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Magnetization and Demagnetization of Ferromagnetic Materials Staying in Static State in Geomagnetic Field

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Abstract

The objective of this study was to seek the reason causing the spontaneous magnetization and automatically demagnetization of ferromagnetic materials staying in static state in the geomagnetic field. Through the theoretical analysis on magnetism metallography and the experience of magnetic particle testing The answer may be considered as follows: The magnetic ageing——the magnetism of ferromagnetic materials and the spatial arrangement of magnetic domains all lag behind the magnetizing field applied upon them. The periodical changes of the geomagnetic field strength in magnitudes and directions with the passage of time. Ageing of metals——the increasing of mechanical stress in the materials versus time induces the change of magnetization curve and metallographic constitutional changes as well as the appearance of the delayed cracking etc. These understanding will provide theoretical guide and support for magnetic particle inspection and metal magnetic memory testing and diagnostics.

Keywords:
Magnetization, Demagnetization, Ferromagnetic, Static State, Geomagnetic

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Background to the Study

The spontaneous magnetization of the objects made from ferromagnetic materials rotating or moving parallel in the geomagnetic field have been respectively discussed in references [1]～[3]. But in the nature there still exist two phenomena different to these—— ferromagnetic materials staying in static state in geomagnetic field not only can be magnetized spontaneously, but also may be demagnetized automatically. The following analysis will be carried out to clarify their causes.

Spontaneous Magnetization and Automatic Demagnetization Met in Practice

Many magnetic NDT persons have experiences as follows: Some work pieces, which have been examined by magnetic particle testing and demagnetized fully staying in static state for a period of time possess magnetism again. The magnetism of some parts intensely spontaneously magnetized decreases gradually with the passage of time. For example, in January of 1980, when a 23 MW gas turbine was manufactured in Nanjing Turbine and Electric Machinery Works Nanjing, China, it was found that the rotor shaft can attract a 12 inches screw-driver at power end and bearing neck of the shaft, but in April of that year only three needles (every one weighs 0.08 gram approximately) could be attracted up[4]. The magnetism calibrated for a magnetic standard specimen in a laboratory of a university has been found changed at the worksite. The reason causing the magnetization by machining and magnetization through operation of machinery was preliminarily analyzed in reference [5]. And what leads to the changes mentioned above?

Magnetic Domain Construction and Magnetic ageing

1. In magnetism[6~8], it is believed that the ferromagnetic materials consist of a lots of small
2. Region magnetic domain, magnetized spontaneously to saturation. The magnetization of every magnetic
3. Domain M keeps constant in magnitude and direction, but the magnetizing directions of different magnetic domains are different. When the material has not been magnetized, the orientation of every magnetic domain is irregular. So the material does not display magnetism totally. When a magnetizing field H_a is applied, these magnetic domains will be oriented and put in good order, that is, M of every magnetic domain turns to the direction of H_a step by step. As a result, the material reveals intense magnetism.

After magnetic particle inspection, the lasting time of the demagnetizing electric current for small or middle parts is short in general. Under its action, a part of magnetic domains appearing residual magnetism originally (indicated as d_1) turn about to balance the residual magnetism of another part domains (indicated as d_2), for which there is not enough time to turn about. So the residual magnetism of the workpiece is demagnetized wholly (Fig.1.a, b). Because every magnetic domain is all affected by elastic force and elastic moment from another neighbouring magnetic domains, when the demagnetizing field H_t is applied (Fig.1.b), magnetic domains d_2 cannot turn about since the obstruction of the elastic moment. Though magnetic domains d_1 have turned about in forced manner, but they bear extreme elastic reacting moment, which force them to return back to their original condition. While once the demagnetizing field H_t is removed, most of d_2 is left intact, only rare of them turns about slowly. At the same time d_1 is suddenly rebounded and vibrates attenuate around its centre of rotation. So after stopping of the demagnetizing electric current, the residual magnetism with original polarity will appear on the workpiece (Fig.1.c). But with the lapse of time, the attenuate vibration of d_1 ceases gradually, their orientation is all opposite to the original residual magnetism. Thereby the residual magnetism of d_2 will be counteracted again (Fig.1.d). In macroscopic view point, there will appear magnetic ageing — — the lag of magnetism[4].

