Novel Demagnetization Method after Magnetic Particle Testing

Takuhiko Ito†, Arihito Kasahara and Michitaka Hori

Nihon Denji Sokki Co., LTD, 8-59-2 Sunagawa-cho Tachikawa-city, TOKYO, JAPAN.
†E-mail: t-ito@j-ndk.co.jp

Abstract

1. Introduction In standards related to nondestructive inspection, it is stipulated that demagnetizing an inspection object after magnetic particle flaw detection test. Generally, when the influence of magnetization becomes a problem in the post-process of the magnetic particle testing, it is necessary to demagnetize the inspection object. 2. New demagnetization method after magnetic testing. It is difficult to demagnetize by the conventional method. Proposal is proposed. As a method of canceling the influence of the external magnetic field, it is necessary to offset small current. We call it NS balance value adjustment function. Variable demagnetizing current value and magnetic field frequency depending on moving speed and material thickness. 3. Basic experiments and results First, basic demagnetization test by coil method was carried out and it is reported. In the coil method, in the case of AC magnetization, the inspection object is generally demagnetized by gradually reducing the alternating current. In demagnetization, it is often influenced by external magnetic field and geomagnetism, and as a method of canceling the influence of the external magnetic field, we propose a small current offset (NS balance value adjustment function) and show its effect. 4. Demagnetization for thick steel plate Next, the method and test results are reported on the application of demagnetization in the case of thick steel plates. When the thickness of the material is large, it is necessary to decrease the frequency and increase the demagnetization current value. However, it is necessary to design the length of the demagnetizing coil beforehand in consideration of the maximum value of the conveying speed. In the case of demagnetizing the thick plate transported in this paper, we report the proposed demagnetization method and test results, and confirmed the effectiveness of the demagnetization method proposed. 5. Conclusion In this paper, we propose the optimum demagnetization method, and conducted basic experiments to confirm its effect and reported the results. As its application, we proposed a demagnetizing method for thick steel plates and confirmed its effectiveness by testing. Demand for demagnetizing ability in industrial world has become severe.

Keywords: Magnetic Particle Testing, magnetic field strength, magnetization, demagnetization, magnetic flux density, residual magnetic flux density
1 Introduction

In JIS Z2320-1, ISO9934, and ASTM E1444 concerning Magnetic Particle Testing (MT), it is stipulated that Demagnetization is performed according to conditions. In MT, magnetize the object to be inspected (=DUT), magnetic particle of testing liquid adheres to magnetic flux leaks phenomenon which generated in the defective portion, and judges the presence or absence of defects from magnetic powder pattern to perform the inspection. Since MT is performed by sufficiently magnetizing DUT, then sends to post process in the magnetized state. In the case where the influence of magnetized state becomes a problem in the post process. For example, adhesion of iron powder or processing, it is necessary to demagnetize DUT to send it. In this report, the magnetized state of DUT after MT was confirmed, Novel Demagnetization Method was proposed along with general demagnetization principle, and a basic demagnetization experiment was conducted and reported. We report the demagnetization of steel plate as an application example. We also mention issues such as the influence of external magnetic field and demands on demagnetization accuracy in industry.

2 Magnetization in Magnetic Particle Testing

The basic principle diagram of MT is shown in Figure 1. Magnetize the steel material, magnetic particle of testing liquid adheres to magnetic flux leaks phenomenon which generated from the crack/flaw, and it is done by observing the indication of that part which irradiate with black light.

![Figure 1: The basic principle diagram of MT.](image-url)
Magnetization method as shown in Figure 2, axial current method, coil method, through conductor method, through flux method are mainly used. In order to magnetize DUT, it is selected from alternating current, single-phase half-wave and full-wave rectifying, three-phase full-wave rectifying, pulse type. The magnetized state of DUT by these magnetization currents is different. The penetration depth of the magnetic field differs depending on the frequency of magnetizing current, magnetic permeability and conductivity of DUT. As the frequency of magnetizing current decreases, the magnetic field permeates deeply. When the frequency is high, the magnetic field concentrates on the surface layer portion. When a crack/flaw to be inspected is located in the surface layer portion uses AC. And in the case where located inside the surface layer often uses single-phase half-wave rectifying in which the direct current. It is confirmed experimentally how the magnetic field penetrates depending on the type of magnetizing current.

