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Study on The Character of Metal Magnetic Memory Signal in The Course of High-cycle Fatigue Experiment for 16MnR Steel*

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Abstract: Fatigue damage is a slow process of accumulation of damage, there is no obvious macroeconomic plastic deformation, therefore the assessment of the security status about component bore alternating load would have a difficulty. Although there are many kinds of effective nondestructive testing methods currently, the structure of Equipment components and various unfavorable interference factors restrict the implementation of these methods. Metal magnetic memory method has been widely used in detection and experimental research project because of its characteristic: early detect on the flaw, easily accessible and accurate. But there are some questions which are the mechanism of magnetic memory method and characteristics of magnetic memory signal in the process of fatigue to be resolved. This article selects 16MnR steel as the fatigue specimen for research, the magnetic memory signal was tested in different fatigue life to study the characteristics of magnetic memory fatigue signal. The results showed that: fatigue cracks occur within the region where the magnetic field intensity curve is concave fluctuations; tiny crack is an important factor to change of the metal magnetic field intensity, and partial magnetic field changes which is caused by tiny cracks is a partial magnetic field effects; the magnetic signal curve changes in rates is tremendous in the region of fatigue crack, with the increase of the fatigue life magnetic field intensity change rate get to be larger than before ,and the gradient of magnetic field increases rapidly after the fatigue cracks germinated.

Key words: 16MnR；high-cycle fatigue；metal magnetic memory；

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0. Introduction

Equipment components often bear alternating load because of the changes of the operation, the external environment and a variety of artificial factors. The result of these is fatigue damage engendered on components. Fatigue damage is a slow process of accumulation of damage, and there is no obvious macroeconomic plastic deformation. In this process, the reciprocating slippage continues to accumulate due to the internal tissue structure of ferromagnetism materials what bore alternating loads. As time passes the consequences of these action is fatigue crack initiation, development and even disastrous. So the segment of detection and assessment on the stage of equipment components' safety will have a decisive role. At the present, in the field of NDT, there are many well-established conventional detection methods, such as X-ray, ultrasound and Barkhausen [1-2]. However, the confine of the equipment component's structural as well as some interferential factors bring a lot of inconvenience to these conventional methods. So there is a need for more simple and convenient method of NDT to detect in practice of engineering.

In the 1990s, the Russian scholar Professor Dubov A firstly proposed metal magnetic memory method, which collects the advantages of fracture mechanics, metal materials, non-destructive testing, and so on. With the unique feature that the early diagnosis of flaw as the main characteristics. Moreover, this method have characters as simple, convenient and free from the detecting environment's impact and equipment components' impact [3-5].Because the technology has tremendous potential for nondestructive testing works, the engineer and the academician are all concern about this technology from it comes out [6-10], Metal magnetic memory method has been widely used in the detection of electrical equipments and pressure vessels [8-12]. However, as a new technology metal magnetic memory method is not mature, there are a lot of theory and application issues to be resolved. The magneto-mechanical effect has formed a complete theoretical system since the 19th century, some applications have been mature. However, there are still many phenomenon that the stress - magnetization curve of the macro-modeling can not be fully consistent with experiments and facts, the mechanism of the magneto-mechanical effect can not be expounded completely clear essentially. Specifically, in the weak magnetic field environment, there are vacancy about study on the magneto-mechanical effect under the status of non –elastic stress and non-linear stress distribution (such as stress concentration). And research work about the magnetic memory mainly in the area of applications. Too many impact factors of magnetic memory testing, so its physical mechanism is not yet understanding in-depth and there have been some conflicting test results. At the same time from the aspect of magnetic memory method itself, it is using magnetic fields to detect the abnormity of magnetic field which is caused by stress concentration, while the geomagnetic field what is a vector field has different sizes in different directions, and it is also a weak magnetic field, so there are also limitations in practice. For example, the remaining magnetic intensity will be greatly exceeding the geomagnetic field intensity after the detection of magnet-power. It is possible to cover up the aberrance of the magnetic field caused by stress concentration. In a complex engineering environment, the fact whether the metal magnetic memory methods can be really solve the practical problems or not related to this method itself, and this is also must be resolved at present in application.

In this paper, the relationship between characteristics of magnetic memory signal and material fatigue level is built, and the impact caused by magnetic field on magnetic memory signal is also studied. The optional steel for pressure vessel, 16MnR, is taken as the object to be studied. Prepared fatigue specimens without prefabricated flaw, recorded the magnetic memory signal under different fatigue life in the process of high-cycle fatigue. With a view to clarify the characteristics of magnetic memory signal in the course of high-cycle fatigue experiment and to discuss the relationship between magnetic memory signals and the fatigue state of ferromagnetic components.

