Research on local compensation technology of large diameter steel pipe with heterogeneous structure and analysis of application

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Abstract. When large-diameter steel pipes have special structures with stiffening rings, grouting holes, etc., the electrostatic spray epoxy powder anti-corrosion process is likely to produce large temperature differences due to the sudden thickness changes during heating, which cannot meet the temperature requirements of powder spraying. This paper designs a set of automatic temperature compensation technology for large-diameter steel pipes with stiffening rings and grouting holes, which aims to solve the problem of uneven heating of stiffening rings and grouting holes in the medium frequency induction heating powder spraying process. Through the method of "intermediate frequency heating + stiffening ring temperature compensation", the inner and outer parts of the steel pipe are heated evenly and the temperature difference is reduced. The temperature difference between the inner wall of the steel pipe is reduced to 3~15°C in the area of the stiffening ring, and the temperature is reduced in the area of the grouting hole. The difference is reduced from 70°C to 57°C to 20°C, the temperature difference is controlled within the allowable range of technical requirements, and the temperature compensation effect is good. The process has the advantages of simple device structure, high work efficiency, and small temperature difference in the spraying area, and is suitable for use on similar large-diameter steel pipes or other hydraulic metal structures.

1. Introduction

In the field of anti-corrosion in pipelines, liquid epoxy coatings are widely used [1-4]. This coating has the advantages of simple molding process and complete detection methods. However, because liquid epoxy is cured at room temperature, there may be insufficient curing. Defects such as completeness and low adhesion [5-7]. The epoxy powder is the best coating for the inner wall of steel pipes. However, the existing epoxy powder internal coating molding technology also has many defects, such as complex equipment structure, long installation period, complex molding process, etc., which greatly restrict the ring Popularization and application of oxygen powder coating [8-12].

The epoxy powder coating does not contain organic solvents, which eliminates the loss of solvents and has little environmental pollution [13-15]. The fusion-bonded epoxy powder anti-corrosion layer is a new type of anti-corrosion layer developed in the past two to thirty years [16-17]. It uses electrostatic spraying technology to form a film at one time. The coating has the characteristics of no pollution, strong adhesion, good wear resistance, high temperature resistance, acid and alkali resistance. At present, the application of fusion-bonded epoxy powder spraying anti-corrosion technology in petroleum pipelines (the diameter is usually below 1m) is relatively mature, the
diameter of the steel pipe is small, the structure is simple, the steel pipe heating technology, the use of preheating furnace or intermediate frequency coil outer wall can be heated quickly. The temperature rises to meet the powder spraying temperature requirements. However, in the face of the internal anti-corrosion of the steel pipe with a large diameter and a stiffening ring, the existing fusion-bonded epoxy powder anti-corrosion technology also has many problems, such as the complex structure of the equipment, and the equipment requires a long workbench. The electric load is large, the power requirement of the intermediate frequency power supply is high, the large temperature difference at the stiffening ring affects the heating temperature and the adhesion of the coating, the internal temperature measurement accuracy is not high, the coating thickness is difficult to control, etc., and the epoxy powder cannot be welded. Application of internal corrosion protection under special working conditions. The water pipeline of a water supply project in southern China is a large-diameter steel pipe with an inner diameter of 4800mm, and the thickness of the steel plate is 14~22mm. It has the characteristics of large diameter and small thickness. According to the design drawings, the outer wall of the steel pipe needs to be welded to install the stiffening ring. The stiffening ring is 120mm high, 24mm wide, and 1.5m apart. The inner wall needs to be protected by electrostatic spraying epoxy powder anti-corrosion (FBE) technology. At present, in the FBE anti-corrosion process of large-diameter steel pipes, the heating of the steel pipe is carried out by using multiple sets of intermediate frequency coils arranged on the inner wall of the steel pipe. When the thickness of the steel pipe heating is constant and there is no other special structure, the temperature of the spraying area can be controlled by adjusting the heating power. However, in the face of such a large diameter special steel pipe with stiffening ring and grouting hole, there is no anti-corrosion construction case at home and abroad. If the large diameter, stiffening ring, grouting hole and other special structures are not considered, the stiffening ring and grouting hole when heating the steel pipe. There is uneven heating between the steel pipe and other parts of the steel pipe, and the temperature difference is greater than ±35°C. The temperature difference of the epoxy powder spraying area is required to be within ±10°C. Exceeding the standard will directly affect the overall FBE anti-corrosion spraying effect of the steel pipe. The temperature does not reach or exceed the part Anti-corrosion materials are easy to fall off from the pipe wall or the color becomes black, which affects the quality of steel pipe products.

