Metal Magnetic Memory Testing Technique for Stress Measurement

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Abstract

Stress concentration is the main reason to cause fatigue failure and damage. However the early damage, especially the hidden that with no-continuance in it is very difficult to be taken effective evaluation. Metal magnetic memory (MMM) testing technique is a new technique in the field of non-destructive testing, which is effective for the diagnosis before ferromagnetic parts failure. MMM testing principle was presented, and MMM diagnostics instrument (EMS-2003) was used to test the specimens. The relationship between torsion and the vertical component of surface magnetic intensity-Hp(y) was also analyzed. Hp(y) gradient as well as dots where Hp(y) changes its polarity was used to diagnose the stress concentration zones. Conclusions were derived based on the experiment results, and its trend was highlighted.

Keywords: Metal Magnetic Memory; Ferromagnetic Material; Stress Concentration; Magnetic Flux Leakage

1. Introduction

Microscopic and macroscopic stress concentration is the main reason to cause fatigue and failure of component parts and metal structures. In the stress concentration zones, fatigue, corrosion and creep develop; in the microscopic defect area, stress concentration exists. Hence, the evaluation of stress, especially the critical stress that causes damage is an important basis for structural strength, reliability estimation and life prediction[1]. Traditional NDT methods have been widely applied for industrial non-destructive testing. However, due to the principle and technique limitation, traditional methods could only inspect the developed defects. New theories and instruments are needed for the inspection of early metallic damage, especially the hidden that with no-continuance in it with good reliability and sensibility.

MMM produced by Doubov in Russia in the late 1990s[2-3], which is based on the magneto-mechanical effect, can estimate the early damage degree of ferromagnetic materials using MMM signals effect occurred under both of applied load and earth magnetic field existing. Not only stress concentration zones but also defects in the ferromagnetic materials can be found by MMM, so it has been used widely in the engineering field due to simple operation. Compared with other NDT methods, the merits of MMM are shown as followed[4-5]:

(1) Not only defects but also stress concentration zones can be detected. With early diagnose, the accurate evaluation of equipment safety could be achieved.

(2) Real-time on-line inspection

(3) No pretreatment is needed, and non-contact probe with a maximum lift-off height of 150mm was adopted.

(4) Little influence of lift-off effect; good sensitivity, repeatability and reliability.

(5) Compared with MFL, MMM utilizes geomagnetic field that makes the instrument small in volume and light in weight, which enables high on-line inspection velocity.

For the past decade, MMM has been a hot spot among NDT methods. However, most researches focus on the uniaxial tensile experiment; MMM signal under complex stress is relatively unexplored. In this paper, torsion tests for low carbon steel samples were performed, with EMS-2003 smart MMM detecting instrument measuring MMM signal of the material surface, the relationship between MMM signal and applied torsion was investigated. MMM signal characters for stress concentration zones were given and theoretical analysis was drawn from the experiment results.

2. Theory of Metal Magnetic Memory

The basic principle of MMM[6-8] can be expressed as: due to magnetostriction, under both of applied load and earth magnetic field existing, the direction and irreversible reorientation of the magnetic domain textures will take place around stress concentrations of the ferromagnetic materials. The irreversible change of magnetic domains shall preserve after loads, and has a relationship with maximum applied stress.

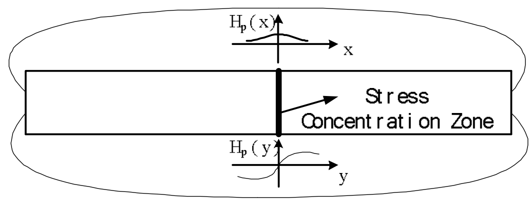


Figure 1. MMM principle

Due to the applied load, leakage magnetic field - Hp forms. As shown in figure 1, around stress concentration zones, Hp(x) exhibits a peak and Hp(y) changes its polarity where Hp(x) is the field strength parallel to the material surface and Hp(y) is the field strength perpendicular to the material surface. So stress concentrations of ferromagnetic materials could be inspected through measurement of Hp(y) value.

3. Torsion experiment

3.1 Samples

Low carbon steel was used for test samples of which dimensions and mechanical properties are shown in figure 2 and table 1 respectively.

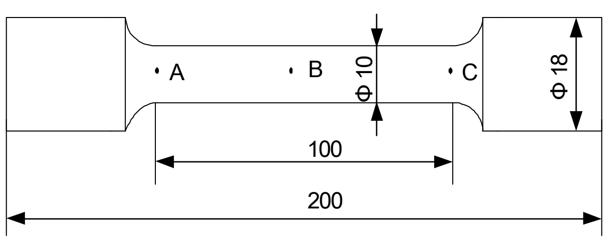


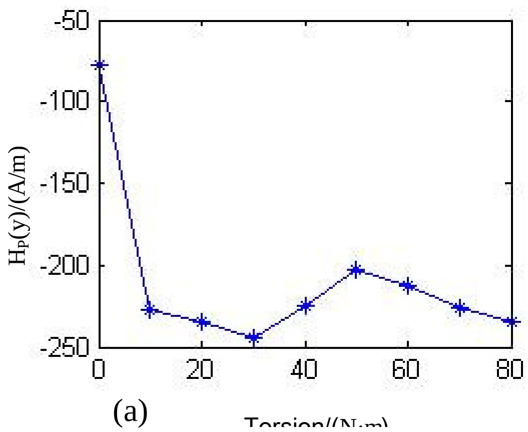
Figure 2. Sample dimensions with size in mm

