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Performance Investigation of Induction Heater

***Abstract**. To achieve high and even-distributed temperature of the rotatory part, an induction heater is designed and its performance of different structure is investigated. By the erected electromagnetic model, structure parameters including height, length and position of induction copper layer are optimized. Its temperature distribution is obtained based on another coupled-field model combining electromagnet field with temperature field. The predicted results show not only the steady temperature distribution, but also the temperature dynamic variation, which are also validated by the prototype measurement. Since the test temperature can almost keep constant and uniform with corresponding temperature controller, the proposed induction heater meets the design requirement.*

***Streszczenie.** Zaprojektowano nagrzewnicę indukcyjną do nagrzewania ruchomych elementów. Optymalizowano parametry, takie jak wysokość, długość I pozycja wartwy miedzianej. (**Analiza właściwości nagrzewnicy indukcyjnej**)*

Keywords: induction heater, electromagnetic field model, coupled-field model, temperature distribution
Słowa kluczowe: nagrzewanie indukcyjne, rozkład temperatury

Introduction

A lot of heat equipments are applied in the textile equipments to heat the textile or oil equipments to avoid paraffin deposition [1-2]. They should produce high and uniform temperature of a rotatory mechanism without any electrical contacting. In order to meet this requirement, the induction heaters are adopted.

The induction heaters normally produce the eddy current loss in copper or aluminium layer by induction phenomena. Due to different requirements of applications, many different structures are designed. For armature windings, there are single-phase winding, modular three-phase winding, multi-phase winding and superconductive winding [3-5]. To magnetic field, it can be produced by permanent magnets to obtain suitable temperature for heating not high-temperature equipments such as the oil tube. But to high temperature in textile or chemical industry, it should be produced by the electromagnets for reliability. Although so many new complicated structures are proposed to obtain high performance, the simple structure with single-phase electromagnet is still preferred due to low cost and high reliability. In order to meet different applications, the main research is to optimize the structure [6-8].

This paper designs an induction heater adopting single-phase electromagnet for textile industry. In order to obtain high efficiency and high enough temperature, the performance investigations of different structure parameters are carried out in detail. Finally the predicted results are verified by prototype measurements.

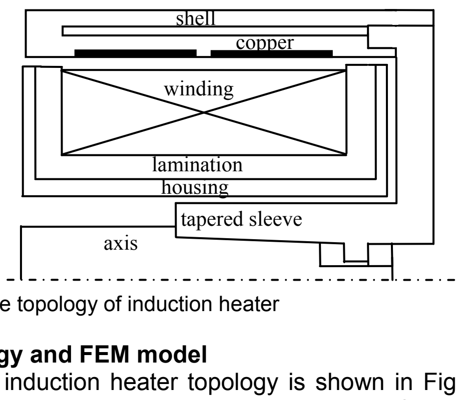


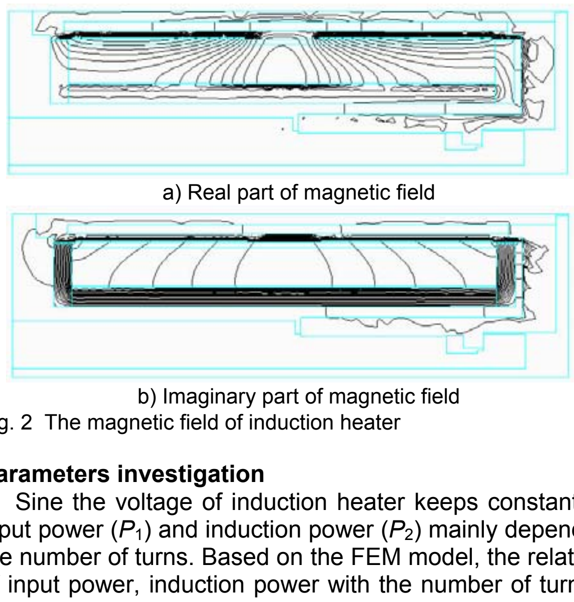
Fig. 1 The topology of induction heater

Topology and FEM model

The induction heater topology is shown in Fig.1, which has stator and rotor. The stator consists of single-phase winding, lamination and non-ferromagnetic housing, which is connected with stationary bracket. The rotor includes copper layer, steel shell, axis and tapered sleeve, which is driven by the induction motor. The energy conversion part is copper layer which has either one part or two parts. A hole is adopted in the mover shell for obtaining uniform temperature.