As an example shown in Figure 3, AC and single-phase half-wave rectifying are applied to DUT of a soft magnetic material having 50mm diameter and 150mm length by axial current method. A slit with 3mm width was machined on DUT, and measured the magnetic flux density (=B) inside the steel material with a Tesla meter.
Table 1 shows the magnetization state inside the steel material using AC. The horizontal axis shows the distance from the surface of the steel material to the center direction, the vertical axis shows B. It can be seen that B concentrates on the surface layer in AC magnetization. Table 2 shows the magnetization state inside the steel material using DC. It can be seen that in DC magnetization, the center portion only decreases to about 1/2 with respect to the surface layer portion, and the magnetic field penetrates into the inside portion. In the figure, the magnetization state by the magnetization current shows in increments of 200A from 200A to 1200A in peak value. From this result, it was confirmed that in the case of DC magnetization, the magnetic field penetrated inside the steel material. Steel plate etc. are often carried out by electromagnets suction in transportation, so it is considered that there is a high possibility residual magnetism will remain inside.

### Table 1: AC magnetization B

<table>
<thead>
<tr>
<th>Distance from the surface (mm)</th>
<th>B (mT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>40</td>
</tr>
<tr>
<td>5</td>
<td>30</td>
</tr>
<tr>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>20</td>
<td>0</td>
</tr>
</tbody>
</table>

### Table 2: DC magnetization B

<table>
<thead>
<tr>
<th>Distance from the surface (mm)</th>
<th>B (mT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>60</td>
</tr>
<tr>
<td>5</td>
<td>50</td>
</tr>
<tr>
<td>10</td>
<td>40</td>
</tr>
<tr>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

### 3 General Demagnetization method

#### 3.1 Demagnetization principle

Generally, as a method of demagnetizing a magnetized steel material, there are applying magnetism and heat. In the case of applying heat, it is necessary to heat the steel material to the Curie temperature (Fe=770℃), the equipment becomes bigger and the processing time also increases. For this reason, a method of demagnetization used by applying magnetism in general. The method of applying magnetism as shown in Figure 4, the magnetic field strength (=H) applied to the steel material is alternately applied from H at saturation magnetization in the positive and the negative direction, gradually decreasing and attenuating to zero.
The method of gradually decreasing the magnetism as shown in Figure 5, there is generated a constant alternating magnetic field in the coil and $H$ applied to the steel material weakened by keeping the steel material away from the coil. And there is weakened the energizing current gradually in order to gradually weaken the alternating magnetic field generated in the coil. In general, the distance attenuation method for penetrating the steel in the coil can be simple, demagnetization processing time is short, and the cost lowered. An example is shown in Figure 6.
3.2 The definition of Demagnetization in Standards

Demagnetization after the MT is carried out by attenuating the current from a current larger than the magnetization current to zero when the magnetization uses the axial current and coil method. Alternatively, Demagnetization may be performed by passing DUT through an alternating magnetic field in the air-core coil. In the case of AC magnetization, it is demagnetized by AC, and when it is magnetized with DC, demagnetization is performed by using low frequency or DC Inversion method. The demagnetization accuracy is defined as "Standard value 0.4 to 1.0kA/m (B=0.5 to 1.25mT) in JIS-Z2320, confirmed that has been demagnetized using Tesla meter etc. as necessary after demagnetization". In ASTM E1444-12 used for MT of aircraft parts etc., it is stated that the magnetic field should not be detected 0.3mT or more in absolute value by the calibrated Field Indicator.

Figure 6: Tunnel type demagnetizer an example of distance attenuation method.

