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Theoretical and experimental research on the law of flexible roll profile electromagnetic control

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ABSTRACT

To obtain a better strip shape, this paper proposes a new micro-scale roll profile control technology. According to the principle of the technology, it can be called roll profile electromagnetic control technology (RPECT). To achieve multi-point and real-time measurement the profile of electromagnetic control roll, the new roll profile test technology is proposed. Relying on the RPECT and new roll profile test technology, a φ270 mm × 300 mm roll profile electromagnetic control experimental platform (RPECEP) is designed and built. An electromagnetic-thermal- mechanical coupled axisymmetric simulation model with the same size is established. Through experiments and simulations, RPECT is confirmed to achieve micro-scale flexible roll profile adjustment. An all-around comparison of experimental results and calculated results confirms that the new roll profile test technology is feasible and the calculatde results agree well with the experimental results. Based on the model, the variation of the roll profile is analysed for different electromagnetic parameters; the structures and positions of the electromagnetic stick, reasonable electromagnetic parameters and optimal time period for the roll profile control are determined, and methods for changing the number of roll profile curves are given.

1. Introduction

In the process of cold-rolled strip, a lot of strip shape control methods have been proposed and researched to obtain a better strip shape, which has greatly improved the quality of strip and obtained great application value. Ginzburg, (1993) introduced CVC (continuously variable crown) technology. The technology uses two s-shaped rolls of the same shape inverted to each other by 180 degrees and two roll axial movement to achieve flatness control. CVC technology can control the strip shape by changing the shape of the roll gap and has been widely applied in industry, but there are significant limitations. On one hand, the roll profile is fixed once it is processed, and the ability of the strip to adapt to different specifications is limited; on the other hand, when using the roll, the original crown wears out, leading to a change in the roll profile that cannot be measured, affecting the flatness control expectations. Therefore, bulging technology with flexible roll profile control has become a focus in the field with wide application prospects.

Currently, bulging technology with flexible roll profile control mainly includes hydro-bulging technology and thermal-bulging technology. Yamada et al. (1982) developed VC (Variable Crown) roll. The VC roll adds a hydraulic chamber between the roll core and roll shell, and the outward expansion crown of the roll shell is controlled by changing the pressure in the hydraulic chamber. Zhang et al. (2008) introduced the principle of DSR (dynamic shape roll) and the analysis of the flatness control behaviour of a DSR mill by using ANSYS software. According to the working principle of VC roll and DSR, hydraulic pressure changes the roll shell crown in the VC roll and DSR roll. However, due to the hydraulic oil seal, the pressure applied to the roll shell is limited; specifically, the pressure of the VC roll is generally less than 60 MPa. Thus, to obtain a larger crown change, the roll shell cannot be too thick. In addition to hydraulic bulging, SUMITOMO METAL IND, (1994) applied for a thermal-bulging technology patent. In the patent, an electrical stick is the primary heat source, and the induction heating technology not be used. For this technology, the heating efficiency is low, the thermal inertia is larger, and the roll crown response speed is slower. Therefore, thermal-bulging technology is still in a patented state. Based on induction heating and metal thermal expansion principle, Yanshan University (2012) proposed roll profile electromagnetic control technology (RPECT) to achieve flexible control of the roll profile. The technology can convert the thermal energy into thermodynamic hybrid power, and greatly enhances the rate

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of roll crown control. For the industrial application of this technology, it needs a lot of theoretical and experimental research.

About the problem of electromagnetic-thermal and electromagnetic-thermal-mechanical coupling, scholars have done a lot research. Song and Moon (2016) analyzed the induction heating for forging of marine crankshaft through FE analysis combined with equivalent circuit model, and the experiments was used to validated the numerical technique. The results show that the numerical technique and the experimental measurements have a good agreement. Fu et al. (2017) designed two induction coil structures, and analyzed the effect of two induction coil structures on the gear heating process through finite element calculations. An experiment was used to validate the simulation results, and the simulation results agreed well with the experimental results. Han et al. (2016) established an electricmagnetic-thermal-movement coupling model, analysed the formation mechanism of hard and soft spots in the internal gear ring, and used an experiment to confirm the accuracy of the research. Wen and Han, (2016) analyzed the effects of circular coils and profile coils on induction heating process of heavy-duty sprockets by finite element modelling, and an experiment was used to validate the simulation results. Yang et al. (2016) established an 3-D electromagnetic-thermal-mechanical couping model, analyzed the electromagnetic loss, temperature and stress distribution of a cable joint under different internal defects, and simplified cable joint experiments was used to verify the accuracy of the coupling model. Based on the previous studies, finite element modelling is commonly used to analyse electromagnetic-thermal or electromagnetic-thermal-mechanical coupling, and experiments are used to validate the simulation results. This model for research problems can also be used for researching the problem in this paper. Meanwhile, these studies also provide guidance for establishing the electromagnetic-thermal-mechanical coupling model in this paper.