1. The principle of Metal magnetic memory method

Under normal circumstances the internal structure of ferromagnetic metal materials is polycrystalline-like and has the complex structure of the magnetic domain. Generally, the phenomenon that the ferromagnetism materials get magnetism from itself and residual magnetic field status has a direct relationship to the mechanical stress, the mechanical stress together with the earth magnetism field decrease the permeability rate of the magnetic material in the region where is flaw of the ferromagnetic material, and enhance the magnetic field intensity in the stress centralization region (that is, magneto-mechanical effect) [13],When the elastic stress effect on the surface of ferromagnetic, high stress energy can be gathered discontinuously in components. Because of the effect of magneto-mechanical effect ,displacement occurs in the magnetic domain of the component's internal tissue, or even irreversible rearrange, the magnetic domain of this order will be preserved when a dynamic load elimination, So it bound to make the magnetic field intensity of the component surface to change. Metal magnetic memory method is built up to a nondestructive testing method on based of the change in the magnetic field intensity [3-12].

2. Magnetic memory testing scheme and preparation of specimens

2.1 Material for experiment

The material, 16MnR, is hot-rolled plate, The chemical constitution of it as shown in table 1, the mechanical properties is shown in table 2.

Tab1 The chemical constitution of 16MnR (%)

C	Si	Mn	P	S
0.12	0.37	1.42	0.016	0.016

Tab2 The mechanical performance of 16MnR

Young's modulus	Tensile strength σb	Yield stress σs	Upper yield point	Lower yield point
207.6GPa	549.9 MPa	398.0 MPa	402.3 MPa	398.0 MPa

2.2 Scheme for experiment

2.2.1 Preparation of specimens

The preparation of specimens is on bases of GB 3075-82. The form of specimens is shown in figure 1. The axial direction is the same as the specimen-rolling direction. In order to find out the effect of tiny flaw on magnetic memory signal, distinguished from the majority of other literatures [6,11,13-15], this experiment did not create any surface flaw, So fatigue crack initiation is randomness to ensure that magnetic memory signal is not effected by prefabricated flaw.

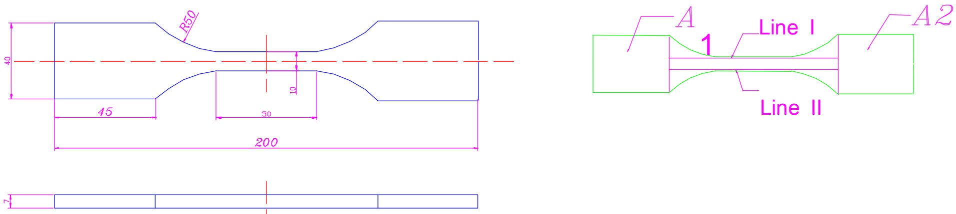

Fig1 The form of fatigue specimen and magnetic memory testing

2.2.2 Pretreatment on specimens

To remove the influence caused by machining on the magnetic field on the surface of specimen, First of all relief stress annealing has been done to the specimens at 600 □, the process of annealing as follow: specimen in the furnace was heated to 600 □, holding one hour and then air-cooled to room temperature. So the original magnetic signal on specimen's surface will to be removed.

2.2.3 The selection of fatigue load

Before the start of magnetic memory testing, fatigue life experiments were conducted in eight different stress level by use of same specimens, With a view to find a suitable fatigue life for magnetic memory testing, and the basic principle is that guarantee a certain fatigue life cycle (more or less 10 times for magnetic memory testing can be done in the process of fatigue), and the whole process of fatigue do not need long time (increase efficiency).

According to results about fatigue life experiment, the final choice is 0.5σb stress level, the fatigue life in this level is about 930×10^{-3} cycles.

Select stress ratio R=0.1 , the process of calculation about dynamic load and static load as follow：

σ_b=549.9MPa；A=70mm^2

σ_{max} =0.5σ_b =274.95 MPa；σ_{min}=0.1×σ_{max}=27.495 MPa

$$\sigma_m = \frac{\sigma\ max - \sigma\ min}{2} = 151.17MPa \text{ ， } \sigma_a = \frac{\sigma\ max - \sigma\ min}{2} = 123.7MPa$$

F_s=10.59KN；F_d=σ_a×A=8.66KN

Where σ_b is Tensile strength; A is the cross section area of specimen; σ_{max} is the maximum of stress; σ_{min} is the minimum of stress; F_s is the static load on specimen ；F_d is the dynamic load on specimen.

