Magnetic array knitting needle driving system design

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Abstract. The traditional needle driving in knitting machine has drawbacks, such as vibration, noise, temperature rising, high energy consumption, and so on. A new non-contact magnetic array needle driving method is proposed in principle, which completely overcome traditional mechanical cam driving shortcomings. The permanent magnet together with knitting needle as the permanent knitting needle, the control system real-time controls the electromagnet coil current direction and value, which can generate different magnetic force to drive the needle movement. The magnetic array needle driving structure and its DSP control system are designed, the mathematic model is analysed, and the experiment and simulation are applied. By comparing the experiment and simulation, the control system is verified to satisfy the new knitting needle driving.

1. Introduction
Knitwear are widely used in our daily life, such as T-shirts, sweaters, socks, shoes and so on. Knitting machines are very important equipment for these productions. Knitting needles driving is the key mechanism in these machines. The movement of knitting needles plays an important role in the process of clothing [1]. Traditional knitting needles movement is controlled by the needle selection mechanism and the mechanical cam, so that the process is accompanied with the equipment temperature rising, noise, and vibration, which usually breaks the knitting needles, and seriously affects the clothing quality.

In order to address the above problems, much research has been conducted to study the knitting machine and its needle driving by different methods. Chen [2] designed a downward pressing mesh mechanism and sinker thereof for flat knitting machines, the cam has a guide track to drive the sinker swinging, which caused the sinker rapid to be produced and replace. Mariana [3] studied the weaving action of needles. Most basic movements of knitting were simulated by software, which was used in the computer teaching process to enhance students’ interest in learning. Zhang [4] and Yuan [5] researched on early discovery theory of induction magnetic field distribution, magnetic density is directly related to the size of the driving coil profile and magnetic size with coil profile changes, concluded that a smooth F-z curve can be constructed by changing the contour shape of the driving coil, and the optimized driving structure is obtained, which provides a theoretical basis for the verification of the later experimental system. Chottikampon [6] measured the movement of arms to examine the effect of arm movement on quality of knitting fabric. The results revealed the procedure used to crochet knitting machines were very different in appearance, knitting and speed. Conti [7] made a comparison with hand knitting, knitting needles produce warp knitting, whereas crochet work is an example of weft knitting. The needles fitted
to knitting machines may be of different types depending on how the machine works. Mobarok [8] developed the form of an equation based on the mechanical consideration of yarn during dynamic circular weft knitting process that runs with positive storage feed system, observed that for spun polyester knitted fabric, as used in the experimental part, the model worked very effectively through precision prediction by showing very low average mean difference in predicted course length from that measured from the actual fabric. Akbar [9] investigated weft knitted heating pad on V-bed hand flat knitting machine by using acrylic, polyester as a main yarns and three different Copernic, thermotic –N, thermogram as conductive yarns with both all knit and inlaid insertion, analyzed conductive yarn that inlaid in the acrylic yarn showed satisfactory heating performance for different time periods and retained more heat rather than polyester yarn.

The mentioned researches from the mechanism and its optimization, which reduced the friction force between the cam and the knitting needle, saved the machinery energy consumption, but does not get rid of the limitation of the traditional knitting needle driving principle of the cam and the needle rubbing. These developed machines still have problems with temperature rise and vibration. According to these problems, magnetic array knitting needle driving system is proposed. Using magnet force between the permanent magnet and electromagnet, the knitting needle can rise along the groove of the flat machine bed without rub with the cam. This method can not only reduce the heat generation and temperature rise of the equipment during processing, but also greatly simplify the structural design of the flat knitting machine and improve the maintenance performance of the equipment.

2. A needle driving structure for flat knitting machine

The structure of the electromagnetic and needle array driving is shown in Figure 1. The electromagnets are composed of stators and coils, the electromagnet array is embedded in the head of the flat knitting machine, and the moving motor with the motive head can reciprocate in the horizontal direction. The knitting needle and the permanent magnet bind together as a permanent magnet knitting needle. These kinds of needles are is uniformly installed in the needle groove of flat knitting machine bed, which limits the displacement of the needles rising and falling. The bottom of the permanent magnet needle array is provided with a partition plate, which limits the needle’s lowest position. The electromagnetic array control system is used to control the direction of the value of coil current, which can direct change the driving force between magnetic needle and electromagnet. The electromagnet array forms a synthetic magnetic field, and the non-contact acts on the permanent magnet knitting needle to make each knitting needle rising and falling movements can be achieved according to their process actions.

![Figure 1. Electromagnet and needle array driving structure](image-url)
3. Needle driving control system design

3.1. The Structure of the needle driving control system

By controlling every coil current direction and value, the electromagnet array synthetic magnetic field can generate a sort of driving force, which can drive every permanent magnetic knitting needle rising and falling movement. In order to apply the coil current control, a magnetic array knitting driving system is designed, the diagram is show in Figure 2. The control system is composed of DSP (Digital Signal Processing), Encoder, Power, Flash, PC and array of power-driven circuit.

PC in charge of the knitting data preparation, which can send the data to DSP chip by RS232 communication port.

DSP is the core of the control system, there are many tasks it should be do, such as receive the knitting data from the RS232 port, save the knitting data to the flash storage, sample the encoder signal to get the location of the machine head when its running, calculate the current value according to the current location of head reality, drive every coil current by power-driven circuit.

