17th World Conference on Nondestructive Testing, 25-28 Oct 2008, Shanghai, China

Progress in Nondestructive Evaluation of Stress Concentration with MMM Method

Liqiang ZHONG [1], Luming LI [1], Xing CHEN [2]
[1]School of Aerospace, Tsinghua Univ., Beijing, 100084, China
Tel: 010-62795716, Fax: 010-62795716
E-mail: lilm@tsinghua.edu.cn Web: hy.tsinghua.edu.cn/intro/IMMEE
[2]Department of Mechanical Engineering, Tsinghua Univ., Beijing, 100084, China

Abstract:

It has been proved by experiments that the metal magnetic memory (MMM) NDT method can effectively detect the stress concentration of ferromagnetic metal parts. But it is still hard to evaluate the stress concentration quantitatively because of the confusion in the mechanism of MMM method. In this paper experiments are designed and carried out to investigate the relationship between the MMM signal and its key influencing factors: stress concentration and magnetic field, one part in the mechanism of MMM method. The result shows that the p-p value of MMM signal is almost linear with the maximum stress in an appropriate arrange under the geomagnetic field. But on the other hand, the influence of magnetic environment can't be ignored; particularly in detection the MMM signal may be quite different with the same stress when magnetic field differs. This result provides a potential method: to get a more reliable evaluation of stress concentration with multi-magnetic field in detection. Also, the data presents that the MMM signal during generation is more sensitive with the weak magnetic environment (in the range of geomagnetic level) than strong magnetic field (over several times of geomagnetic field). Magnetic field should be paid much more attention for MMM testing.

Keyword: Nondestructive Evaluation, Metal Magnetic Memory, Environmental magnetic field，stress concentration

1. Introduction

Compared with conventional NDT methods, the metal magnetic memory (MMM) method has its own advantage because it can quickly detect the stress concentration of ferromagnetic metal parts, just by measuring the distortion of the magnetic field perpendicular to the surface of inspected area under geomagnetic field without any complex surface treatments and artificial magnetization [1]. However, because of the confusion in the mechanism of MMM method, whether the MMM signal can tell the real magnitude of the stress concentration is still a question, which has become a bottleneck hindering its application [2].

In our previous work, it has been proved that the MMM method can effectively test the existence and the position of stress concentration [3] [4] which generated in welding or caused by discontinuous of metal parts [5-8], and the magnetic field is an important influencing factor in detection and generation of MMM signal [2]. The method is demonstrated a relative “reliable” method for abnormal stress concentration checking, but not a reliable method to evaluate the stress concentration quantitatively.

Base on the result of our previous studies, we believed that to make sure how the stress concentration and magnetic field change the MMM signal is fundamental to evaluate the stress concentration with MMM method more accurately. In this paper, experiments are designed and carried out to study the influence of them.

2. Experiment Details

There are some key factors in MMM method: stress concentration, magnetic field and magnetic memory field [2]. The major work in experiments we designed to research the relationships between them is to measure the magnetic distortion caused by different tension in controlled magnetic environment, and then respectively analyze the influence of the stress concentration and the magnetic field.

Then the experiment system is established as Fig.1, which is made up by following parts: a magnetic field measurement unit based on a GMR sensor; a tension means consisted by a tension load unit for applying tensile stress to specimens, and a display unit which displays the degree of force; a Helmholtz coil used for controlling the magnetic field; and a computer used as the central controller.