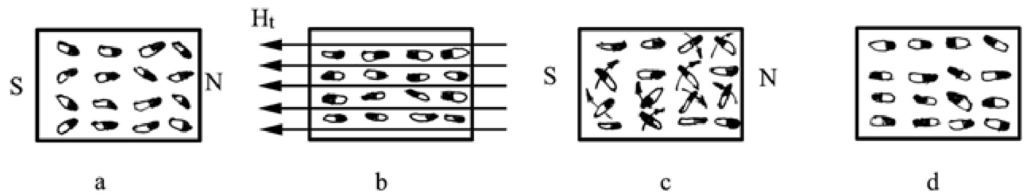

Fig.1 Schematic diagram showing the magnetic domain (represented by magnetic dipole) in a workpiece before and after completion of magnetic particle inspection and demagnetization

a. Rresidual magnetism presenting
b. Residual magnetism being demagnetized
c. Residual magnetism reappearing
d. Residual magnetism being removed

The change of geomagnetic field versus time and the geomagnetic induction

In 1653, H. Gellibrand first demonstrated that the declination (the angle between the geographic north and the geomagnetic north, Fig.2[9]) at the same place on the Earth will change as time goes on. Then the daily change and the long term variations of the magnetic declination and magnetic inclination (Fig.2) have been observed and investigated by British Astronomer E. Halley in 1683, G Gaham in 1722, German scientist A.V. Humbolt in 1860 and D.F.Arago between 1820—1825[8]. Thus it is known that the magnetic declination and magnetic inclination at a site on the Earth all variate continuously versus time. Though the daily variety of the geomagnetic field strength is extreme small, but the daily change of its horizontal component is larger[8].

In brief, $$\frac{dH_e \neq 0}{dt} \qquad (1)$$

in which, H_e = geomagnetic field strength, T
t = time, s

According to M. Farady's Law on Electromagnetic Induction [8], the induced electromotive force E (V) must be generated in the transverse section S (m^2) of the ferromagnetic materials perpendicular to H_e:

$$E = -\mu_r \mu_o S \frac{dH_e}{dt} \qquad (2)$$

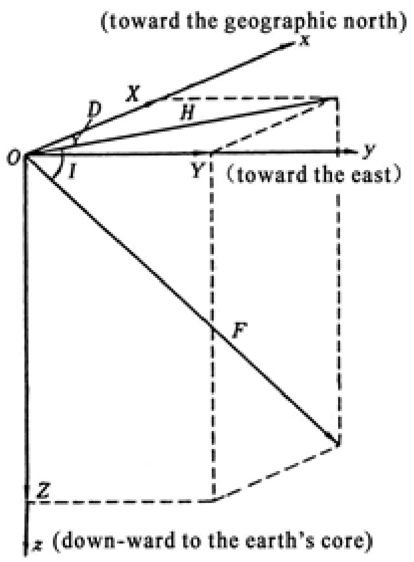

Fig. 2: Schema of geomagnetic elements[9]

F = total intensity of geomagnetic field.
H = the horizontal component of F, and called the horizontal intensity.
D = magnetic declination, the azimuth of the horizontal intensity, reckoned positively from the geographic north toward the east.
I = magnetic inclination, reckoned positive when the direction of F inclines down-ward.
here,
μ_r= relative magnetic permeability for the material, it is a pure number without dimensions
μ_o = magnetic permeability for vacuum, $\mu_o = 4\pi\times10^{-7}$H/m

E causes the appearing of induced electrical current i (A) in S. And i excites certainly induced magnetic field H[10,11] to magnetize or demagnetize the workpiece spontaneously. The result depends on the relation between the magnetic polarity of H and original polarity of the workpiece—— alike directions, spontaneous magnetization of the material; opposite directions, automatic demagnetization of the specimen. In the ferromagnetic materials staying in static state in geomagnetic field, which didn't appear magnetism previously, there must be intensely spontaneous magnetization with the passage of the time.

Change of Material's Magnetism Caused by Ageing of Metals

The Transformation of stress Magnetization

The mechanical stress in a workpiece will change after its staying in static state for a period of time (ageing of metals). And this will cause the variation of magnetization curves of some materials. Then some materials, that don't reveal magnetism when they bear no stress, will transform to them having strong residual magnetism and high coersive force due to bearing high stress[5].

The Transformation of Stress Structure

Mechanical stress can change the relative distance, location of atoms and ions in metal lattice. Thereby the magnetization characteristics of the material will be influenced. Besides, mechanical stress may still lead to the metallographic constitutional changes, for example, the austenite in steel, having no magnetism can be transformed by mechanical stress to the ferrite possessing magnetism[5].

The delayed cracking may appear in the process of metals ageing [12], slot arises between magnetic domains which connect head to tail and their magnetism offset each other originally. Thus intense magnetic leakage field will appear.

Conclusion

The periodic variation of magnetic declination and magnetic inclination at a site on the Earth must induce the magnetizing field in ferromagnetic materials staying in static state in geomagnetic field to magnetize themselves or demagnetize automatically.

The magnetic domain structure and magnetic ageing (the rotation of magnetic domain is hindered by the mechanical frictional moment) are the principal reason, why the workpiece demagnetized after magnetic particle testing brings magnetism afresh. In addition, the transformation of stress magnetization, the transformation of stress structure and the appearance of the delayed cracking etc. from metal ageing are also the causes, which make a workpiece having no magnetism to reveal magnetism again.

Recommendation

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