Encoder is a sensor, which can be sampled by DSP to get the location of machine head.

Power is an energy module, which can provide energy for DSP and the amplifier circuit.

![Figure 2. Electromagnetic array driving control system](https://example.com/fig2.png)

3.2. The mathematical model of needle driving

The knitting needle driving system diagram is simple shown as Figure 3. After electromagnet magnetized by magnetic field, there will be magnetized current in the interior and surface magnetized current[10].

![Figure 3. Simple diagram of permanent magnetic needle driving structure](https://example.com/fig3.png)

The magnetized current density and surface magnetized current density is given by \( \delta_i, \delta_s \)

\[
\delta_i = \nabla \times M
\]  

\[
\delta_s = -n \times M
\]
The permanent magnet needle force can be written

\[ F = \iiint_Y \nabla \times B dv + \iint_S \delta S \times Bds = \iiint_Y (\nabla \times M) \times Bdv + \iint_S (-n \times M) \times Bds \]  

(3)

Where \( B \) is magnetic induction intensity. For isotropic media, the force is given by

\[ F = \iiint_Y (\nabla \times M) \times Bdv \]  

(4)

Since \( M = \frac{\mu_r - 1}{\mu_0 \mu_r} B \), where \( \mu_0 \) is vacuum permeability, \( \mu_r \) is relative permeability of magnetic medium.

The formula of vector gradient is given

\[ \iiint_S \nabla \phi dv = \iint \phi ds \]  

(5)

Substituting (5) into (4), we obtain

\[ F = \frac{\mu_r - 1}{\mu_0 \mu_r} \iint_S B^2 ds = \frac{1}{2\mu_0} BHS \frac{BHS}{2} \]  

(6)

Where \( M \) is medium intensity, \( n \) is the surface normal vector, \( \mu_0 \) is vacuum permeability, \( \mu_r \) is relative permeability of magnetic medium, \( H \) is magnetic field intensity of the surface, \( S \) is the area of the surface, \( B \) is magnetic induction intensity.

Permanent magnetic needing rising process, the needle has the magnetic repulsion upward force, the downward gravity and friction. Applying Newton’s second law, we can write

\[ F - mg - f = ma \]  

(7)

Permanent magnetic needing falling process, the needle has the friction upward force, the downward gravity and magnetic attraction force. Applying Newton’s second law, we can write

\[ F + mg - f = ma \]  

(8)

Where \( F \) is the magnetic driving force, \( m \) is the mass of permanent magnetic needle, \( f \) is the friction between the needle and machine bed, \( a \) is the acceleration of the needle movement.

4. Knitting needle Driving system Experiment and simulation

4.1. Experiment platform design

A simple experiment platform is designed as Figure 4. The experiment platform is composed of controller, magnetic needle array, sensor and monitoring pc. The inner of the controller is designed as the structure of the Figure 2. DSP is the core of the controller, which can apply the current vector of the electromagnetic to provide the vertical movement of the needle in machine bed. The sensor is designed to detect the displacement of the needle, which provide important parameter for the driving current data. The screen of the computer displays the current DSP control timing.
4.2. **Knitting needle driving system experiment and simulation**

The real experiment platform parameter is shown in Table 1. The cylinder electromagnet and permanent magnetic needle is designed, which have the same radium 5mm, but have respectively 10mm and 1mm thickness. The skeleton of the coil material is steel, the coil material is copper, the permanent magnet material is NdFe35. The electromagnet has 500 turns of coil.

|                | Electromagnet | Permanent Magnetic Needle |
|----------------|---------------|---------------------------|
| Material       | steel/copper  | NdFe35                    |
| Shape          | cylinder      | cylinder                  |
| Radium         | 5mm           | 5mm                       |
| Thickness      | 10mm          | 1mm                       |
| Coil Current   | 2.4sin(10πt)  | —                         |
| Coil Turns     | 500           | —                         |

When the coil applies the time-current, the current equation is shown as

\[ i(t) = 2.4\sin(10\pi t) \] (9)

The time-current plot is shown in Figure 5. The permanent magnetic needle displacement from the 1mm to 16mm, the magnetic force between the knitting needle and the electromagnet experiment and simulation curve are shown in Figure 6.

![Figure 5. Driving current curve](image)
Figure 6. Driving magnetic force between knitting needle and the electromagnet

From the Figure 6, we can find that experiment magnetic force is small than the simulation because of the magnetic flux leakage. But the experiment and simulation have the same period, which follow the applied current variation. Because of the rapid change of current and the coil magnetoresistance effect, the driving force is weak. The magnetic force reduced as the displacement increase, when the displacement arrived 14mm or 15mm, the magnetic force is nearly 0.

5. Conclusion

From the magnetic array knitting needle driving system design and the comparing of the experiment and simulation conclusion, we can find that the magnetic driving force can follow the current variation, but the force is very weak which cannot drive the movement of the knitting needle to the height more than 14mm. In order to get more displacement, we can reduce the frequency of the current variation or increase the value of the driving current.

From the experiment and simulation, we can conclude that the control system can satisfy the magnetic array knitting needle driving system.

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).

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