Recent progress of induction heating technology in Baosteel

C.Y.Wu, X.L.Jin and Y.M.Zhou

Research Institute, Baoshan Iron&Steel Co. Ltd., Fujin Road, Baoshan District, Shanghai,China

Corresponding author: wucunyou@baosteel.com

Abstract
During researching on induction heating technology, attentions are focused on improvement of heating efficiency and heating effect. This paper briefly introduces recent research progress of induction heating technology in Baosteel, that is, development of full coil static induction heating technology of backup roller, developing of induction hardening technology of steel pipe, and research on sparking phenomenon during edge induction heating. A computer simulation method has been established and used in these research subjects, which can precisely calculate the whole heating processes and the system parameters. Based on experimental test and verification, the simulation model has been greatly improved and the corresponding computed results can be directly used as guidance for production process, which makes these research works more efficient and accurate.
Key words: induction heating, computer simulation, backup roller

Introduction

Efficiency, quality and cost are the three primary concerns of steel companies, while EPM technologies mostly deal with matters related to product quality. Regarding the induction heating technology, to maintain the output of a power source in a stable state as well as to obtain a desired temperature value are the most two important objects. Especially, the heating process and uniformity of temperature distribution are always the most concerned objectives in the application of induction heating technology, which mainly depend on reasonable designing of induction coil structure and precise controlling of heating process parameters. With the development of computer simulation technology, the accurate calculation of induction heating process becomes possible, which makes the application of this technology faster and more efficient. In addition, it is easy not only to obtain the heating temperature but also the induction heating system parameters by computer simulation[1-3].

Recently, the EPM team in Baosteel Research Institute has successfully carried out a full coil static induction heating technology for large forged back-up roller, a inner scanning induction heating technology for large steel pipe, as well as the edge heating technology for hot rolled steel plate. This paper gives a brief introduction to the development process and main difficulties of the above mentioned induction heating technologies. Three research topics during induction heating process, which are the end-effect and its countermeasures, the precise control of heating temperature as well as the electromagnetic field analysis under complicate working conditions, have been explored and will be mainly discussed.

Contents

1 Full coil static induction heating technology of backup roller

A full coil static induction heating technology is developed for induction hardening of backup roller, where a solenoid coil with multiple turns covers all the working surface of the heated backup roller during heating[4]. The roller rotates to improve circumferential temperature uniformity, while it is kept relative static to the induction coil in the axial direction. Compare to conventional heat treatment technologies, the full coil static induction heating technology has advantages of much deeper hardened layer and larger hardness value when used for heat treating of backup roller. By using of this technology, wear resistance and service life of the treated roller can be improved so as to reduce production and maintenance costs. Since a backup roller usually has a diameter larger than 1.5 meter and a height higher than 2 meter, it inevitably takes much longer heat treating time than that of conventional induction heating. Moreover, difference of temperature distribution along the whole roller surface is restricted within ± 10 ℃. These requirements make the industry application of this technology hard to realize, unless we can precisely calculate the induction heating system parameters and control the heating process[5-7].

In this study, the backup roller is heated from 450℃ to above 900℃， which has a great change of physical properties during the heating process and leads to a remarkable fluctuation of the heating system load. This phenomenon makes it difficult to precisely control the heating process. As shown in Fig.1, the equivalent inductance firstly drops with increasing of temperature and then finally reaches a stable value. Furthermore, the initial inductance is almost twice as much as that of high temperature, which causes the heating frequency increases almost 50% during the whole heating process under the condition that the load capacitance remains constant. This phenomenon not only greatly influences the stable running of the induction heating system, but also has an important effect on temperature distribution. Since

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the thickness of the induction heated layer is required to be more than 100mm, the heating frequency is usually under 100Hz. On the other hand, the parameters of the induction system changes with the size of the backup roller and its corresponding heating coil, which makes designing of the induction system parameters and control of the heating process more complicated.

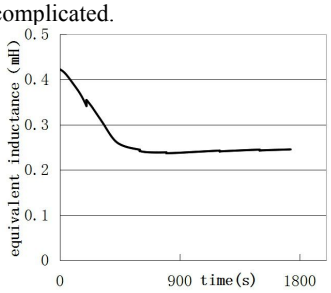


Fig. 1: Calculated equivalent inductance curve over time

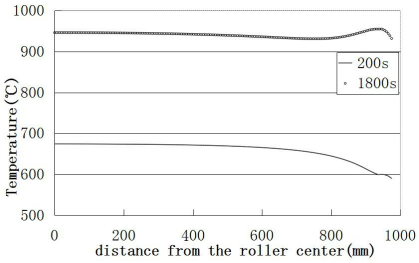


Fig. 2: Calculated temperature curves along the axial direction of roller surface at different temperature

Regarding the temperature distribution, it is relatively easy to obtain a desirable temperature distribution at the radius direction. However, the End Effect inevitably occurs when using a solenoid-type induction coil during the heating process, which makes the roller surface temperature difficult to control[8]. As can be seen in Fig.2, the roller surface temperature along the axial direction presents different features of nonlinear distribution over time, which mainly depends on the coil structure, roller height and coil to roller space. When the roll surface temperature is lower than the Curie temperature, the temperatures at the end part of the roller is much lower than that of the center part. However, when the roll surface temperature exceeds the Curie temperature during induction heating, the temperature at the end part of the roller will rise especially rapid and exceed that of other parts. This means simply changing the induction heating parameters can not improve the uniformity of temperature distribution. To solve this problem, an effective way has been proposed and conducted, which adjusts the heating coils currents separately based on the surface temperatures of the corresponding heated roller parts.