In order to solve the temperature difference control when the special steel pipe is heated, an automatic temperature compensation device is added to the outer wall. The device moves the steel pipe to be heated axially through the motion module. The intermediate frequency heating module heats the inner pipe wall. At the same time, the steel pipe to be heated rotates around its axis through the rotating assembly. The outside of the steel pipe to be heated is provided with a stiffening ring for detecting the position of the stiffening ring. The temperature compensation heating module that heats the ring part, through the process test application and effect analysis of multiple sets of intermediate frequency heating modules and temperature compensation heating modules, realized that the temperature difference between the inner wall of the stiffening ring, the periphery of the grouting hole and other normal parts of the pipe inner wall is controlled within ±10%.

Figure 1. Schematic diagram of each module.
2. Process introduction of automatic temperature compensation system

The process consists of four parts: motion module, intermediate frequency heating module, supplementary temperature heating module and central control system module (Figure 1).

2.1. Motion module

The motion module uses the anti-corrosion special roller frame to realize the axial screw advancement of the steel pipe, and uses the guide rails arranged on both sides of the roller frame to realize the axial and radial position adjustment of the temperature compensation device as shown in Figure 2. Among them, the driving wheel and the driven wheel of the roller frame are respectively arranged at the two axial ends of the steel pipe to be heated, the driving wheel support is connected with the passive wheel and the support base, and the anticorrosive roller frame is placed on the ground guide rail; the stiffening ring is used for temperature compensation and slurry hole compensation. The temperature device is arranged on the anti-corrosion roller frame on both sides, and the movement is controlled by the electric drive of the control unit.

![Figure 2](image1.png)

**Figure 2.** Schematic diagram of intermediate frequency heating module and supplementary heating.

![Figure 3](image2.png)

**Figure 3.** Stiffening ring temperature compensation and slurry hole compensation device.

2.2. Intermediate frequency heating module

The intermediate frequency heating module uses a 1500kw thyristor intermediate frequency power supply. As shown in Figure 2, the heating method is the inner wall heating of the pipeline, and the inductor adopts a sector-shaped cross array structure, which is divided into 4 pieces (Figure 3). The sensor is connected to the central control system module through the control circuit, and the heating temperature can be automatically adjusted by the central control system according to the production speed, the thickness of the pipe wall, and the desired coating gelation and curing time.
2.3. Complementary temperature heating module
Two high-frequency induction stiffening ring temperature compensation and grout hole compensation devices are arranged on both sides on the anti-corrosion roller rack. As shown in Figure 4, the stiffening ring and the grouting hole are heated by the heating device, and the power is 60KW and 120KW, the power supply adopts IGBT type, and the technical parameters of the temperature compensation power supply are shown in Table 1. Including an axial linear guide, a linear motor set in conjunction with the linear guide, a detection element (photoelectric ranging sensor), an external high-frequency induction heater and a single-chip microcomputer. Among them, the linear guide rail is set on the roller frame; the axial motor is provided with a photoelectric ranging sensor, a radial movement unit and a high-frequency induction heater facing the steel pipe to be heated. The process test process of the intermediate frequency heating module and the supplementary heating module is as follows shown in Figure 5.

| Name                            | Parameter       | 60kW   | 120kW  |
|---------------------------------|-----------------|--------|--------|
| Input power                     | 120kW           | 60kW   |
| Input voltage                   | 342V-430V       | 342V-430V |
| Input current (maximum)         | 180A            | 120A   |
| Frequency                       | 20kHz           | 20kHz  |
| Water temperature protection point | 50°C            | 50°C   |

Figure 4. Physical picture of grouting hole temperature compensation device.

Figure 5. Process flow chart of intermediate frequency heating module and supplementary heating module.
When the steel pipe to be sprayed is heated, the photoelectric distance measuring sensor is controlled to collect the distance between the steel pipe to be heated and the distance value is sent to the single-chip microcomputer; when the above-mentioned distance value changes, the distance value is judged by the program preloaded in the single-chip microcomputer (Figure 6). Whether it becomes larger or smaller, if the distance value becomes smaller, it is the position of the stiffening ring. At this time, the single-chip microcomputer controls the high-frequency induction heater to start working; after the high-frequency induction heater works for 2 to 5 minutes, use the high-frequency induction. The heater heats up the steel pipe stiffening ring to 110°C and keeps it warm (Figure 7). After spraying, the single-chip microcomputer controls the linear motor to move along the linear guide. At this time, the above-mentioned distance value increases from small to large and continues to be maintained; until the distance value decreases again, the above steps are repeated.