The pulsating magnetic field is erected in air gap when the single-phase winding is supplied with AC current. After the rotor rotates with certain speed, the copper layer produces eddy currents by electromagnetic induction, and then the copper loss makes the temperature of the rotor raise. As it can be imaged, the temperature around copper layer is higher than other place, but the hole of shell makes the temperature evenly distribute in the outside of rotor.

The induction power can be calculated by erected electromagnetic field FEM model which is supplied by constant voltage power supply. Due to tubular shape, an axis-symmetrical model is adopted. Based on this FEM model, the magnetic field and induction power of copper layer are easily achieved. Fig.2 a) and Fig.2 b) show the real part and imaginary part of magnetic field respectively. Apparently, most magnetic flux goes through the inner part of the shell in the rotor.



a) Real part of magnetic field

b) Imaginary part of magnetic field

Fig. 2 The magnetic field of induction heater

Parameters investigation

Sine the voltage of induction heater keeps constant, its input power (P_1) and induction power (P_2) mainly depend on the number of turns. Based on the FEM model, the relations of input power, induction power with the number of turns is investigated when the height of copper layer is 1mm, shown in Fig.3. Apparently, both input power and induction power are inversely proportional to the number of turns, and have dramatically variation when the number of turns is relatively low. Moreover, the efficiency is almost constant. Due to the power requirement is 8kW, the number of turns can selected 300 and the height of copper layer is 1mm.

Since the copper layer is main part to realize the function of energy conversion, its parameters of height, length and position are important. Fig.4 shows the input power and induction power of different copper height. They are directly proportional to copper layer height, but the increment gradually lowers. In the same time, the efficiency also decreases. While the power factor rapidly improves along with the increasing of the copper layer height during the range of 0 to 0.5mm, and then almost keeps constant after over than 0.5mm. Therefore, the copper layer height can choose 1mm for taking both induction power and efficiency into consideration.

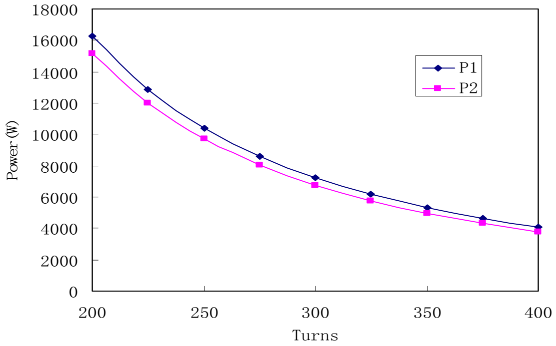
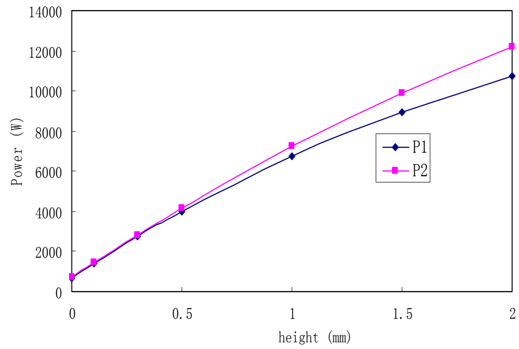
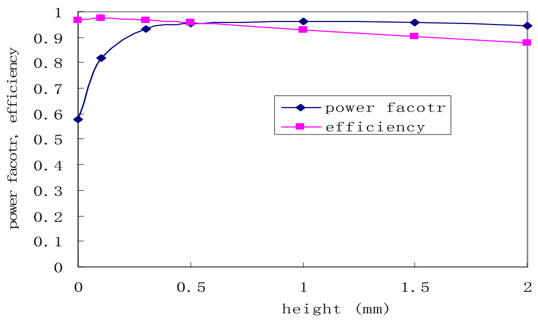


