Analysis of Demagnetization Characteristics of X70 Steel Based on Permanent Magnet Demagnetization Method

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Abstract. High steel pipelines will generate remanence during work, transportation, inspection, and maintenance. Due to the existence of residual magnetism, high steel pipelines will have magnetic bias during the welding process, resulting in difficulty in pipeline welding, deterioration of welding quality, and even inability to weld the pipeline. In order to eliminate the residual magnetism in the pipeline as much as possible, the X70 steel pipeline is taken as the research object. Based on Maxwell simulation software, the X70 steel pipeline magnetization and dynamic permanent magnet demagnetization simulation model of X70 steel pipeline are established, and the X70 steel pipeline is magnetized and demagnetized respectively. Taking the magnetic field strength and demagnetization speed of the X70 steel pipeline dynamic permanent magnet demagnetization simulation model as variables, the demagnetization rate of the X70 steel pipeline under different magnetic field strength and demagnetization speed is obtained. Based on the response surface method optimization, the response surface method prediction model is established, and the simulation data is imported into the response surface method prediction model. The magnetic field intensity and demagnetization speed of the X70 steel pipeline dynamic permanent magnet demagnetization simulation model are optimized. It is concluded that the demagnetization effect of X70 steel pipeline is best when the demagnetization speed is 1.0 m/s and the magnetic field intensity is 200000 A/m, and the demagnetization rate can reach 70.73%. The research results can provide a theoretical basis for the permanent magnet demagnetization method of X70 steel pipeline.

Keywords: remanence · X70 steel · Maxwell · response surface methodology · demagnetization rate

1 Introduction

Pipeline transport as one of today's world the five modes of transportation, has a large capacity, low cost, safe and reliable and other unique advantages [1, 2]. However, in the process of long-term work, inspection and welding, a large amount of remanent magnetism will be generated in the pipeline, and the existence of remanent magnetism will

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bring huge losses to the safety and economy of pipeline transportation. Remanence refers to the magnetization of ferromagnetic materials due to their exposure to the external magnetic field. When the external magnetic field gradually disappears, part of magnetization remains in ferromagnetic materials, which is called remanence [3, 4]. Remanence mainly includes process remanence and induced remanence, in which process remanence refers to the remanence generated by the construction process, and induced remanence refers to the magnetism generated by the pipeline under the induction of magnetic field. Due to the existence of remanence, pipeline remanence in welding will have a great influence on it, for example: Arc ignition difficulty, ignition inadequate, unstable, coupled with the force of arc column is not strong, the irregular drop transition, can affect weld, cause the bite edge of intermittent or continuous, fusion, such as lack of penetration defects, in addition to arc magnetic blow happens affect the welding process, and even lead to can't normal welding [5, 6].

At present, the main demagnetization methods are DC demagnetization, AC demagnetization, permanent magnet demagnetization and Curie point thermal demagnetization [7, 8]. Due to the limitation of oil and gas pipeline working conditions and length, the above four methods have their own disadvantages in actual working conditions. G. Shelikhov et al. designed and studied a set of permanent magnet demagnetization device, which can realize the relative movement between the pipe and the permanent magnet demagnetization device to demagnetization the pipe. The permanent magnet demagnetization method can realize the demagnetization of long-distance oil and gas pipeline well in practical working conditions and has become a more suitable method for the demagnetization of oil and gas pipeline [9, 10]. At present, there is a lack of research on the demagnetization of X70 steel tube at home and abroad. Therefore, this paper conducts a simulation study on X70 steel tube, analyzes its dynamic demagnetization characteristics, and then optimizes it based on response surface method to obtain the best demagnetization scheme.

2 Demagnetization Principle

2.1 Hysteresis Curve

The hysteresis curve of X70 steel measured by vibrating magnetometer is shown in Fig. 1. The lower curve is the initial curve. The hysteresis curve represents the relationship between magnetic induction intensity and magnetic field intensity of ferromagnetic materials in the process of magnetization and demagnetization. X70 steel is placed in an external magnetic field with a magnetic field intensity of 0 A/m, and the magnetic induction intensity increases gradually. When the external magnetic field intensity is increased to a certain value, the magnetic induction intensity of X70 steel is no longer parallel to B axis, and the magnetic induction intensity of X70 steel reaches saturation value. Then, when the magnetic field intensity of the external magnetic field decreases, the magnetic induction intensity of X70 steel decreases, but it does not return according to the initial curve, but there is a certain lag [11–13]. When the magnetic field intensity of the external magnetic field decreases to 0 A/m, the magnetic induction intensity of X70 steel is still not 0 mT, then it is necessary to add a reverse magnetic field to X70 steel, when the reverse magnetic field reaches a certain value, the magnetic induction