Photo1: Field Indicator.
3.3 Method of measuring residual magnetic flux density

In measuring the residual magnetic flux density (Br) after demagnetization, it is common to use a magnetic flux density meter (Tesla meter) by a Hall element. Since the Hall element has a small magnetosensitive surface, it is possible to measure Br locally and accurately over the details of DUT. However, since the measured values are different depending on the distance to the magnetosensitive surface and the size of it, attention must be paid to the characteristics of the sensor probe of the measuring instrument. In ASTM standard, Field Indicator is used to confirm demagnetization accuracy. Regarding the performance evaluation of demagnetization, not only the evaluation that B after demagnetization is less than some mT. It defined the mechanical ability to demonstrate the quality ability by demagnetizing continuously, demands for demagnetizing ability are increasing. In some cases, accuracy evaluate the dispersion of demagnetization. The DUT of MT is a ferromagnetic material and the magnetic permeability is high, the magnetization state changes with the strength of minute magnetic field, so it is susceptible to the influence of geomagnetism and external magnetic field. It is thought that it is necessary to sufficiently define the measurement method and environment.

4 High accuracy Demagnetization method and demagnetization result

4.1 High accuracy Demagnetization method

When magnetized by AC in the coil method, it is common to attenuate the current with AC to demagnetize. In demagnetization, it is often affected by the geomagnetism and external magnetic field, and caution is required when strict demagnetization accuracy is required. As a method of canceling the influence of the external magnetic field due to the geomagnetism and external magnetic field etc. in order to balance in the coil. We devised to adjust H by offsetting the energizing current in the positive or negative direction (referred to as NS balance). When an external magnetic field acts, the intensity of the magnetic field of the vermillion in Figure 7 is applied and residual magnetism remains. For this reason, an offset current is superimposed on the demagnetization current and the action of the external magnetic field is canceled.
4.2 Basic Demagnetization experiment

We report the basic demagnetization test in the coil method. In order to carry out the experiment, there were used as a sample that an air core coil having 350mm diameter, 80mm length, 5 turns, and a soft iron bar having 22mm diameter, 580mm length. B of the coil center is 12.5mT/1000A. Table 3 shows Br at both ends of the sample when the AC magnetizing current was increased from 200 to 1000A at every 200A. In the table, Top indicates one end portion of the bar and Bottom indicates the other end portion. As a result, it can be seen that the sample steel is saturated at a magnetization current of about 1000A.
Demagnetization was carried out using a magnetically saturated steel material. In order to confirm the effectiveness of the NS balance, it is confirmed the change in \( B_r \) when the current was offset. Table 4 shows the results of \( B_r \) how becomes at both ends of the sample when the demagnetizing current is offset. To achieve high accuracy demagnetization, the offset value (NS balance value) is varied to obtain the optimum NS balance value from the magnitude of \( B_r \) at both ends of the sample. For example extremely, it is offset to the \( N \) (+) pole side to measure \( B_r \), then, it is offset to the \( S \) (-) pole side to measure \( B_r \), and the optimum value of the NS balance can be found out the \( B_r \) intersection of the straight lines at the both ends (Top and Bottom). The horizontal axis indicates the NS balance value, and the vertical axis indicates \( B_r \). When the NS balance value was 49, it was confirmed that \( B_r \) was \( S \) pole 0.13mT & \( S \) pole 0.06mT, and demagnetization was possible with high accuracy. Using the sample magnetized at 1000A, varied AC demagnetization current value.

<table>
<thead>
<tr>
<th>NS balance value</th>
<th>( B_r ) (mT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-12</td>
</tr>
<tr>
<td>50</td>
<td>-8</td>
</tr>
<tr>
<td>100</td>
<td>-4</td>
</tr>
<tr>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>50</td>
<td>8</td>
</tr>
<tr>
<td>100</td>
<td>12</td>
</tr>
</tbody>
</table>

Table 4: Demagnetization adjustment (NS balance mechanism) result.