2.2.4 The scheme of magnetic memory method testing

According to the results of fatigue life experiment before, experimental interval was determined as N = 150 × 10^3 cycles. The original state of magnetic memory signal was tested before the cycle of fatigue loading. Then the magnetic memory signals were tested at different stages in the process of fatigue experiments. Ensure that the specimen was put at the same location when testing to minimize the impact of external factors; Magnetic memory signals were tested in the horizon plane and the plane vertical with magnetic vector, and along the lines in A-side and B-side. In order to improve reliability of results, each line was scanned three times to ensure the accuracy. The equipment for testing the magnetic memory method signal is TSC-1M-4 which is manufactured by Energodiagnostika Co.Ltd of Russia.

3. The results of testing and analysis

Through the experiment about testing characteristics of magnetic memory signal in the process of fatigue, in accordance with the requirements of improving the reliability of data, a number of fatigue experiments under 0.5σ_b stress level were conducted to many specimens which are 16MnR base metal specimens and specimens with welded joint. As a result the magnetic memory signal characteristics data of different type specimens at horizontal plane and the plane vertical magnetic vector were gained. There were great similarities among the large amounts of data by analyzing and comparing with each other, so it cited only typical ones. The magnetic memory signal's characteristic curves are as follows.

3.1 The magnetic memory signal characteristic curves about base metal specimen

Because the development of fatigue crack was observed real-time in the process of fatigue,

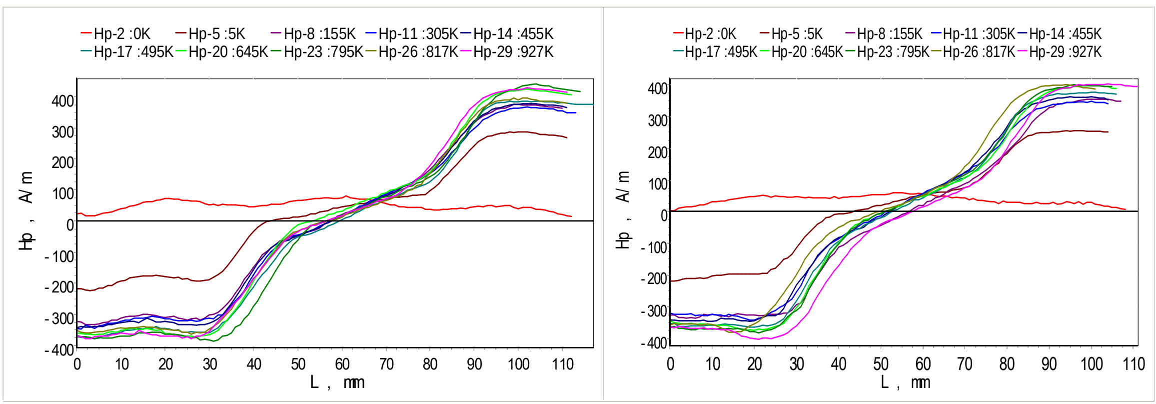

Fig2a MMMT curve on lineII in A side

Fig2 MMMT curves in horizon plane about base metal specimen the result showed that fatigue cracks appeared longer than the first at the position where lineⅠ in specimen’s B side, and therefore the magnetic memory signal characteristic curves are listed as shown in Figure 2 and Figure 3.

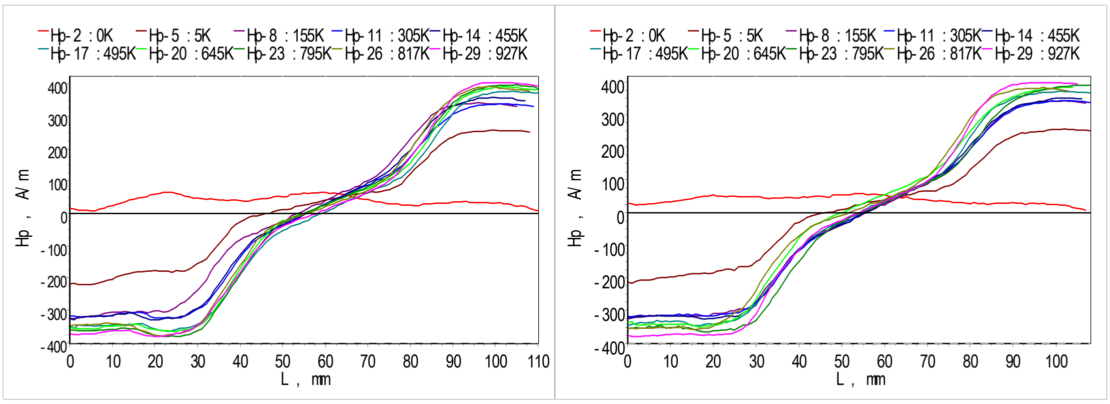

Fig3a MMMT curve on lineⅡin A-side

Fig3 MMMT curve in the plane vertical magnetic vector about base metal specimen

3.2 The magnetic memory signal characteristic curves about specimen with welded joint

Taking into account the actual project structure are welded together by components. A high cycle fatigue experiment on specimen with welded joint was conducted to test the characteristics of magnetic memory signal. The results were shown in Figure 4 and Figure 5.