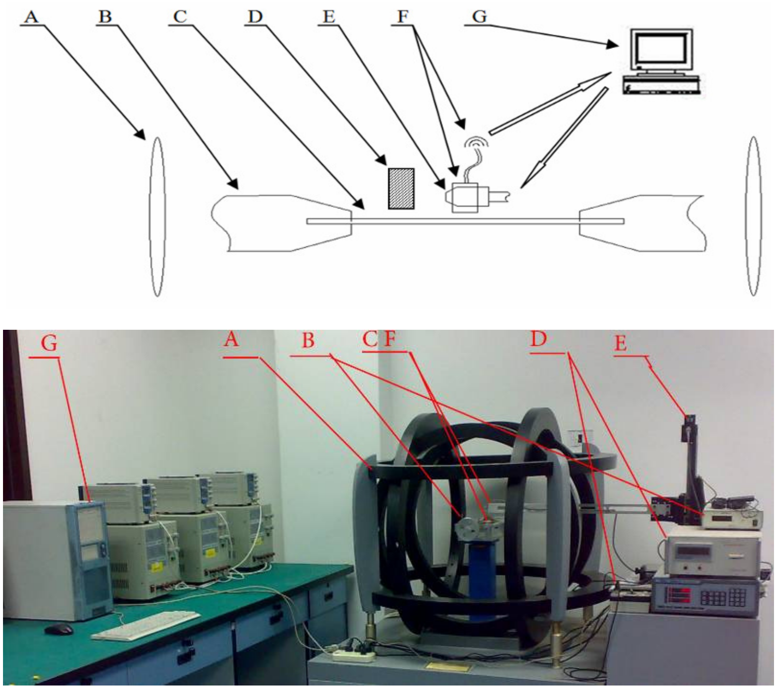


Fig.1 Experiment System (A: 3D Helmholtz Coil; B: Portable Tensile Means; C:Specimens; D: Flux Gate Magnetometer and Tesla Magnetometer; E: 3D Displacement Controller, F: Wireless Micro-magnetic Detector and the GMR Sensor, G:Computer)

2.1. Condition Control System

Magnetic environment controller: The 3D magnetic Helmholtz coil system is established to control the magnetic environment , which can generate a constant magnetic field with a range from -20Gs to 20Gs in a globular space with a diameter of 10 cm. The coil system also includes 3 compensative coils which can compensate the geomagnetic field to less than 50nT. The flux gate magnetometer and the Tesla magnetometer are used to help controlling the magnetic field accurately.

Stress status controller: The portable tensile means is designed to apply a tension from 0N to 2000N to specimens, made of aluminum to avoid the magnetic interference from the tensile means. The degree of force can read from its display unit.

2.2. Measurement System

The measurement system which controlled by the computer contains a 3D displacement controller and a wireless micro-magnetic detector. The GMR sensor of the detector can reach a high sensitivity of 20nT with a measuring range from -6Gs to 6Gs, equipped on the 3D displacement controller. In experiments the sensor may measure the distribution of the magnetic field perpendicular to the specimen's surface along the scanning line which has been indicated in Fig.2with a lift-off of 2 mm.

It should be noted that, if there is no special explanation, the surface magnetic field in this paper means magnetic field normal component perpendicular to the surface of specimens.

2.3. Specimens

The material of specimens we used is 45# carbons steel whose components and mechanical properties are given in table 1 and table 2. The flat-type specimen as shown in Fig.2 has a regular round hole in center, and stress concentration will generate around the hole when tensile force is applied to the specimen by the portable tensile means.

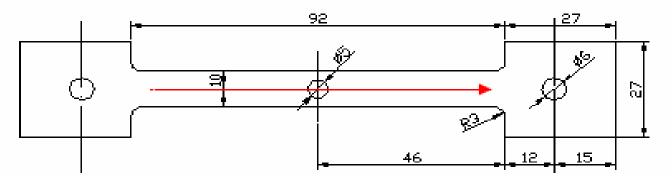


Fig.2 Specimen dimensions and scanning line

Table.1 Component of the material

C /wt%	Si /wt%	Mn /wt%	P	S	Cr	Ni	Cu
			Less than				
0.36~0.45	0.14~0.40	0.47~0.83	0.040	0.040	0.28	0.28	0.28

Table.2 Physical properties of the material

σ_b /MPa	σ_s /MPa	δ_5 /%
608	353	17

2.4. Analysis of Stress Distribution

Fig.3 shows the theoretical analysis of the stress distribution around the round hole [2]. When the specimen is applied to a certain tensile force, the stress concentration will be generated in the area around the hole and in the two boundaries along width direction. The maximum value of the stresses appeared at the two peaks and arrived at a normal value at the borderlines of the specimen.