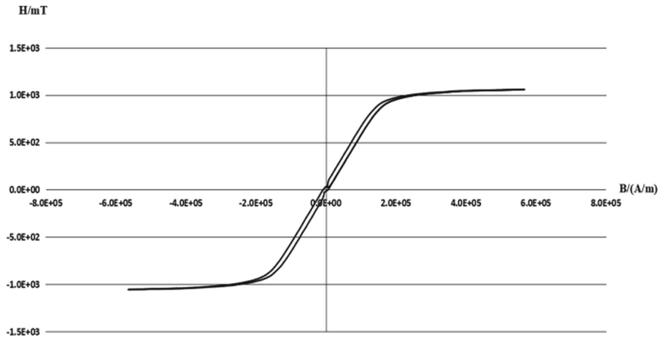
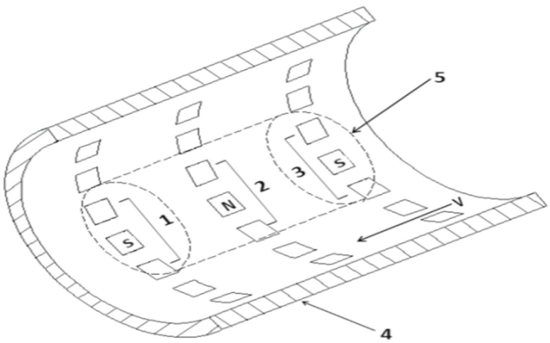


Fig. 1. Hysteresis curve of X70 steel

intensity of X70 steel becomes 0 mT, at this time the value of the reverse magnetic field is the coercivity of X70 steel [14, 15].

2.2 Permanent Magnet Demagnetization Method

The permanent magnet demagnetization method is based on a permanent magnet demagnetization device designed by S. Shelikhov et al., which can realize the relative motion between the oil and gas pipeline and the demagnetization device, and provides a better method for the demagnetization of the oil and gas pipeline, as shown in Fig. 2 and Fig. 3. Figure 2 shows the permanent magnet ferromagnetic ring demagnetization device, and Fig. 3 shows the demagnetization principle of permanent magnet demagnetization method. In Fig. 3, the abscissa is the magnetic field intensity, and the ordinate is the magnetic induction intensity. Every two adjacent magnetic rings in the permanent magnet demagnetization device have opposite magnetic properties. After applying the magnetic field for the first time, the magnetic field intensity increases to H1, and the magnetic induction intensity in the pipeline can change. At this time, the residual magnetic induction intensity in the pipeline is denoted as B1. After a period of time, the reverse magnetic field is applied to this position, and the magnetic field intensity changes to H2. At this time, the remanent magnetic induction intensity decreases to −B2. Then the magnetic field is applied again, and the residual magnetic induction in the pipe decreases to nearly zero. Through the device and the ferromagnetic material by relative movement to gradually eliminate the magnetic in the material. Permanent magnet demagnetization method of X70 steel repeatedly demagnetization, demagnetization to achieve the purpose of demagnetization, but in actual working conditions often make X70 steel in the end of demagnetization and reverse demagnetization phenomenon, resulting in the demagnetization efficiency of the permanent magnet demagnetization method is reduced phenomenon, in order to avoid the occurrence of this kind of situation, When using permanent magnet demagnetization, the magnetic field strength and demagnetization speed of demagnetization device should be controlled.



1- first ring magnet; 2- second ring magnet; 3-third ring magnet; 4 - pipe; 5 - carrier; Direction of v-carrier operation.

Fig. 2. Schematic diagram of permanent magnet ferromagnetic ring demagnetization device