Regarding the hurdles mentioned above, a computer simulation was carried out to accurately simulate the induction heating process and temperature distribution. The simulation model was firstly verified an optimized by experiment results. And the final calculated temperature distribution of the roller along the longitudinal direction is shown in Fig.3, where it can be seen that the temperature uniformity of the roller surface layer is well controlled, while the inner part of the roller remains at relative low temperature. Results of an infrared temperature measurement show that the temperature difference of the entire roll surface is less than ±5 ℃, as shown in Fig.4., where S1~S5 are the temperature curves measured by infrared radiation thermometer at different locations of the roller surface during the final stage of the induction heating process. The five curves all but overlap with each other, which means a very uniform temperature distribution at the entire roller surface has been obtained.

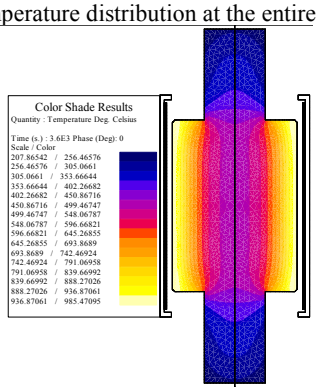


Fig. 3: The calculated temperature distribution after all induction heating stages.

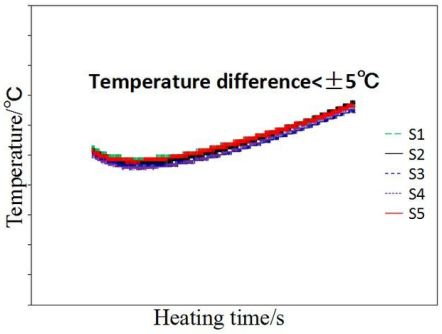


Fig. 4: Temperatures measured at different locations of the roller surface by infrared radiation thermometer.

2. Induction hardening technology of steel pipe

Wear resistance is one of the key performance indexes of steel pipe when it is used for material transportation, which directly affects its service life and cost performance. In the process of steel pipe production, the use of heat treatment technology to improve its hardness and wear resistance is an effective method, and has a wide range of applications in

industry lines. However, for large diameter steel pipes that used for transportation, there are many difficulties in using conventional heat treatment methods. In this study, a scanning induction hardening technology was applied to the inner surface of the steel pipe, so as to improve its inner hardness and wear resistance. By carrying out a series of research works of composition study, computer simulation, physical experiment, temperature measurement, hardness testing and micro-structure analysis etc., a steel pipe with gradient strength distribution along the wall thickness direction has been obtained.

To improve its service life, the steel pipe is preferred to be induction hardened with more than 50% of its wall thickness. Since over-heating will make grain coarsening, it is important to control the maximum temperature below a certain temperature during the heating process. This peak temperature can be controlled by heating power, heating frequency and moving speed of the steel pipe. In order to precisely control the whole heating process, a computer simulation has been carried out. As we know that at a low moving speed, heat conduction becomes dominant, which makes temperature gradient hard to be obtained. As shown in Fig.5, there is a peak value of the inner surface temperature during heating, while the temperature difference along the radius direction soon becomes gentle out of the heating coil, where the temperature difference between the inner and outer surfaces is only within 20 degrees at the starting quenching position. Therefore, in order to increase the temperature gradient, moving speed of the steel pipe should be increased.

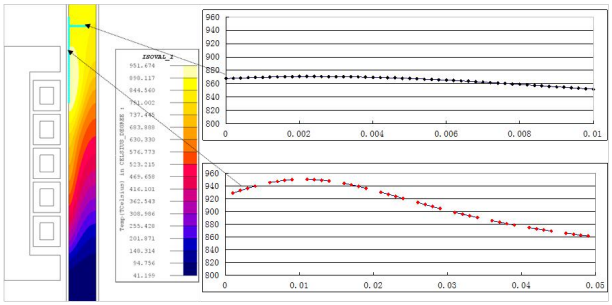


Fig. 5: Computer simulation model and calculated temperature distribution curves.



Fig. 6: Experimental equipment and temperature distribution of the induct heated steel pipe.

An induction hardening experiment has been carried out to study the real heating process and the mechanical properties of the treated steel pipe. The temperatures measured by thermocouples at different location of the steel pipe during the induction hardening process are in well accordance with the calculated results. As can be seen from Fig.6, a high temperature ring with uniform temperature distribution in the circumferential direction of the steel pipe can be seen during the experiment. This ring moves with constant speed and stable temperature distribution during the whole induction hardening process, which guarantees a 1400MPa strength of 10mm thickness of the steel pipe under a suitable steel composition.

