A Survey of Temperature Control Methods of Electromagnetic Induction Heating

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Keywords: Induction Heating, Temperature Control, PID Control, Intelligent Control

Abstract: Electromagnetic induction heating has been widely used because of its green, high efficiency and small heat dissipation, but the control of its heating process has developed slowly. PID control and intelligent control have good adaptability to the unsteady system. Combining the two, we can design a more adaptive controller under the small sample data, which shows a broad application prospect. In view of this, the current research status of temperature control of induction heating is described and analyzed in detail. It is divided into PID control, PID optimization control and intelligent control, and its advantages and disadvantages are summarized. Finally, the research of temperature control of induction heating is prospected.

1. Introduction

China consumes a lot of heat energy in ferrous metal, non-ferrous metal, machinery manufacturing, automobile, military and other manufacturing industries. The heating efficiency of flame furnace and resistance furnace is low, and the heat loss is large, which results in huge energy waste. Induction heating has the advantages of green, high efficiency, fast heating speed, small heat loss and so on[1]. It plays an extremely important role in modern heating process. Due to the nonlinear, strong coupling and large time delay characteristics of induction heating system, it is very difficult to make accurate quantitative control of induction heating process. Generally, the composition of induction heating system is shown in Figure 1. In many heating processes, if the control system has a large temperature oscillation or a long time to reach the stable stage, it is likely to lead to the scrap of billet in the process of reaching the stable stage[2]. However, the precise control of temperature not only determines the production quality of the product, but also relates to the optimal utilization of energy. Moreover, the temperature control of induction heating includes the general existence of most industrial control processes The research on the temperature control of induction heating has a positive reference value for other industrial control processes. Therefore, many scholars at home and abroad have done a lot of research on this issue. In this paper, the research on temperature control of electromagnetic induction heating at home and abroad is briefly summarized and analyzed, and its development is prospected.

2. Introduction of Induction Heating Method

2.1. Introduction to Induction Heating

Induction heating is a process in which the eddy current effect is produced by the electromagnetic induction between the induction coil and the conductor. It is the application of a physical phenomenon revealed by electromagnetic induction law in engineering[3]. When a conductor is in a changing magnetic field or a relatively moving magnetic field, an induced current will be generated inside. This current is called eddy current, or eddy current for short. Because the resistance of a conductor with a large volume is very small, this eddy current can reach a great strength. Eddy current will produce a lot of Joule heat when it moves in the conductor. This physical phenomenon is used in industry to provide energy for the industrial process that consumes heat energy.

  DOI: 10.25236/cseem.2020.148

2.2. Introduction to Temperature Control Method

The difficulty of temperature control lies in its control accuracy. The error of temperature control mainly comes from the inaccuracy of measurement and control. Due to the influence of the external oxide layer and the physical structure of the material, it is difficult to collect the accurate temperature value inside the heated workpiece[4]. At present, there is no ideal temperature measuring instrument or scheme to collect the reliable internal temperature value of the material, resulting in the direct control object of the control system itself can not be effectively and accurately determined. In addition, due to the large inertia and large inertia of the induction heating temperature control system Time delay, strong coupling and nonlinearity make it difficult to guarantee the stability and accuracy of the temperature control system. The most direct way to control the temperature is to control the output of the power supply. The open-loop control method is adopted in the overall scheme of the system, which is the most commonly used method in the classical control theory. This method avoids the uncertainty in the process of temperature acquisition, but it is difficult to achieve the optimal effect for the control of the unsteady system such as induction heating[5]. The parameter setting of classical PID control relies on continuous trial setting, but the induction heating system is a time-varying system. The parameters of the properties of heating materials and the system itself change with the change of temperature. Setting the controller parameters in advance will have a great impact on the control performance of the system, which can not meet the temperature accuracy For the control system with higher requirements, some scholars have adopted several PID controllers to deal with different control variables, such as temperature feedback loop, power parameter feedback loop, etc., in order to compensate for the poor accuracy and stability of the control system caused by the time delay of the system, and achieved certain results. Therefore, some scholars have introduced the intelligent algorithm based on the data statistics law into the system control of electromagnetic induction heating, and achieved a more accurate control effect. This control strategy based on database does not need precise mathematical model, which is very convenient for complex industrial control process. In conclusion, the current temperature control methods of induction heating mainly include PID control, PID optimization control and intelligent control.