Fig. 3 Input power and induction power of different number of turns



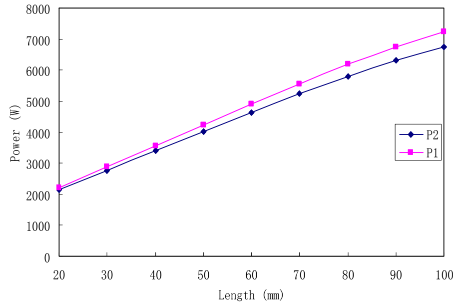
a) Input power and induction power



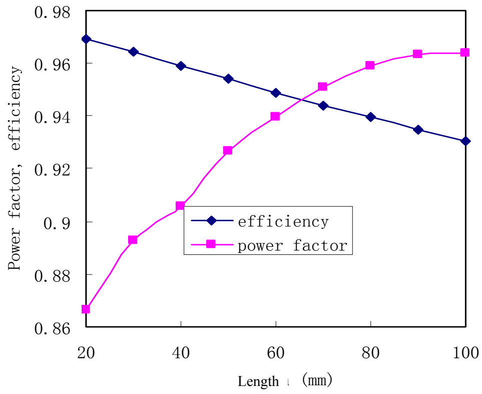
b) Power factor and efficiency

Fig.4 The Performance of different copper layer height

Fig.5 shows the input power and induction power of the induction heater with different copper layer length when it has two copper layers. In this condition, the distance between two copper layers keeps constant, and then the length of two copper layers symmetrically enlarges towards two ends. As it can be seen, both input power and induction power are proportional to copper layer length. The efficiency decreases, but power factor increases rapidly. Therefore, the copper layer length can choose 100mm for taking into consideration both the induction power and power factor.



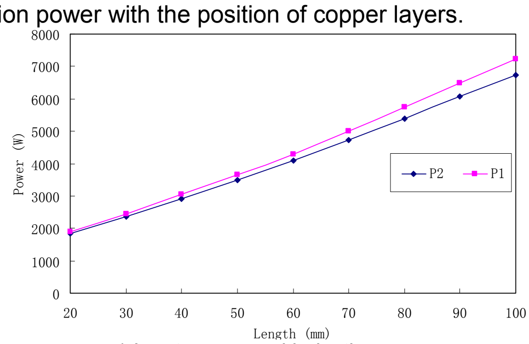
a) Input power and induction power



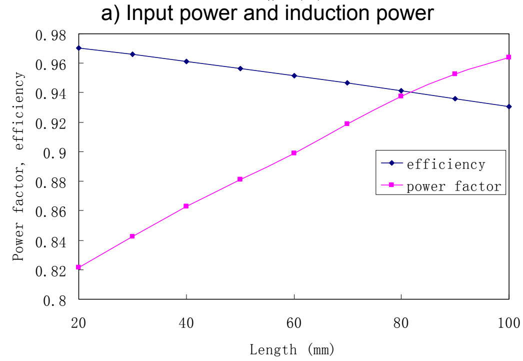
b) Power factor and efficiency

Fig. 5 The performance of different copper layer length with constant distance between two copper layers

Fig.6 also shows the input power and induction power of induction heater with different copper layer length when it has two copper layers. The difference is the outside position of each copper layer is fixed, and then the distance between two copper layers becomes smaller and smaller along with the increasing of copper layer length. Apparently, the variation is same to that of Fig.5. That is to say, the position of copper layers doesn't affect the performance. It is also can be seen in Fig.7 which shows the relationship of induction power with the position of copper layers.



