., USA) was used for computer simulation. Analysis of magnetic field strength, pattern, and thermal analysis according to the amplitude and frequency of voltage input to the coil, and magnetic field and thermal analysis were performed under the pulse voltage input condition of 950 Volts. A coil is a wire wound in a circular shape. Since the strength H of the magnetic field by the entire electric wire is the sum of the length of the minute current and the minute magnetic field, it can be expressed as a line integral as shown in Equation (1) below.

$$H = \int dH = \frac{I}{4\pi}\int \frac{dl\sin\theta}{r^2} \quad [\frac{AT}{m}] \qquad (1)$$

The voltage applied to the coil analysis was 950 Volts, the time was 130 μs, and the frequencies were 5, 10, 50, 100, 200, and 250 Hz. The voltage used is converted into current (I) by the specific resistance of copper. The intensity of the magnetic field is adjusted by the magnitude of the current, and through this, the intensity of the tactile sensation can be controlled. Also, the number of turns of the coil is proportional to the intensity of the tactile sensation, but because the size increases, voltage, which is electrically easy to control, was used. The flow of simulation using ANSYS is shown in Figure 1.

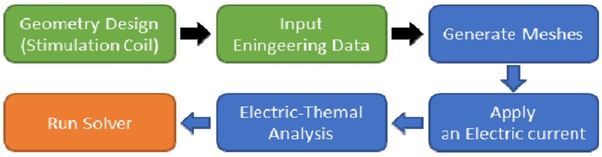

Figure 1. Simulation procedure using ANSYS Workbench.

B. *Coil geometry*

The geometric shape of the coil was modeled as shown in Figure 2, the material was copper, and the number of turns was set to 28 according to the environment in which the coil would be applied. The physical properties of the copper were specific resistance 1.69×10^{-2} [Ω/m], wire length 3.8 [m], specific heat 0.0924 [Cal/g × °C], and weight 800 [gram].

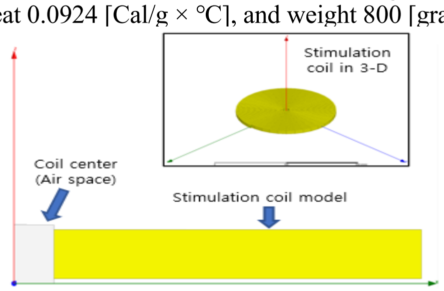

Figure 2. 2D and 3D shapes for coil simulation.

III. RESULTS

In the analysis of the change in magnetic field density according to the frequency, the difference in the density of the magnetic field calculated at a point 5 cm perpendicular to the plane of the coil was approximately 2.03 % at 5 Hz and 250 Hz, and the change was small (Figure 3(a)). When power is applied to the wire, heat is generated by the resistance component of the wire. The maximum temperature varied with frequency in the coil used. In the case of 250 Hz, the maximum temperature was 57.2 °C, and in the case of 5 Hz, the temperature rise was small at 24.2 °C. As heat generation increases, the size of resistance decreases, so more energy must be discharged to generate a magnetic field of the same size. Therefore, since the efficiency is reduced, this must be considered when manufacturing the coil. In addition, at each maximum temperature, heatsink by natural convection fell to the initial temperature within 3.6 minutes (Figure 3(b)). Since the pattern of the magnetic field according to the frequency is constant and the heat rise is not large, it means that the formation of the magnetic field for magnetic stimulation is constant even if the coil used is changed in the set frequency range (Figure 3(c) and (d).

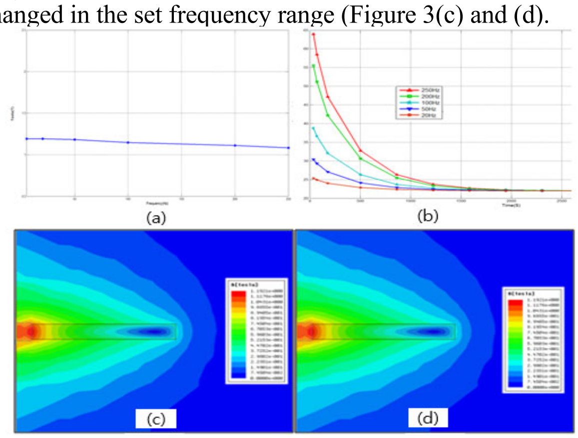

Figure 3. Simulation results for circular-coil. (a) Magnetic field density, (b) Heat dissipation profile, (c) Magnetic field map for 5 Hz and (d) 250 Hz.

IV. CONCLUSION

In this paper, the change in magnetic field pattern and temperature according to the application of pulsed power to the magnetic field generating coil was confirmed. The change in the density and field pattern of the magnetic field was small according to the frequency in the range of 5 to 250 Hz. In the case of temperature, the maximum rose about 33.1°C. It was confirmed that the coil of the proposed shape had a small difference between low frequency and high frequency, so that it was possible to induce a tactile sensation with constant strength and strength even when used for a long time. A large coil is used to induce a tactile sensation in the bare hand, but it is composed with an encloser made of wood or plastic, so it can be used for the purpose of inducing a tactile sensation with an invisible actuator.

ACKNOWLEDGMENT

This work was supported by a Mid-career Researcher Program Grant through the National Research Foundation of Korea (NRF), funded by the Ministry of Education (MOE) (No. NRF-2021R1A2C2009136).

REFERENCES

[1] A. Iftene and D. Trandabăț, "Enhancing the Attractiveness of Learning through Augmented Reality," Procedia. Comput. Sci. vol. 126, pp. 166-175, 2018, https://doi.org/10.1016/j.procs.2018.07.220.

[2] T. Rose, C. S. Nam, and K. B. Chen, "Immersion of virtual reality for rehabilitation – Review," Appl. Ergon. vol. 69, pp. 153-161, 2018, https://doi.org/10.1016/j.apergo.2018.01.009.

[3] T. Hoshi, M. Takahashi, T. Iwamoto, and H. Shinoda, "Noncontact Tactile Display Based on Radiation Pressure of Airborne Ultrasound," IEEE Trans. Haptics. vol. 3, pp. 155-165, 2010, https://doi.org/10.1109/TOH.2010.4.

[4] H. S. Kim, et al., "Development of tactile actuator with non-contact and trans-object characteristics using time-varying magnetic field," Actuators, vol. 10, pp. 1-11, 2021, https://doi.org/10.3390/act10060106.