In this paper, to determine the effect of electromagnetic parameters, as well as the electromagnetic stick structure and electromagnetic stick on the roll profile and the principle of RPECT, a φ270 mm × 300 mm roll profile electromagnetic control experimental platform (RPECEP) is developed, new roll profile testing technology is provided, electromagnetic- thermal-mechanical coupled axisymmetric model is established, and the PRECT is studied through finite element modelling and experiment.

2. RPECT principle and experiment

2.1. RPECT principle

The core equipment of RPECT is electromagnetic control roll (ECR). And the cores component of ECR are hollow roll, induction coil, electromagnetic stick, electric conduction link, etc. An electromagnetic stick is assembled with the hollow roll. The induction coil is wound on the electromagnetic stick. Both ends of the coil are connected to an induction power supply via electric conduction link. In the ECR, the induction coil heats the electromagnetic stick and hollow roll, causing the temperature of the electromagnetic stick and hollow roll to increase, occuring thermal expansion and generating the contact pressure between the electromagnetic stick and hollow roll, achieved roll profile control, and there can be one or more electromagnetic sticks. In this study, the inner part of the ECR is one electromagnetic stick, the principle shown in Fig. 1. In the induction heating process, area I is heated directly by the induction coil, increasing the temperature; the temperature of area II also increases because the contact heat transfer occurs in the contact area. So, local temperature increase will occur in the hollow roll, causing the roll profile to change. Meanwhile, the temperature of electromagnetic stick increases during induction heating, and the diameter increases too; the local temperature of the hole in the hollow roll increases, the diameter of the hole in the hollow roll decreases. Due to the constraint mechanism of the electromagnetic stick on the hollow roll, the contact pressure on the contact surface will

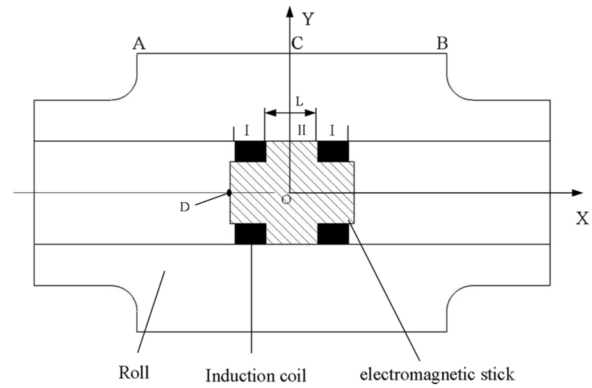

Fig. 1. Principle diagram of the ECR.

increase, which will change the roll crown, the principle shown in Fig. 2.

2.2. Principle of new roll profile test technology

Roll profile test technology is the basis for studying RPECT. However, the roll profile test instrument that can achieve multi-point and real-time measurement with high accuracy is very expensive, so it is unrealistic to use this instrument in the experiment. Therefore, this paper presents a new roll profile test technology. The technology is based on assumptions that the roll, electromagnetic stick and induction coil are ideal cylinders, and the magnetic properties and thermal conductivity of the material remain constant. According to the assumptions, heat from the induction coil is consistent axially but differs circumferentially in the electromagnetic stick, and heat is the same axially but differs circumferentially in the hollow roll. Thus, temperature and circumferential strain are consistent axially but differ circumferentially on the roll surface. It is known that the essence of roll profile measurement is to obtain radius values of the roll in different axial directions. According to the above analysis, the circumferential strain of the roll surface equals the radial strain of the roll surface, so the radial strain of the roll surface can be obtained by measuring the circumferential strain, and roll radius changes can be calculated. Due to long induction heating, the roll surface temperature will slightly increase, affecting measurement results of the circumferential strain on the roll surface, and temperature interference should be excluded. While the relationship between circumferential strain and axial strain on the roll surface are unknown, a bridge circuit cannot be used to balance the temperature interference. In this paper, a temperature compensation strain sensor with low temperature sensitivity is used to measure the circumferential strain of the roll surface. A strain sensor performance test device is used to obtain the heat output of the roll material. Meanwhile, temperature sensors are placed on the same axis but differ circumferentially on the strain sensor to obtain the change of roll surface temperature with induction heating. According to this method, the true strain value of the roll surface can be obtained when temperature interference strain is excluded.

In summary, new roll profile test technology is used to measure the true strain value of a roll surface varying with induction heating by installing strain sensors and temperature sensors in different axial positions of the roll surface. Then, the radius change in different axial positions is calculated, and multi-point and real-time measurement of the roll profile is achieved.

2.3. Design of the RPECEP

According to the principle of RPECT and the new roll profile test technology, the RPECEP is designed and built. The platform consists of ECR, induction power supply and a roll profile test device. The