3. Research on sparking phenomenon during edge induction heating

An edge heater having a “C” shape connecting core is used for induction heating of hot rolled steel plate. During application of edge heater, a spark phenomenon often occurs, which is induced by discharge arcing between the conveyor roller and the heated steel plate. In order to avoid the occurrence of spark, some preventive measures such as keeping conveyor rollers insulated to the ground, manufacturing the roller with unequal diameter, inputting the nearby coil currents with opposite direction and so on. Because of the bad conditions at the production line, iron scurf and water mist can soon destroy the insulation grade of the roller. It is very difficult to keep the high value of insulation for a long time, which brings great challenge to stable production and maintenance.

Analysis show that the main factors that causing spark phenomenon can be surmised as: (1) surface roughness of the roller; (2) the insulation value of the conveyor rollers; (3) magnitude of the induced eddy current in the contact positions between the conveyor roller and steel plate. The surface roughness and the insulation value of the roller basically depend on field maintenance of the conveyer rollers, while the induced eddy current is influenced by many factors, such as the deviation of the steel plate during moving, the width of the steel plate, the relative position of the coil, the heating power and so on. It is obvious that if the induced eddy current at the positions that conveyor roller contacting with steel plate is small, sparking between the steel plate and the roller is less likely to occur. In this study, the above mentioned factors that affect induced eddy current are analyzed by numerical simulation. The numerical simulation model was verified and optimized by experiment results to improve its accuracy.

It is found that there is a significant difference for different steel plate width in their current density distribution along

the roller to plate contacting line. The maximum eddy current density at the contact line of narrow steel plate is bigger than that of wide steel plate. This result reveals that it is more likely to cause spark when heating a narrow steel plate.
On the other hand, there are usually four coils connected in parallel on both sides of the steel plates. During the heating process, steel plates are easily shifted to one side, which cause the load match unbalanced for the induction heating power system, as shown in Fig.8. It is found that under the same input current, the induced current on more coil-covered side of the steel plate is larger than that on the other side. This result indicates that the probability of spark is greatly increased when the steel plate deviates to one side of the induction coils. Moreover, the above mentioned load match unbalance further strengthens the uneven distribution of input current in the coil, resulting in a great bias on the induced current in the steel plate. Thus, the steel plate will be heated to different temperatures at each side of the steel plate, resulting in uneven physical properties along the steel plate width. Therefore, it is strongly recommended that effective measures should be took to avoid bias of the steel plate so as to decrease spark phenomenon.

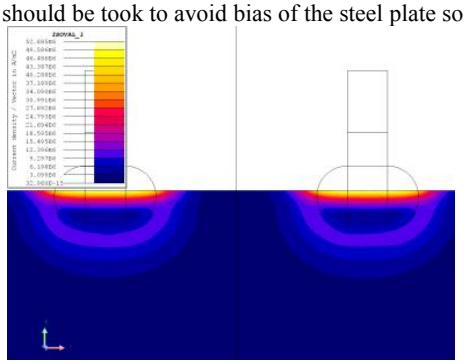


Fig. 7: Current density distribution along the steel plate surface.

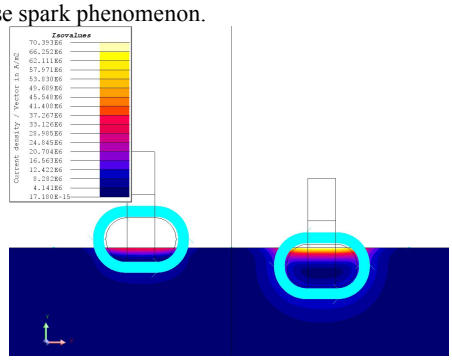


Fig. 8: Current density distribution along the steel plate surface when the steel plate is off-tracking.

Conclusions

This paper mainly focuses on recent researches about applications of induction heating technology in Baosteel, where three research topics related to roller, plate and pipe has been studied. Although shapes of the treated work pieces are very simple in these cases, special requirements make the industry application of induction heating technically difficult. Through the above mentioned researches, following conclusions can be obtained:

1) Computation simulation is an indispensable way in application of modern induction heating technology, which can accurately guide industry process;
2) Sufficient attentions should be paid to non-electrical factors that greatly affect induction heating process, such as moving speed, surrounding condition and so on.

References

1.Yu. A. Samoilovich, Steel in Translation, 45(2015), 73-79
2.S.Nobuo,M.Shinji,E.Shigeru, JFE technical report, 2008, 11,1-6
3.M.Behulova,B.Masek,L.W. Meyer, Materialpruefung, 2006, 48,217-224
4.Union Electric Steel, Forged Roll Heat Treatment[OL], http://www.uniones.com/the-ues-difference/forged-roll-technology/forged-roll-heat-treatment.
5.L.Zhigang,J.Haichao,Z;Feng,et al., Heat Treatment of Metals, 36(2011):115-118
6.C.Tianxiang,W.Zhanjun, Heat Treatment of Metals ,41(2016),149-153
7.W.Cunyou,J.Xiaoli,Z.Yueming,Heat Treatment of Metals, 43(2018),216-221
8.R.E. Haimbaugh,Practical induction heat treating[M],ASM international,2001,50-51