a) Input power and induction power



b) Power factor and efficiency

Fig. 6 The Performance of different copper layer length with constant outside position of two copper layers

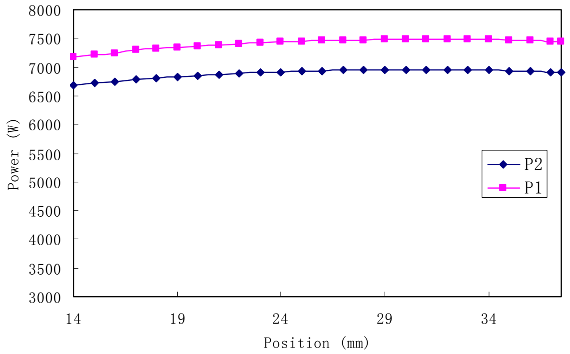
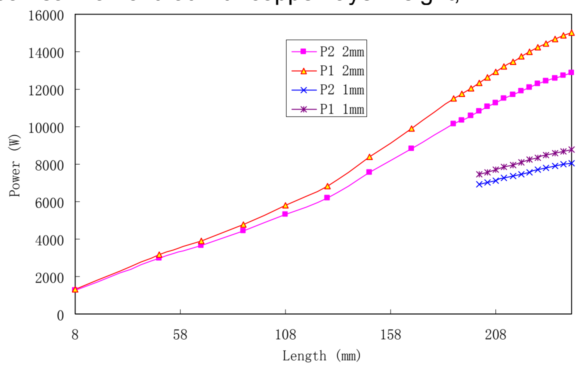
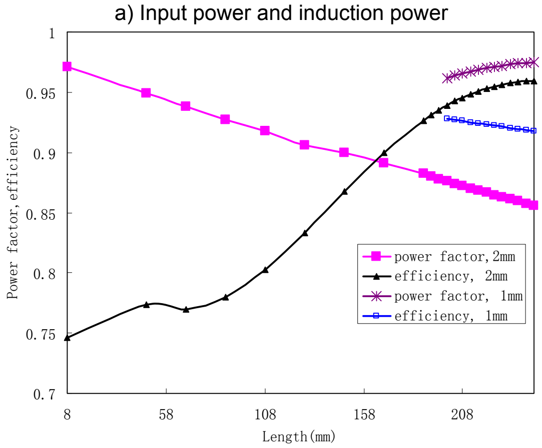


Fig. 7 The relationship of input power and induction power with different position of two copper layers

Except the structure with two copper layers, the induction heater also can adopt one copper layer. Fig.8 shows the input power, induction power and power factor, efficiency of different copper layer length at this condition. Due to without separate distance between two copper layers, the whole length of copper layer can be bigger than that of the former condition. Therefore, the maximum power is bigger than former, but the efficiency is also lowered. By comparing, the induction heater with copper layer height, 1mm, can obtain high efficiency and power factor, but the induction power is also near half of that with copper layer height, 2mm.



a) Input power and induction power



b) Power factor and efficiency

Fig. 8 The Performance of different copper layer length with one copper layer

Comparing Fig.5 with Fig.6, the performances of two copper layers structure and one copper layer structure are almost same. Therefore, two copper layers structure is selected in order to decrease the temperature in middle part and shorten the length of each copper layer for easy manufacture.

By the investigation, the performance of induction heater is greatly affected by copper layers. For considering both performance and cost, the structure of two copper layers is chosen, and the suitable height and length are 1mm, 100mm respectively.

Temperature investigation

The induction heater is used to produce not only high enough temperature, but also uniformly distribution temperature along the axis, so the temperature analysis is required. For considering both electromagnetic field and temperature, a coupled-field model is erected. By this model, the electromagnetic field and temperature field are calculated alternatively by the given step.

Fig.9 shows the temperature of the induction heater with copper layer height, 1mm, in different time. From bottom to top, the time is 80s to 720s with step 80s. Along the axis, although the high temperature occurs around the copper layers and the low temperature exists in two ends and middle position, the temperature can be taken as same due to the small difference. Moreover, the difference in middle part can become smaller and smaller along with the average temperature increasing.