Table 1. Mechanical properties of low carbon steel sample

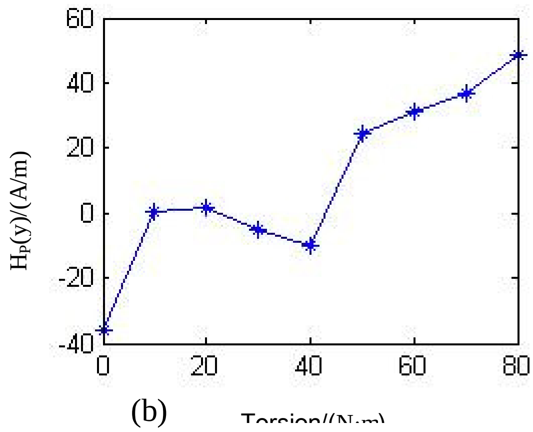
σ_s/Mpa	σ_b/Mpa	E/Gpa	μ
275.6	421.8	216	0.28

3.2 Torsion experiment process

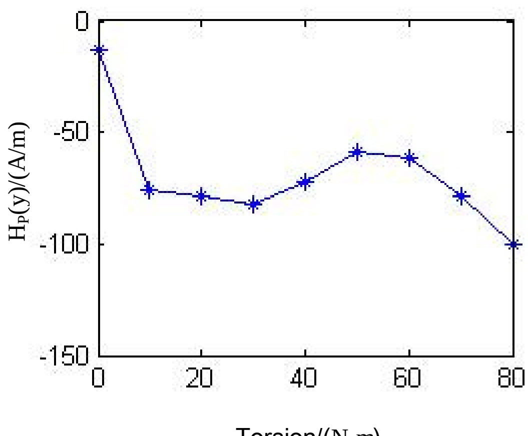
A torsion test machine NJS – 02 was used to apply torsion to the samples from 0 to 80 N·m with a step of 10 N·m. Previous testing showed that the yield load for this material is 50 N·m. In the experiment, earth magnetic field strength was kept as a constant. EMS-2003 was adopted to measure Hp(y) value of three representative points A, B and C respectively. Relationship between Hp(y) value and torsion could be drawn from the experiment results. Figure 3 shows the relationship between Hp(y) value and torsion of point A, B and C. Table 2 shows the points where Hp(y) changes its polarity.



(a)



(b)



(c)

Figure 3. $H_p(y)$ for the applied torsion of point A (a), B (b) and C (c)

Table 2. $H_p(y)$ zero-crossing points from point A

Torsion/N·m	Position/mm
10	50
20	49.54 ; 50.32
50	20 ; 80
60	18.9 ; 82.2
70	22.36 ; 73.62
80	30 ; 73.82

3.3 Results and analysis

Change of MMM signal under different deformation stages: In the elastic deformation stage, in addition to the change of applied load, the absolute magnetic field strength of point A and C increases; the Hp(y) value of point B changes its polarity and reaches a peak. In the plastic deformation stage, the absolute Hp(y) value of point A, B and C increase with torsion increasing.

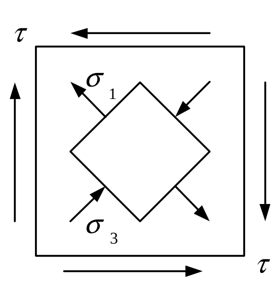


Figure 4. Stress state of the torsion sample

Analysis: Under the torsional loads, shear stress is applied to the sample. The angles between normal stresses and axial direction are +45°and -45°respectively, with one is the tensile stress and another one is the compressive stress, which is shown in figure 4.

In the elastic deformation stage, the stress of the sample section increases with torsion increasing. The stress energy of item with isotropic magnetostriction is given by:

$$E\sigma = - \textbf{Fehler!} \lambda s\sigma\cos 2\theta \quad (1)$$

Where, σ is stress, λs is magnetostriction coefficient, θ is angle between stress and magnetization directions.

Hence, under the applied load, the magnetic domains turn to direction of $\sigma 1$, which is shown in figure 4. So magnetic field strength increases with applied load increasing.

In the plastic deformation stage, due to the initiation and movement of dislocations and the formation of slip bands which cause movements of domain walls; on the other hand, the increase of dislocation intensity causes microscopic defects of the sample, and finally the extension of cracks. Reasons mentioned above make Hp(y) absolute value increases with torsion increasing.

In the industrial applications, the Hp(y) zero-crossing points usually represent stress concentration zones. However, the existence of Hp(y) zero-crossing points is not sufficient condition for stress concentration zones. As shown is figure 5, Hp(y) zero-crossing points appear in the middle of the sample when the torsion is 10 N·m and 20 N·m respectively. Sometimes Hp(y) zero crossing points are not defects, but natural zero-crossing points which caused by the heat treatment process. The stress concentration zones mainly depend on the material strength. Also, when the torsion is from 50 N·m to 80 N·m ,the zero-crossing points of the left of the sample are not caused by the applied load but just drifts of natural zero-crossing points. Inspections with only Hp(y) zero-crossing points adopted may lead to misjudgments. So Hp(y) gradient K which is given by equation 2 as well as Hp(y) zero-crossing points needs to be adopted for the inspection of stress concentration zones.

$$K = \textbf{Fehler!} \quad (2)$$

After comparing K value in table 2, we are sure that stress concentrates at 73mm from point A due to large K value, which was proved by the fracture experiment.

4. Conclusions

Based on the torsion experiment of low carbon steel samples, the relationship between MMM signal and torsion was analyzed and conclusions were derived from the experiment results:

(1) The Hp(y) absolute value increases with torsion increasing

(2) With torsion increasing, several Hp(y) zero-crossing points may exist, but not all of them represent stress concentration, with some are just drifts of natural zero-crossing points.

(3) Hp(y) gradient as well as Hp(y) zero-crossing points need to be adopted for the inspection of stress concentration zones.

Further research directions will include combination of multiple NDT methods for stress measurement. The combination of Barkhausen Noise and MMM will be investigated in the future.

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