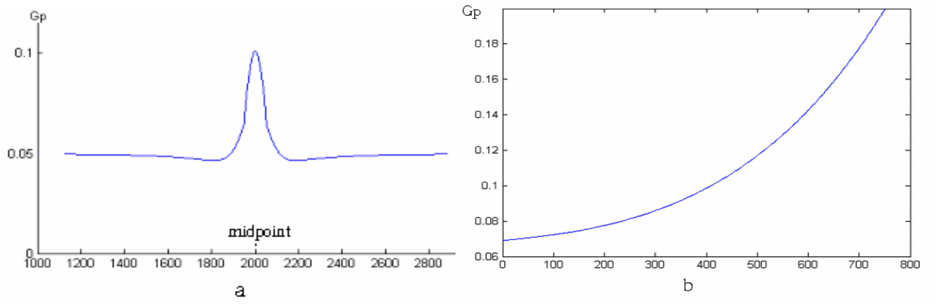


Fig.3 a. shows σ_y distribution on the scanning line of Fig.2; b. shows σ_y distribution on x axis of Fig.2, point zero is on the boundary of the specimen.

2.5. Experiment Method

With the experiment system shown in Fig.1, the experiment is carried out as follow:

After demagnetization, a ferromagnetic specimen is put into the given magnetic field space generated by the 3D Helmholtz coil, then a specific tension is loaded. While testing, the magnetic field should also be controlled so that the different effects of magnetic field in generation and in detection can be studied.

MMM signals should be measured at each status defined by different levels of stress, magnetic field during generation and detection of MMM signals.

It should be noted that, to study the effect of environment field in detection of MMM signal based on the experiment environment and specification, magnetic field in generation of MMM signals is hoped to be as weak as possible, which mentioned in this paper as "the zero magnetic field". It means that the magnetic field is less than 50nT generated by 3-D Helmholtz coil after compensation of the geomagnetic field.

3. Effects of Stress Concentration

Fig.4 shows the original MMM signal measured in the geomagnetic field when the specimen is tensed to each tensile stress.

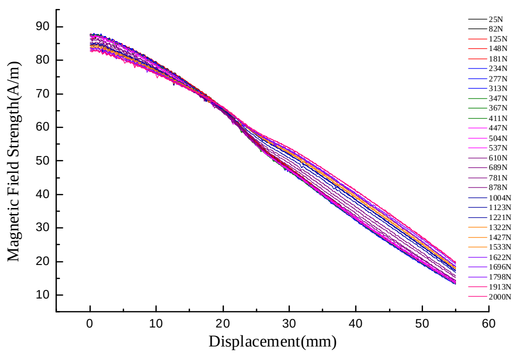
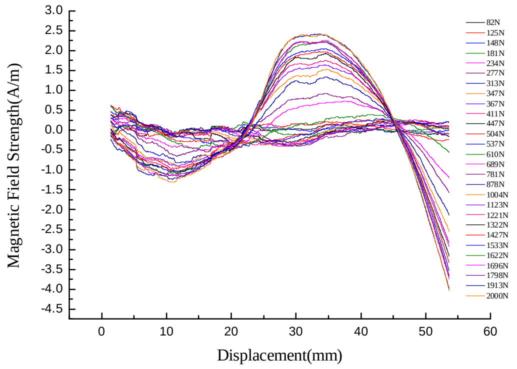


Fig.4 MMM signal of each tensile stress under geomagnetic field

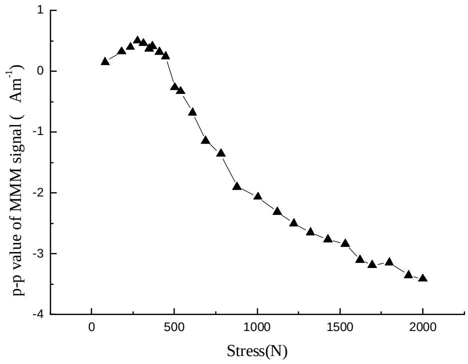
As shown in Fig.4， the original signal of magnetic field is complicated, which includes the abnormality of the magnetic distribution caused by stress concentration, caused by shape particularly the hole in the center and also includes the slope caused by entirety magnetization. In order to extract the stress induce abnormality, influence of shape and slope caused by entirety should be considered and smoothed away.

Slope is simulated by linear fit and subtracted from the signal. The original influence of the hole is the abnormality of the field before load and it is subtracted from other signals. The p-p value of each signal is counted as a symbol of the magnitude of magnetic distortion.