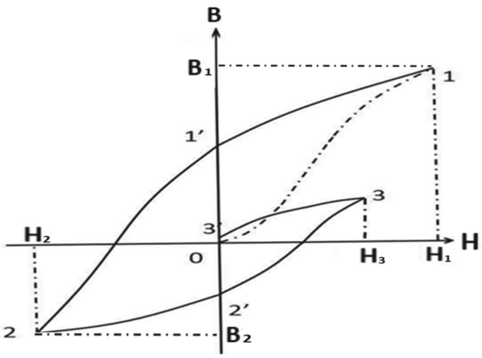


Fig. 3. Permanent magnet demagnetization schematic diagram

3 The Simulation Analysis

Based on Maxwell simulation software, the X70 steel pipeline magnetization and demagnetization simulation model is established as shown in Fig. 4. The simulation model includes X70 steel pipeline, magnetization device, demagnetization device and vacuum domain. The B-H curve of the X70 steel pipe is measured by a vibrating magnetometer and imported into Maxwell; the magnetizing device is a 30 kA, 1500-turn copper coil, and the demagnetizing device includes a yoke and a permanent magnet. The yoke is Steel-1010, and the permanent magnet is NdFe35. The length of the X70 steel pipe is 1000 mm, the outer diameter is 315 mm, and the wall thickness is 15 mm. The X70 steel pipe, magnetization device, demagnetization device and vacuum domain are meshed, and the meshes of each component are divided by different maximum element lengths of regular hexahedron. The X70 steel pipe is wrapped in the dynamic domain

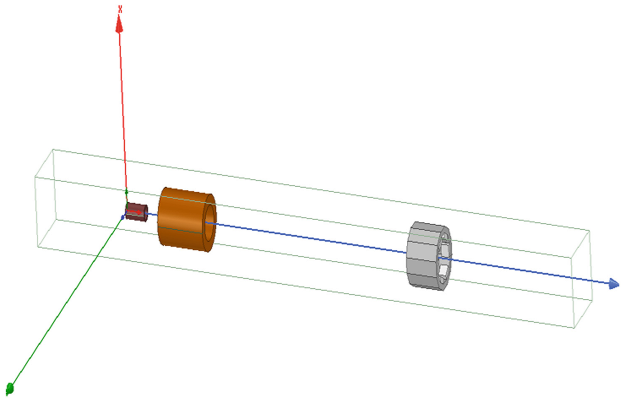


Fig. 4. Simulation model of magnetization and demagnetization of X70 steel

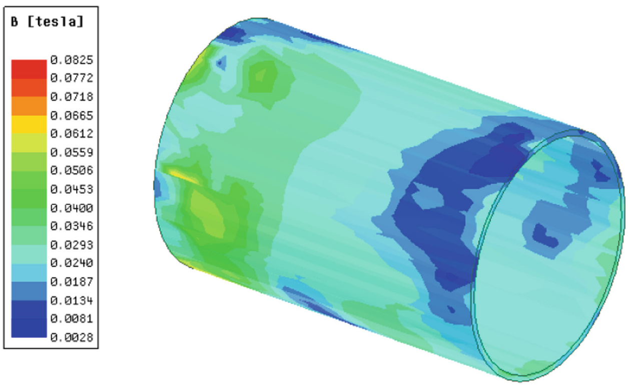


Fig. 5(a). Simulation cloud picture of X70 steel tube after

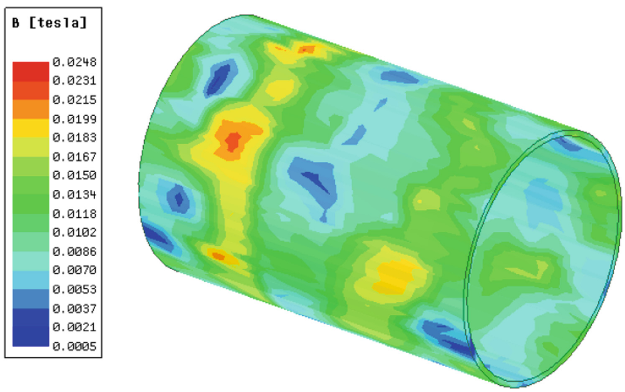


Fig. 5(b). Simulation cloud image of X70 steel tube after demagnetization

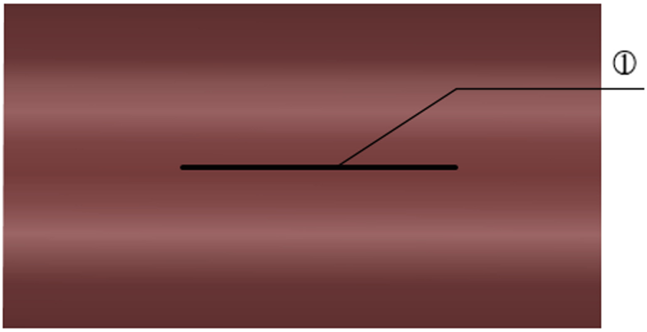


Fig. 6. X70 pipeline magnetic field intensity reference line

through the copper coil and the permanent magnet demagnetization device to realize the magnetization and demagnetization process.