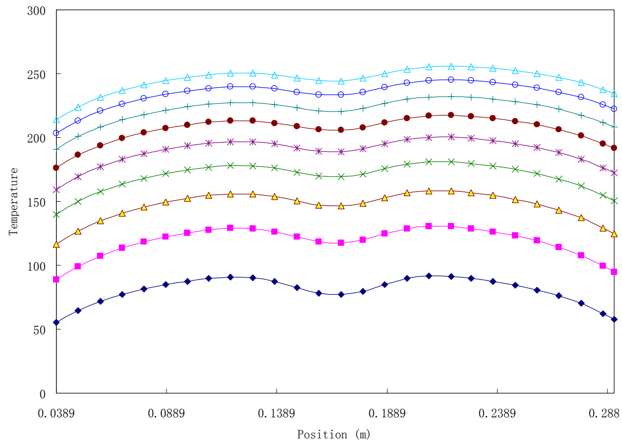


Fig. 9 The temperature distribution of induction heater with copper height, 1mm.

Along the time, the temperature rises very quickly, but the increment decreases gradually. In Fig.9, the predicted stable temperature can arrive near 250 degree with a cover at no load condition. That is to say, all induction power is used to rise the temperature. In fact, the available stable temperature is finally decided by the load since a lot of induction power is taken away by load.

Fig.10 shows the temperature of the induction heater with copper height, 2mm, in different time with a cover at no load. From bottom to top, the time is 80s to 720s with step 80s. Apparently, the variation is same to Fig.9, but temperature rising is still very big even at 720s. As it can be imaged, the stable temperature is over than 300 degree, which is higher than former one.

Comparing with two structures, the induction heater with 1mm copper layer can produce more uniform temperature to meet the design requirement, which is adopted by prototype.

Prototype and measurement

The prototype is made for measurement, shown in Fig.11. Fig.11a) shows the stator including lamination and winding and Fig.11b) is the whole structure of induction heater. In test platform, the induction heater is driven by a variable speed induction motor. A non-contacting temperature sensor measures the rotor temperature, and then feeds back to induction heater controller. The controller dynamically controls the input power by a switch. Therefore, given temperature of the rotor can be any value during the allowed range.

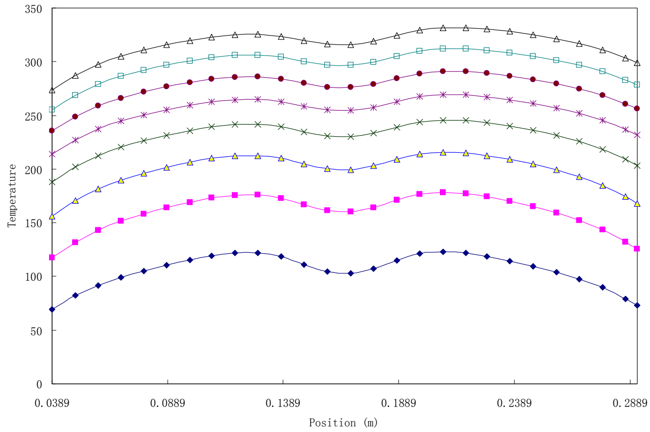


Fig. 10 The temperature distribution of induction heater with copper layer height, 2mm.

a) The stator of induction heater b) Induction heater

Fig. 11 Prototype of the induction heater.

Fig.12 shows the measurement results when the given temperature is 90degree, 105 degree, 130 degree and 160 degree. They are almost same to predicted result, but have some difference in two ends at high temperature. At given 160 degree, the measured results show the temperature decreases quickly in two ends, which is mainly caused by their better heat dissipation condition than that of middle part. In fact, the impact factor of two ends is very difficult to be simulated accurately in analysis.