2.4. Central control system module
The central control system consists of two parts: real-time picture display and data collection and processing. The real-time picture system includes a set of online video monitoring systems at the spray gun position, the surface position of the steel pipe to be sprayed, and the heating position. The operator of the central control room can follow up the working conditions of the powder spraying area in time. The data acquisition and processing system can automatically collect, record, alarm and other functions for the main equipment, and the entire control system is digitized and visualized. A high-precision thermal imager is installed in the online video monitoring system to detect the temperature of the inner wall of the steel pipe. Figure 8 is a screenshot of the high-precision thermal imager. The performance of the equipment is as follows: (1) Real-time online monitoring, multi-point temperature measurement, and up to 100 temperatures monitoring points can be set. (2) Control, alarm and record the entire heating cycle process. (3) Thermal imager (1024×768 resolution), temperature accuracy ±1.5 degrees Celsius. (4) Spatial resolution: 0.49mRa, thermal sensitivity: at 30°C target temperature, ≤0.05°C.

3. Process performance comparison

3.1. Normal steel pipe
In view of the influence of different steel pipe wall thickness, different welding methods of stiffening ring, different thickness, and different thickness of grouting hole on the temperature uniformity of spraying area, after many tests, the best temperature point of powder spraying area is 210-230°C, The temperature difference is controlled at ±10°C, and the stiffening ring is used to heat the temperature to meet the temperature uniformity requirements.

When the thickness of the steel pipe is constant and there is no other special structure, multiple sets of intermediate frequency coils are arranged on the inner wall of the steel pipe circumference, and the
distance between the steel pipe to be heated and the coil is collected by a photoelectric ranging sensor, and the distance value is sent to the single-chip microcomputer. And the frequency induction heater starts to work. After the induction heater works for 2 to 5 minutes, the steel pipe is heated to 210°C and keeps it warm, as shown in Figure 8. When the spraying is completed, the single-chip microcomputer controls the intermediate frequency coil to move along the linear guide. Through the control of the distance value, the heating power is continuously adjusted to control the temperature of the spraying area within a certain range.

![Figure 8. The working screenshot of the high-precision thermal imager.](image)

**3.2. Stiffening ring area**

It can be seen from Figure 9 that when the temperature of the stiffening ring is not compensated, the temperature of Point 4 outside the stiffening ring area is 184.3°C, while the temperature of Point 1 (Point 1) located in the center of the stiffening ring area is only 145.4°C. The temperature difference of the inner wall of the steel pipe in the adjacent area is 29-40°C, far exceeding the technical requirement of ±10°C.

![Figure 9. Thermal imaging before stiffening ring.](image)

After the stiffening ring is heated (the stiffening ring is heated to 110°C), the temperature difference between the adjacent areas of Line 1~Line 4 is 3~15°C, which can meet the temperature difference requirement of ±10°C, as shown in Figure 10. It can be seen that the temperature difference problem of the stiffening ring is well solved by the stiffening ring.
3.3. Grouting hole area

It can be seen from the thermal image of the grouting hole area before the temperature compensation in Figure 11 that the lowest temperature P3 is only 162.4°C, the highest temperature C1 can reach 231.2°C, and the temperature difference between the adjacent areas of the grouting hole without temperature compensation is 70°C. The temperature compensation function is adopted. Later, as shown in Figure 12, the temperature difference in the spraying area was reduced to 20°C, which met the technical requirements of ±10°C, and the temperature difference problem of the grouting hole was also better solved. In addition, the area within the scope of C1 needs repair welding of grouting holes in the steel pipe circle, so aluminum foil paper is applied to the diameter of the grouting hole area of 300mm without spraying.

Through advanced thermal imaging technology, analysis of the steel pipe stiffening ring, grouting hole, etc., it can be concluded that the automatic temperature compensation process and the technical advantages of the traditional process: the use of external compensation temperature in the steel pipe can effectively reduce the conventional inner wall and stiffening of the steel pipe The temperature difference of the inner wall of the steel pipe at the ring.

4. Conclusions

(1) A set of automatic temperature compensation technology for large diameter steel pipes with stiffening rings and grouting holes is designed by itself. It consists of four parts: motion module, intermediate frequency heating module, supplementary temperature heating module and central control system module, which solves the problem of intermediate frequency induction. In the heating
powder spraying process, the stiffening ring and the grouting hole are unevenly heated, which causes the problem of excessive temperature difference of the steel pipe. Through the method of "medium frequency heating + stiffening ring temperature compensation", the inner and outer parts of the steel pipe are heated evenly and the temperature difference is reduced.

(2) Compared with the traditional FBE anti-corrosion process without heating process, the automatic heating process of large diameter steel pipes reduces the temperature difference of the inner wall of the steel pipe to 3–15°C on the inner wall of the stiffening ring area, and the temperature difference of the inner wall is controlled within the technical requirements. Within the range, that is, 220°C±10°C. Grouting hole area: Compared with the traditional FBE anti-corrosion process without temperature compensation process, this process also achieves a good effect in the grouting hole area, reducing the temperature difference from 70°C ~57°C to 20°C, which is under wall temperature difference control Within the scope allowed by the technical requirements, the supplementary temperature effect is good.