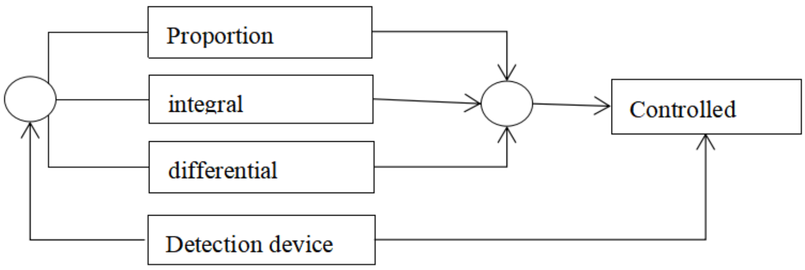

Figure 1 Classic PID control schematic diagram

3. PID Control

3.1. Temperature Monitoring

By analyzing the mechanism of induction heating, Liu Zili established the relationship model between temperature and electrical parameters[6]. On this basis, the PID controller in PLC was used to realize the closed-loop control of the inductor. The essence of calculating the temperature of workpiece by measuring the output power of power supply, ambient temperature, cooling water temperature and flow rate is to improve the control quality of sensor outlet temperature by reducing the error caused by temperature acquisition. Zhao Yajun set up the temperature detection point of the medium around the heater, and calculated the temperature of the heating billet by monitoring the temperature of the air, load and heat sink. On this basis, he established the temperature correction curve by testing the reliability of the collected temperature data in advance, and further reduced the collected temperature value error by error correction. In addition, pulse frequency modulation is used to improve the response efficiency before the peak efficiency of the system[7]. This method aims to optimize the control quality by directly controlling the input error of variables, but the temperature measurement itself has the problems of delay and accuracy, and the same problem will be faced for the temperature collection of the heat transfer medium around the inductor. This method of correcting the temperature value has a high requirement for the fitting error of error correction curve, while the error control of error correction curve involves the sampling data As for the number and diversity of data, just like intelligent control, the correction of prediction curve needs large sample data training to ensure its prediction ability and adaptability. Andrzejfraczyk put forward the precise temperature control of the cylinder billet by moving the inductor, and put forward the scheme of analyzing the temperature movement from the infrared image to correct the error of the measured temperature data, and controlling the inductor to move along the direction of the cylinder billet bus by analyzing the algorithm of establishing the infrared temperature movement image[8]. This requires that the conversion algorithm of graph and temperature value meet the requirements of process accuracy, which is more difficult.

3.2. Control System Structure Optimization

In order to improve the response speed, accuracy and anti-interference of the system on the basis of PID regulation as much as possible, Luo Jijun controls the outlet temperature of the workpiece by controlling the angular speed, electrical parameters and heating time of the intermediate frequency induction heater, the inner loop feeds back the voltage information, calibrates the power supply voltage, the outer loop feeds back the outlet temperature information, and provides the compensation electricity compared with the set temperature Pressure value[9]. The controller improves the overall response accuracy of the system, but the PI regulator is used in both closed-loop loops, which can not control the overshoot problem of the system when it reaches the set value quickly, and will prolong the time from overshoot to stability. Similar to Luo Jijun, Jonathan zerad designed a parallel resonant inverter, using PI algorithm, adding a layer of feedback loop under the classical PID feedback mode. By synchronizing the feedback signal back to the inverter, outputting the signal again and again, the system's robustness and anti-interference ability can be improved. On this basis, Chen Jiemin made a selective choice in the differential link, taking the characteristic parameters such as amplification coefficient, time constant and lag time as the main research object, through the single loop control system, using the incremental PID algorithm to realize the temperature control of the drying cylinder in the case of small scale, large integration time, small or no differential link, and through the experiment The peak value error is about 10 ℃. All the above control strategies fail to consider the temperature uniformity of the whole billet. Jurajkapusta sets different monitoring feedback points in different parts of an approximate linear area to ensure that the temperature of different sections of the billet remains similar and improve the heating uniformity. However, the overshoot problem of PID control itself needs to be solved. It is difficult to control the uniformity without precision.

4. Intelligent Control

Zhu Gang established the neural network self-learning control to solve the temperature control problem. Based on the step response data, he established the network training mode to identify the induction heating object. The experiment verified that the maximum control error was 1.34 ℃, but only trained a set of workpiece model, which is the test of the effectiveness of the neural network intelligent control in the complex industrial process Card. Most of the mathematical models describing the induction heating process are nonlinear equations, which are difficult to solve. Pan Sanqiang established the electric parameter model and electric power model of the heating process through the observation and analysis of the original data in the production process. Due to the loss of information in the mutual conversion of binary and decimal data in the electric parameter model, the prediction accuracy is not as good as the electric power model, and finally used the electric power model to predict the temperature field. On this basis, by adjusting the voltage control curve to control the billet outlet temperature to meet the process requirements. After verification, the control accuracy deviation is about 2%, which realizes the high precision temperature control in the induction heating process of the hot rolling production line. However, this document does not consider the disturbance of batch feeding to the system in the continuous production process of billet, nor the problem of "high head and low tail" of temperature distribution when the billet passes through the heater. After analyzing the heat transfer mechanism of steel pipe, Yang qinta uses the thermodynamic theory of temperature field to model, and from the perspective of power conversion coefficient and temperature coefficient matrix, uses the genetic algorithm to adjust it, which is proved to have high accuracy and adaptability. Zhou Yueqing put forward a kind of fuzzy neural network controller, which trains the traditional fuzzy control rules through neural network, and at the same time uses neural network to establish a control rule to precisely control the temperature change of the system. The control strategy further optimizes the anti-interference ability of the system under the small data samples of neural network control. On the uniformity of temperature control, Youhua Wang proposed a speed control particle swarm optimization (vcpso) algorithm to control the uniformity of the temperature distribution of the strip at the exit of the transverse flux induction heater, which replaced the complex and time-consuming coupling calculation in the transverse flux induction heating (TFIH) problem.

5. Conclusion

The temperature control method of electromagnetic induction heating is reviewed. In recent years, some achievements have been made in the temperature control of induction heating, especially in the application of intelligent algorithm to PID control parameter adaptive regulation and the limitation of PID control optimization. However, intelligent algorithm is needed to be combined in overshoot, overshoot state duration and steady-state accuracy Further optimization through cooperation. For some intelligent algorithms, although the simulation experiment shows that they have superior control performance, once the blank to be processed is replaced, or in the batch production, the model needs to be retrained. The model with strong anti-interference ability and in line with flexible production needs a large number of original data support. The simple intelligent algorithm controls the whole system to achieve flexible production In order to solve the problem, the database of induction heating needs to be established. At present, there is no reliable solution for the uniformity of induction heating, which needs more attention. In addition, the intelligent algorithm is combined with the classical control theory and PID control to optimize the parameter setting process. On the premise of small data, the controller which can more accurately compensate the system delay, has higher stability accuracy, strong robustness and better heating uniformity needs more attention.

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