\( B_r \) at both ends of the sample after demagnetization by current attenuation are measured and the results are shown in Table 5. At around 600 to 800A, \( B_r \) satisfied less than the JIS standard 0.5mT. \( B_r \) when measuring DUT in the east-west direction is indicated by a solid line, and in the north-south direction is indicated by a dotted line. It can be seen that \( B_r \) has changed by about 0.2mT at the maximum due to the influence of geomagnetism. It is conceivable that the amount of change further increases for DUT is a long product.
Table 5: Br result after demagnetization.

5 Demagnetization in the line of Iron and Steel

5.1 Proposal of running type demagnetization for steel plate

In the case where the steel sheet is magnetically transported by a magnet chuck etc. after MT in the steel line, demagnetization must be performed before shipment. And steel sheet is conveyed by a magnetic chuck such as DC, the inside of the steel sheet is often magnetized. When demagnetizing the steel plate in the steel line, the frequency of demagnetized alternating magnetic field and the length of air-core coil generating the magnetic field become important due to the thickness of the steel plate and the conveying speed. The penetration depth of the magnetic field differs are,

\[
\delta = \sqrt{\frac{\rho}{\pi \mu_0 \mu f}} \quad (\text{Penetration depth [m]})
\]

\[
\rho: \text{Resistivity [\Omega \cdot m]} \quad f: \text{Frequency [Hz]}
\]

According to, it is necessary to obtain sufficient penetration depth with the frequency lowered. Furthermore, since demagnetization is performed within the range where the magnetic field by the air core coil acts, the length of the coil is also an important factor. In order to obtain magnetically saturating the steel sheet, H at the center of the coil is, in general,

\[
H = \frac{N \cdot I \cdot L}{2(r_2 - r_1) \cdot \ln \frac{r_2}{r_1} + \sqrt{r_2^2 + (L/2)^2} + \sqrt{r_1^2 + (L/2)^2}}
\]

H: Coil center magnetic field \quad N: Coil turns \quad I: Current 

r1: Inner diameter \quad r2: Outer diameter \quad L: Coil length
Represented by that. The demagnetization power supply considers the influence of the demagnetizing field, and requires a current capacity to obtain a sufficient strength of the magnetic field. In the steel line, it is necessary to consider the frequency of generated magnetic field, the coil length, and the demagnetization power source sufficiently. In general, the steel plate is kept stationary on the production line, demagnetization is performed by DC Inversion method in which the magnetic field is attenuated slowly by alternatingly changing the direction of the DC magnetic field while moving the air-core coil. In order to improve work efficiency this time, we attempted to demagnetize with the steel plate carrying on the line. In the case of demagnetizing a steel plate long in the longitudinal direction, it is susceptible to the external magnetic field, so it is necessary to consider canceling the influence of external magnetic field. It is also conceivable that the magnetization locally remains at the central part of the steel plate, and integrates the voltage induced in the search coil as the steel plate passes through that. It may be thought that it is necessary to check the demagnetization situation by measuring the total magnetic flux amount, but this time evaluation was carried out by measuring $B_r$ of the end face of the steel plate.

With commercial AC, the frequency is high and the "Skin Effect" appears, so that the magnetic field permeates only to the surface of the work and the inside may not be demagnetized. In that case, it is necessary to permeate the magnetic field to interior for demagnetizing by lowering the frequency. The larger the volume and area of DUT, the more time it takes for the magnetic field to penetrate inside. Judging from past experience, it is considered that when the thickness is 400mm, the magnetic field penetrates into the interior at the inversion speed of about 1Hz. The inverter demagnetization current is a frequency modulation type AC current, and it can be used modulated to an arbitrary frequency with respect to the commercial frequency. The inverter has high current rise time and can be reversed without requiring a pause time, so the number of steps in a fixed time is large. Furthermore, since the current inversion can be performed at a higher speed than DC, it is also suitable for high speed running demagnetization. In the case of ordinary DC is used at a frequency of about 0.5 to 1Hz, but inverter is possible to use it at 0.5 to 20Hz.