Fig.5 is the result after data processing.



a. the magnetic distortion caused by stress concentration under geomagnetic field



b. p-p value

Fig.5 results after data processing

In Fig.5, the tendency of p-p value is just closed to the result of theoretical calculation [2] using the equivalent magnetic field theory [9]. It points out that the stress concentration which is weaker 70Mpa (350N in these specimens) plays almost an opposite role to which is stronger than 70Mpa [2]. The strength of its influence is approximately proportional to the original magnetization, which has pointed out in the conclusion of the magneto-mechanical effect theory summarized by Jiles [9] [10].

Accord to Fig.5, the relationship between the MMM testing result and the magnitude of the stress concentration is almost linear when the stress concentration is strong enough to attract our attention; in Fig.5 the stress should be stronger than 500N. It means without interfering factors the testing result maybe approximately relates to a status of stress concentration.

4. Influence of Magnetic Field in Stress Concentration Evaluated

Experiment in our previous work shows that the sensitive direction of magnetic field is along the scanning line in Fig.2 [11], as shown in Fig.6. The direction of magnetic field in this paper is all along the scanning line; in other directions, the magnetic field is compensated to zero except if the experiment is carried out in geomagnetic field.

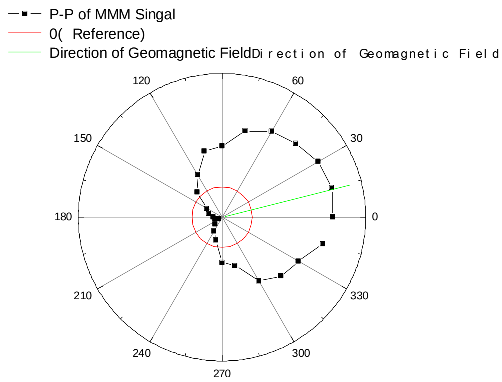


Fig.6 The P-P value of MMM signal changes with the direction of geomagnetic field

4.1. Magnetic Field in Detection

In this part of experiments each specimen is tensed to a predetermined stress in zero magnetic field with an original MMM signal generates and then the environment field is changed from zero to 20Gs in an interval of 2Gs. In each level of magnetic field, the MMM signal is measured.

The predetermined stress of specimens is also in some different levels, with a range from 0N to 2000N.

Fig.7 shows the variation of the P-P value of MMM signal in each level of magnetic field (the average value is set as a referenced value in each level).

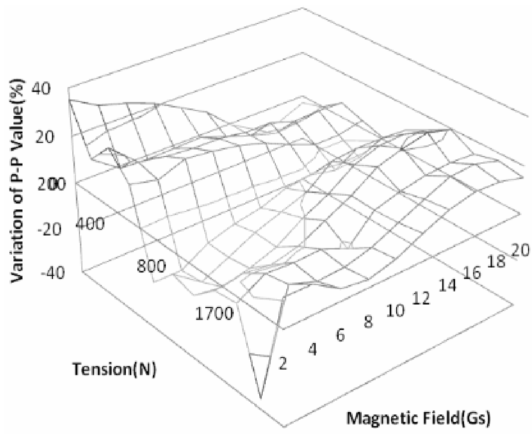


Fig.7 Effect of magnetic field in detection

Fig.7 shows that the tendency of the p-p value depends on both stress concentration and magnetic environment. In our experiments, the p-p value reduces in weak magnetic field, but increase in strong magnetic field with the stress being stronger.

One reason we conclude is that the magnetic field in detection magnifies both the influence of stress and the geometric discontinuous of the specimen. With the effect of geometric mutation magnified by the magnetic field in detection being stronger, its effect may change the p-p value more. The data processing is based on an assumption that there is no geometric deformation generates in loading process, but in fact it exists and magnified by the magnetic field in detection.

Fig.7 .b supported a potential method suggested in our previous work [2]: to get a more reliable evaluation of stress concentration with multi-magnetic field in detection. It shows

that on each level of magnetic field, the p-p value with different tension has a different displacement to the average value of each magnetic environment level.

4.2. Magnetic Field in Generation of MMM signals

In our previous work, it has been pointed out that MMM signal generated in the zero magnetic field and the geomagnetic field is quite different [2]. Realized in generation of MMM signals the magnetic field mostly is uncontrollable in real industrial application, experiments are designed to study the interference of the magnetic in generation to the remanent magnetization.

Experiment is carried out as this: after demagnetization, each specimen is tensed to a predetermined stress in a controlled magnetic field, then the magnetic field is reduced to zero and the MMM signal is measured.