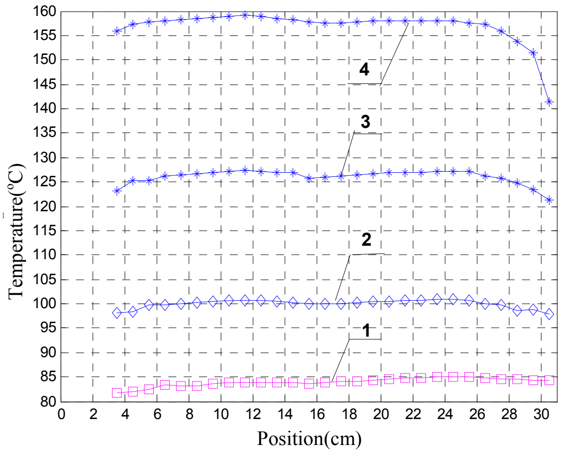


Fig. 12 The measurement results of prototype with different given temperature.

Each available temperature is lower than given value, but the error becomes smaller when the given temperature is high. To 160 degree, the error is only 2-3 degree, which is allowed in this equipment.

The temperature is measured at no load, so it can arrive to much higher value than 160 degree. In application, the load takes away much heat, so the temperature is lowered to certain value by corresponding load.

Conclusions

The proposed induction heater can produce even-distribution temperature in the shell to meet the design requirement, which is validated by prototype measurement. By the investigation, the following aspects could be concluded:

(1) The induction power mainly depends on the number of turns of single-phase winding when supplied with constant voltage power.

(2) The induction power is closely relative to the height and length of copper layer, but not its position.

(3) The temperature of shell with inner hole is almost even distributed, only decreases a bitter in the two ends. It can be kept to given value by the controller.

(4) The efficiency and power factor of this kind induction heat are much high.

This induction heater has simple structure and high efficiency, which can be applied in textile industry and oil field.

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REFERENCES

[1] Bingyi Zhang, Fengxiang Wang, Guihong Feng, A medium-frequency induction heater for development of viscous and high-solidifying oil deposits, Proceedings of The Third International Power Electronics and Motion Control Conference, (IPEMC 2000), Vol.3, pp.1318-1322

[2] Ding Feng, Nian Liu, Xiaofei Chang, Peng Wang, Chao Ruan, Hong Zhang, The application of electric heater in heavy oil desanding of offshore platform, 2011 International Conference on Electric Information and Control Engineering (ICEICE), pp. 1768-1770, 2011

[3] E.A. Golovenko, E.V. Kuznetsov, E.S.C. Kinev, Uniform heating control and reduction current unbalance in polyphase induction heaters, Third International Forum on Strategic Technologies (IFOST 2008), pp. 417 - 420, 2008

[4] M. Runde, N. Magnusson, C. Fulbier, C. Buhrer, Commercial induction heaters with high-temperature superconductor coils, IEEE Transactions on Applied Superconductivity, Vol.21, No.3, pp.1379-1383

[5] H.I. Sewell, D.A. Stone, C.M. Bingham, Novel, three phase, unity power factor modular induction heater, IEE Proceedings Electric Power Applications, Vol.147, No.5, pp. 371 – 378, 2000

[6] K. Chatterjee, V. Ramanarayanan, Optimum design of single switch resonant induction heater, Proceedings of the IEEE International Symposium on Industrial Electronics, Vol.2,pp. 858-859,1992.,

[7] H. Kagimoto, D. Miyagi, N. Takahashi, N. Uchida, K. Kawanaka, Effect of temperature dependence of magnetic properties on heating characteristics of induction heater, IEEE Transactions on Magnetics, Vol.46, No.8, pp.3018-3021, 2010

[8] P. Alotto, A. Spagnolo, B. Paya, Particle Swarm Optimization of a Multi-Coil Transverse Flux Induction Heating System, IEEE Transactions on Magnetics, Vol.47, No.5, pp.1270-1273, 2011

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