5.2 Demagnetizing Equipment

Basically, the Demagnetizing Equipment is composed of a demagnetizing power supply and demagnetizing coil (air-core coil). In designing demagnetizing power and demagnetizing coil, it is also important to know the strength of magnetic field that saturates the steel plate. A sample steel plate 200x300x25mm was placed in the coil and tried to magnetize. The relationship between the
magnetization current and $H$ at the center of the air-core coil is shown in Table 6. It is about 70mT at 2000A. Table 7 shows the results of actually confirming the magnetization state, where the horizontal axis shows the magnetization current and the vertical axis shows $B$ at the end. It is understood that the steel plate is saturated at about 60mT at 1500A.

![Graphs showing $B$ vs. Magnetization current](image)

**Table 6:** $B$ at center of air core coil.  
**Table 7:** $Br$ of steel plate after magnetization.

Demagnetization was attempted by changing the demagnetization current of the sample steel plate after magnetization. The results are shown in Table 8. The demagnetization current is the result of attenuation with positive and negative repetition slowly from each initial current value with initial currents of 500, 1000 and 1500A. When the initial current was 500A, $Br$ was about 1mT, but it was confirmed that when the initial current is 1000 and 1500A, $Br$ can be set to about 0.25mT. It was confirmed that the steel plate could be demagnetized by using an air-core coil having $B$ of about 40 to 60mT which is about 1000A.
5.3 Demagnetization result of steel plate

In order to actually demagnetize the steel plate, demagnetizing power and demagnetizing coil were manufactured and tested on actual steel line. The opening of coil through which the steel plate passes is 4.7×0.7m, and the length is 1m. In the case where the steel plate passes at 6m/min, the time required to pass through the length coil 1m is 10seconds. Since this method is based on the distance attenuation method, the spatial magnetic field continuing from the demagnetizing coil in the longitudinal direction is important. In order to penetrate the magnetic field to the inside of the steel plate sufficiently, the frequency can’t be made high like the commercial frequency, the frequency of the demagnetizing current is set to about 1 Hz so that an alternating current can be passed.
Table 9 shows an example of the results of demagnetization using a steel plate with 50mm thickness, maximum 4.5m width, 9m length, and conveying speed of 6m/min. The NS balance value is shown on the horizontal axis and Br is shown on the vertical axis. As a result, it was confirmed that by setting the NS balance value to about 52.3, demagnetization can be performed up to about 1.7mT at the edge of the steel plate.

![Graph](image)

**Table 9: Demagnetization result of steel plate.**

This time, we proposed a method of demagnetizing while transporting a thick steel plate, but it can also be applied to steel bars and pipes etc.

### 5.4 Other examples

In the Eddy Current flaw detection line for steel pipes, the magnetization is DC excitation and is magnetized up to the center portion of the steel pipe. As a countermeasure against demagnetization, attenuation is applied in a saturated state and the residual magnetism is eliminated. (Figure 8)
In demagnetization line of steel bars, flux amount can be measured using flux meter. The unit is Weber (Wb), it will change the magnetic flux to the sensor part (coil) and time-integrate the induced voltage. (Figure 9)
6 Conclusions

The magnetization state of DUT during AC and DC magnetization in MT was confirmed experimentally. In DC magnetization using single-phase half-wave rectifying, it was confirmed that B was about 1/2 at the center part with respect to the surface layer. In demagnetization, it is thought that it is necessary to consider the magnetization method sufficiently. We conducted fundamental experiments on the optimal demagnetization method and proposed NS balance method to cancel the influence of external magnetization and reported its effect. Demand for demagnetizing ability in industry is becoming severe. From now on, strict management is required for the intensity of a minute magnetic field near zero at demagnetization, the measuring instrument and the measurement environment after demagnetization. As an example of this method, the test results are shown by demagnetization of the steel plate during transportation online. In the future, comprehensive demagnetization method including demagnetization evaluation method will be examined and reported.

References