Research on Electromagnetic Force of Hybrid Electromagnetic Levitation Needle Driving System

Tao Xiong1,a, Wenshu Yin1, Dongdong Li1, Chengjun Zhang1,2,b, Xiaoyan Zuo1,2

1School of Mechanical Engineering and Automation, Wuhan Textile University, Wuhan, Hubei 430073, China
2Hubei Key Laboratory of Digital Textile Equipment, Wuhan, Hubei 430073, China
xiongtao@wtu.edu.cn
*Corresponding author e-mail: zchengj_wuse@wtu.edu.cn

Abstract. Hybrid electromagnetic levitation drive system is the core of the needle drive structure, and its performance directly determines the size of the needle drive force. According to the initial design results, the simulation model of the needle drive is established in the electromagnetic field simulation software Maxwell, and the influence of the structural parameters of the hybrid electromagnetic drive system; the material of the iron core, the number of coil turns on its static characteristics is analyzed. The simulation results show that at the same height, when the isolation ring material is aluminum, the time for the permanent magnet needle to rise to the highest position is the shortest.

1. Introduction
In recent years, with the increasing improvement of people's life, people have put forward higher requirements for the style of fabrics, and at the same time, it challenges the diversification and efficiency of knitting machines[1]. The traditional knitting machine has a series of problems, such as medium pollution, high energy consumption, low efficiency and so on. At present, all kinds of scholars have carried out research and exploration in all aspects to solve this problem. Zhang Wulian[2] explored three kinds of looping knitting methods, analyzed the influence of looping coil length on knitting process. Huang Lin Chu et al[3] pointed out the key points of flat knitting process for multi needle and multi face knitting, and obtained that double flat knitting can make the edge of fabric more beautiful than single flat knitting. Tian Jing et al[4] analyzed and studied the design and knitting process of different concave convex patterns, which expanded the knitting idea of Maoshan fabric. Allaire et al. Designed a hybrid electromagnetic heart pump by using active suspension bearing and permanent magnet, and established the mathematical model of the designed heart pump under the combined action of gravity load and liquid load. When the working speed is 6L / min, the rotation speed is 7000rpm[5].
In this paper, based on Maxwell’s electromagnetic field theory, the equivalent magnetic circuit model is established, and the electromagnetic force calculation formula of circular electromagnet is derived.

2. **3D modeling of driving structure of knitting needle**
As shown in Figure 1, the driving system of knitting needle includes: (1) needle head, (2) needle body, (3) sleeve, (4) pin, (5) electromagnet, (6) top cover and (7) permanent magnet.

![Figure 1. 3D structure of needle driving system](image)

The magnetic poles of the permanent magnet and the electromagnet are set to be the same, so that the needle moves up and down in the vertical direction, and the spatial magnetic field is distributed along the Z axis. At this time, the control system sends out weaving instructions, and the power system applies current to the coil winding of the electromagnet to change the electromagnetic force and drive the needle up and down.

3. **Simulation analysis of knitting structure**
According to the parameters in Table 1, the simulation model of needle driving structure composed of electromagnetic core, coil winding, magnetic separation ring and permanent magnet needle is established.

| Name       | Materials             | Shape    | Size/mm | Current/A | Turn |
|------------|-----------------------|----------|---------|-----------|------|
| Electromagnet | Core: DT4              | cylindrical | Radius:5 | 1.8       | 3000 |
|            | Coil: copper           |          | Diameter:0.2 |          |      |
|            | Isolation ring:        |          | External diameter:12 |          |      |
|            | DT4                   |          | Radius:6 |          |      |
|            |                       |          | Thick:7  |          |      |
|            |                       |          | internal diameter:15 |          |      |
| PM         | NdFe35                 | cylindrical | Thick:1 |          |      |
| Sheeve     | DW35                  | U        | external diameter:17 |          |      |
The magnitude of the magnetic flux is not only related to the ampere turns of the electromagnet, but also related to the magnetic materials in the magnetic circuit. The influence of different isolation ring materials on system characteristic parameters is shown in Figure 4.

As shown in Figure 2, the influence of different isolation ring materials on the knitting needle system is shown in the figure. In Fig. 2 (a), the isolation rings of different materials affect the time for the permanent magnet needle to rise to the highest point. The isolation ring is made of aluminum, which takes less time than silicon and electric pure iron under the same conditions; in Fig. 2 (b), the isolation ring uses aluminum as magnetic insulating material, which can not be attracted by permanent magnet, and the electromagnetic driving force is the largest at the initial stage of needle starting. When the needle rises to the highest position, the driving force oscillates at about 100N, and the isolation ring is made of pure electric iron, and the permanent magnet generates suction on the isolation ring. The driving force should not only overcome the gravity of permanent magnet needle, but also overcome the permanent magnet suction. In the whole system, the driving force produced by the electrified coil has a great influence on the driving performance of the needle. Different coil diameter, load current, coil turns and cross-section shape are directly related to the driving force. The electromagnetic driving force changes the ampere turns of the coil, as shown in Figure 3.
Figure 3 shows that the driving force of the needle is related to the current applied by the electromagnetic coil and the number of turns of the coil in the hybrid electromagnetic floating needle driving structure. In the case of no current in the electromagnetic coil, the driving force is relatively large. This attraction is generated by the coil with different turns in initial state, which is basically equal to the load current of the coil, and the driving force decreases first and then increases. This is because the coil is energized to generate upward electromagnetic force, which overcomes the reaction force of permanent magnet to the coil core. However, when the load current reaches a certain value, the electromagnetic force is greater than the suction force of the core to the needle. At this time, the fixed force of the permanent magnetic needle is upward, and the permanent magnetic needle begins to move.

4. Conclusions
In this paper, the 3D structure of the hybrid electromagnetic levitation needle drive system is established, and the magnetic circuit model of the drive structure is established by using Ohm's law in the magnetic circuit. By analyzing the force of the permanent magnet needle, the electromagnetic driving force model of the permanent magnet needle is established by connecting the magnetic field parameters and mechanical parameters. Finally, using the finite element simulation software, and the influence of different parameters on the electromagnetic driving force of needle is analyzed. The results show that, at the same height, when the isolation ring material is aluminum, the time for the permanent magnet needle to rise to the highest position is the shortest; the driving structure is designed, and the driving time of the isolation ring is half of that without the isolation ring.

Acknowledgments
This work was financially supported by National Natural Science Foundation of China (Grant No. 51875414), Hubei Natural Science Foundation of Hubei Province (Grant No. 2017CFB585), Science and Technology Research Project of Hubei Education Department (Grant No. D20181704).

Reference
[1] Long, H. L. (2004) New technology development of knitting machinery at home and abroad [J]. Jiangsu textile, (05): 16-19.
[2] Zhang, W. L. (2007) Discussion on knitting technology of flat knitting machine sleeve [J]. Knitting industry, (07): 13-16 + 1.
[3] Huang, L. C., Song, G. L. (2012) Discussion on knitting technology of flat end stitch on computerized flat knitting machine [J]. Knitting industry, (10): 25-27 + 71.
[4] Tian, J., Mao, L. L., Wang, B. R. (2008) Research on convex concave pattern design method and knitting technology [J]. Shanghai Textile Science and technology, 36 (11): 47-49.
[5] Allaire, P., Jiang, W., Kailasan, A., et al. (2014) A Prototype Left Ventricular Assist Artificial Heart Pump: An Integrated Permanent Magnet and Active Magnetic Bearing Suspension System. in ASME Turbo Expo 2014: Turbine Technical Conference and Exposition. 2014. American Society of Mechanical Engineers.