(3) The process has the advantages of simple device structure, high work efficiency, and small temperature difference in the spraying area, and is suitable for use on similar large-diameter steel pipes or other hydraulic metal structures.

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References
[1] Aviles M D, Saurin N, Carrion F J, et al. 2019 Epoxy resin coatings modified by ionic liquid. Study of abrasion resistance[J]. eXPRESS Polymer Letters 13(4) 303-310
[2] Biles J E, Mcneal T P and Begley T H 1998 Determination of Bisphenol A Migrating from Epoxy Can Coatings to Infant Formula Liquid Concentrates[J]. Journal of Agricultural & Food Chemistry 45(12) 4697-4700
[3] Rudakova E V, Kovzhina A L, Evtukov N Z, et al. 2013 Study of physico-mechanical properties of epoxy coatings modified with liquid rubbers with terminal carboxyl group[J]. Russian Journal of Applied Chemistry 86(11) 1760-1766
[4] Kapole S A, Bhanvase B A, Pinjari D V, et al. 2014 Intensification of corrosion resistance of 2K epoxy coating by encapsulation of liquid inhibitor in nanocontainer core of sodium zinc molybdate and iron oxide[J]. Composite Interfaces 21(6) 469-486
[5] James, et al. 2015 Renewable Cashew Nutshell Liquid-Based Product Enables Solvent-Free Epoxy Coatings[J]. Paint & Coatings Industry: Serving Liquid and Powder Manufacturers in the Global Marketplace 31(5) 24, 26, 28, 30
[6] Jeremy Pasatta 2016 Improving Epoxy Powder Coating Durability[J]. Paint & Coatings Industry: Serving Liquid and Powder Manufacturers in the Global Marketplace 32(3) 64-66+68
[7] Yang Y J, Yaakob S M, Rabat N E, et al. 2020 Release kinetics study and anti-corrosion behaviour of a pH-responsive ionic liquid-loaded halloysite nanotube-doped epoxy coating[J]. RSC Advances 10
[8] Radhakrishnan S, Sonawane N and Siju C R 2009 Epoxy powder coatings containing polyaniline for enhanced corrosion protection[J]. Progress in Organic Coatings 64(4) 383-386
[9] Zhang Y, Hu X, Zhao J H, et al. 2009 Rheology and Thermal Conductivity of Diamond Powder-Filled Liquid Epoxy Encapsulants for Electronic Packaging[J]. IEEE Transactions on Components & Packaging Technologies 32(4) 716-723
[10] Huttunen-Saarivirta E, Vaganov G V, Yudin V E, et al. 2013 Characterization and corrosion protection properties of epoxy powder coatings containing nanoclays[J]. Progress in Organic Coatings 76(4) 757-767
[11] Parra D F, Mercuri L P, Matos J R, et al. 2002 Thermal behavior of the epoxy and polyester powder coatings using thermogravimetry/differential thermal analysis coupled gas chromatography/mass spectrometry (TG/DTA–GC/MS) technique: identification of the degradation products[J]. Thermochimica Acta 386(2) 143-151

[12] Ramakrishna H V 2005 Studies on Tensile and Flexural Properties of Epoxy Toughened with PMMA/Granite Powder and Epoxy Toughened with PMMA/Fly Ash Composites[J]. Journal of Reinforced Plastics & Composites 24(12) 1269-1277

[13] Huttunen-Saarivirta E, Vaganov G V, Yudin V E, et al. 2013 Characterization and corrosion protection properties of epoxy powder coatings containing nanoclays[J]. Progress in Organic Coatings 76(4) 757-767

[14] Ajer M R 2012 Studies of epoxy powder coated galvanized steel substrate via electrostatic powder coating system[J].

[15] Armstrong G, Thornton R, Ryan M P, et al. 2012 Formulation of epoxy-polyester powder coatings containing silver-modified nanoclays and evaluation of their antimicrobial properties[J]. Polymer Bulletin 68(7) 1951-1963

[16] Chan L, Bei C and Wu Y 2007 An electrochemical method for evaluating the resistance to cathodic disbondment of anti-corrosion coatings on buried pipelines[J]. International Journal of Minerals and Materials 14(005) 414-419

[17] Li H, Feng X, Peng Y, et al. 2020 Durable lubricant-infused coating on a magnesium alloy substrate with anti-biofouling and anti-corrosion properties and excellent thermally assisted healing ability[J]. Nanoscale 12