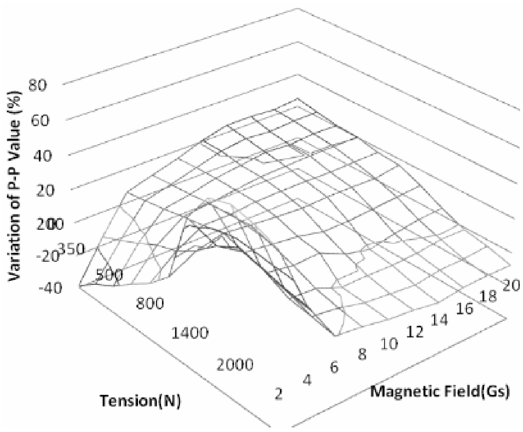


Fig.8 Effect of magnetic field in generation of MMM signals

Fehler! Verweisquelle konnte nicht gefunden werden. shows that when the magnetic field is as weak as zero, the remanent magnetization is quite sensitive with the magnetic environment during generation. But if the magnetic field is strong enough, the effect is stable instead.

In real industrial application, the magnetic environment during stress concentration generation should be considered as an important interference factor because mostly it’s a weak geomagnetic field.

5. . Conclusion

Mostly the relationship between the magnetic distortion and the stress concentration is steady; in weak magnetic environment such as the geomagnetic field the relationship is almost linear when the stress concentration in an appropriate scope (elastic range).

The magnetic field plays an important role in detection. However, it magnifies the magnetic distortion caused by the stress concentration and the discontinuous of specimens at the same time. When the magnetic field is too strong, the main part of the magnetic distortion reflects the discontinuous of specimens, which should be considered and smoothed away.

On each level of magnetic field, magnetic distortion caused by different tension has a different distance to the average value. It’s possible to get a more reliable evaluation of stress concentration with multi-magnetic field in detection.

Also, the magnetic environment strength during stress concentration generation should be considered as an important interference factor, and the MMM signal is more sensitive to weak magnetic environment (in the range of geomagnetic level) than strong magnetic field (over several times of geomagnetic field).

6. Acknowledgement

This work was supported by National Natural Science Foundation of China under Grant No. 50771057.

Reference

[1]. Liu SanJiang, Li BangXian, Zhou YuFeng, et al. Summary and Preparatory Application of Metal Magnetic Memory Testing Technology. Nondestructive Testing, 2002, V24 (9):400~402

[2]. Chen Xing. Research on Evaluation of Stress Concentration Using Metal Magnetic Memory Method: [D]. Materials Science and Engineering, Tsinghua University, Beijing, 2007

[3]. Huang SongLing, Li LuMing, Shi Ker, et al. Magnetic Testing Method Of Residual Stress Distribution By Geomagnetic Excitation. Journal of Tsinghua University (Science and Technology), 2002, V42 (1): 1426~1428

[4]. Li L, Huang S, Wang X, Magnetic field abnormality caused by welding residual stress, journal of magnetism and magnetic materials, 2003, V261(3):385-391

[5]. Dubov AA, Sudy of metal properties using magnetic memory technique, Metallovedenie i Termicheskaya Obrabotka Metallov, 1997, V9:35-39.

[6]. Li L, Huang S, Wang X, Stress induced magnetic field abnormality, Transactions of Nonferrous Metals Society of China (English Edition), 2003, V13(1):6-9.

[7]. Yang E, Li L, Chen X, Magnetic field aberration induced by cycle stress, Journal of Magnetism and Magnetic Materials, 2007,V312(1):72-77.

[8]. Chen Xing, Li LuMing, Yang En, et al. Effect of Stress Cycles on Surface Magnetic Field. Materials Science Forum. 2005. V490-491: 317-321

[9]. Jiles DC, Theory of the Magnetomechanical Effect, Journal of Physics D-Applied Physics, 1995, V28 (8):1537-1546.

[10]. Jiles DC, Theory of the magnetomechanical effect, Journal of Physics D-Applied Physics, 1999, V32 (15):1945-1945.

[11]. Zhong LiQiang, Li LuMing, Chen Xing. The Influence of Geomagnetic Direction on the Magnetic Distortion Caused By Stress Concentration. Nondestructive Testing, Accepted