When the magnetic field intensity of permanent magnet is set at 80000 A/m and the demagnetization speed is set at 0.9 m/s, magnetization and demagnetization are carried out to obtain the simulation cloud picture of magnetized X70 steel tube track as shown in Fig. 5(a). The simulation cloud picture of X70 steel tube track after demagnetization is shown in Fig. 5(b). It can be seen from the figure that the maximum magnetic induction intensity of magnetized X70 steel tube track is 82.5 mT and the minimum is 2.8 mT. After demagnetization, the maximum magnetic induction intensity of X70 steel tube is 24.8 mT and the minimum is 0.5 mT, so the demagnetization effect is significant.

The magnetized X70 steel pipe was selected for the experiment, and the straight line at the center of the surface of the X70 steel pipe was used as the reference line, as shown in Fig. 6. The magnetic induction intensity before and after demagnetization at each point on the line was obtained by simulation, and the magnetic induction intensity before and after demagnetization at each point on the line was obtained by curve fitting, as shown in Fig. 7.

The best demagnetization rate of permanent magnet demagnetization method was studied by changing the magnetic field intensity and demagnetization speed of permanent magnet demagnetization device. Through preliminary experiments, the pipeline demagnetization speed is about 1 m/s when the demagnetization is more uniform. So the magnetic field intensity increased from 80000 A/m to 280000 A/m, and the demagnetization speed increased from 0.9 m/s to 1.1 m/s. The magnetic induction intensity data before and after demagnetization of each point on the straight line in Fig. 6 are used to calculate demagnetization. The calculation formula of demagnetization is shown in Formula 1. There are 18 groups of simulation, as shown in Table 1.

$$\eta = \frac{B1 - B2}{B1} \tag{1}$$

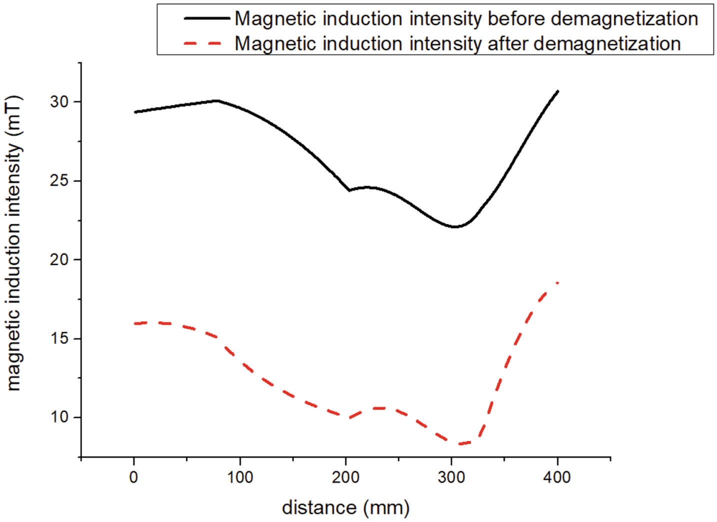


Fig. 7. Magnetic induction intensity before and after demagnetization

Table 1. Simulation data

demagnetizing index%						
speed of demagnetization (m/s)	80000 A/m	120000 A/m	160000 A/m	200000 A/m	240000 A/m	280000 A/m
0.9	57.14	61.48	68.49	70.68	65.28	61.51
1.0	62.49	68.56	70.15	70.73	69.62	68.57
1.1	66.39	70.60	57.50	18.66	11.04	12.13

The data in the table are fitted into a curve as shown in Fig. 8. It can be seen from the figure that the demagnetization rate will increase gradually with the increase of demagnetization rate and magnetic field intensity, but there is a maximum value of demagnetization rate. When the demagnetization rate exceeds this maximum value, the magnetic field intensity and demagnetization rate will continue to increase, resulting in a reverse demagnetization rate.

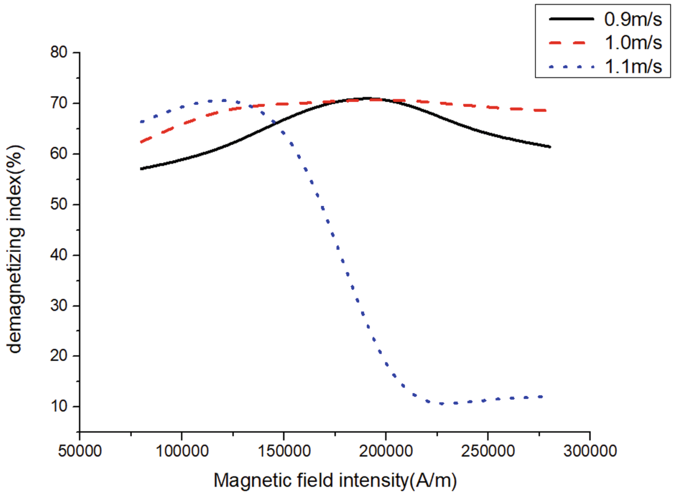


Fig. 8. Relationship between demagnetization velocity, magnetic field intensity and demagnetization rat

4 Response Surface Methodology

When X70 steel tube is demagnetized based on permanent magnet demagnetization method, there will be a reverse demagnetization phenomenon after demagnetization. It can be seen that there is a maximum value of demagnetization rate when magnetic field intensity and demagnetization speed are variables of permanent magnet demagnetization method. Response surface method was used to optimize the demagnetization simulation data, and then the best demagnetization rate of X70 steel tube by permanent magnet demagnetization method was obtained. Response surface method is a statistical method to solve multivariable problems by fitting the relationship between variables and response values by selecting appropriate data points and functions according to the distribution of a series of data, and then analyzing the regression equation and the obtained images to find the optimal process parameters.

Set demagnetization rate as, magnetic field intensity and demagnetization speed as variables, magnetic field intensity from 80000 A/m to 280000 A/m, demagnetization speed from 0.9 m/s to 1.1 m/s as constraints, and establish the objective function as shown in Formula 2.

$$\begin{cases} Min\,\eta(H, v) \\ 80000 < H < 280000 \\ 0.9 < v < 1.1 \end{cases} \tag{2}$$

Regression equation and image fitting processing were carried out on simulation data to obtain the relationship between demagnetization velocity, magnetic field intensity and demagnetization rate, as shown in Formula 3, and the image is shown in Fig. 9.

$$\eta = -163.37 + 234.14 \times v + 2.09 \times 10^{-3} H - 2.17 \times 10^{-3} \times v \times H \tag{3}$$

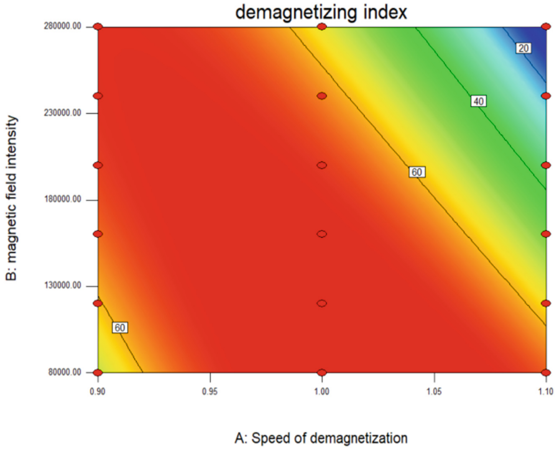


Fig. 9. Response surface method optimization diagram

Table 2. Optimum demagnetization

speed of demagnetization (m/s)	magnetic field intensity (A/m)	demagnetizing index%
0.9	200000	70.68
1.0	200000	70.73
1.1	120000	70.60

In the response surface method optimization figure, the dark red area indicates that the demagnetization effect is better within the range of magnetic field intensity and demagnetization speed, while the green area indicates that the demagnetization effect is worse within the range of magnetic field intensity and demagnetization speed. As can be seen from the figure, when the magnetic field intensity and demagnetization speed are large and small or both are moderate, the demagnetization effect of permanent magnet demagnetization method on X70 steel is better. On the other hand, when the magnetic field strength and demagnetization speed are both large, the demagnetization rate is poor, indicating that the demagnetization of X70 steel by the permanent magnet demagnetization method has already occurred in the reverse magnetization phenomenon, so that the demagnetization rate not only does not increase but decreases. The optimization diagram of response surface method verifies that the demagnetization rate of permanent magnet demagnetization decreases greatly in the process of repeated magnetization and demagnetization due to the demagnetization still continuing after the demagnetization. In order to avoid reverse magnetization in actual working conditions, the relationship between magnetic field intensity and demagnetization speed needs to be controlled. The optimal demagnetization rate in simulation data is shown in Table 2.

5 Conclusion

(1) Based on Maxwell simulation software, the dynamic simulation model of magnetization and demagnetization of X70 steel tube was established. It was concluded that the demagnetization effect of X70 steel tube was the best when the demagnetization speed was 1.0 m/s and the magnetic field intensity was 200000 A/m, and the demagnetization rate could reach 70.73%.

(2) Based on the optimization design of response surface method, the prediction model of response surface method was established, and the relationship between the demagnetization rate, demagnetization speed and magnetic field strength of X70 steel tube meets was obtained, and the reverse demagnetization phenomenon occurred in permanent magnet demagnetization process was verified.

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