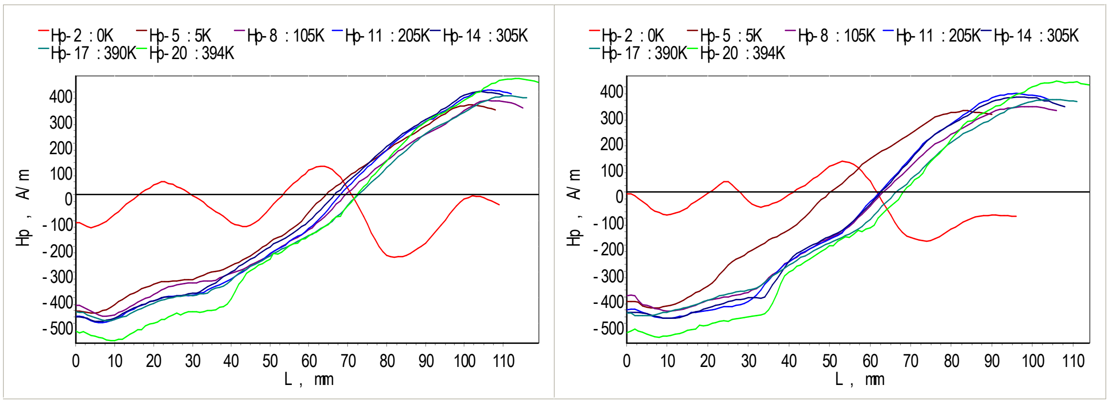

Fig2 MMMT curves in horizon plane about specimen with welded joint

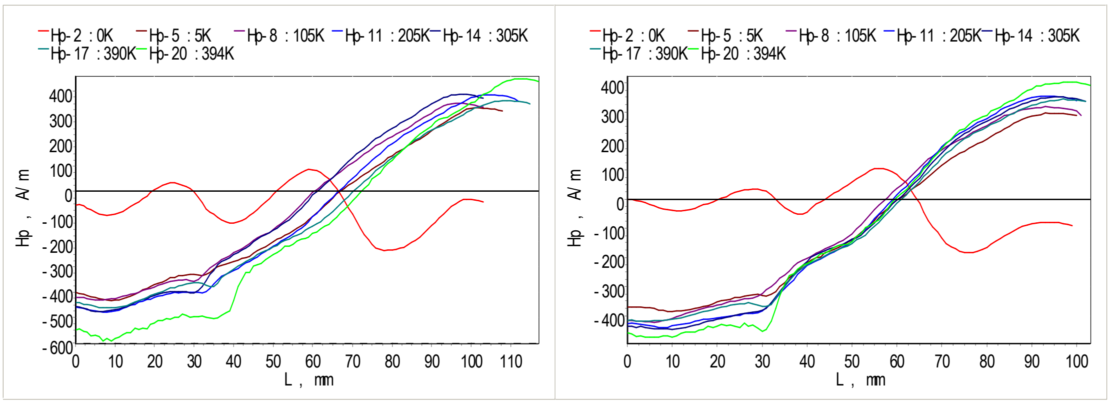

Fig5 MMMT curve in the plane vertical magnetic vector about specimen with welded joint

3.3 The grads of magnetic field intensity about magnetic memory signal in the process of fatigue

The grads of magnetic field intensity about magnetic memory signal is an important norm in the process of analyzing the magnetic memory signal's characteristics, So it also carried out a detailed analysis of the grads of magnetic memory signals, and the grads of the magnetic field intensity curve as shown in Figure 6.

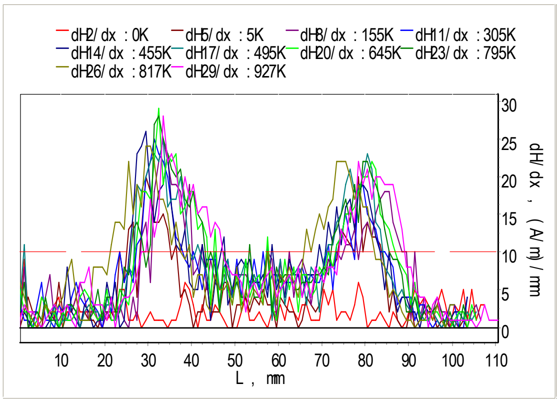

Fig6a The grads of MMMT curve on lineⅠin

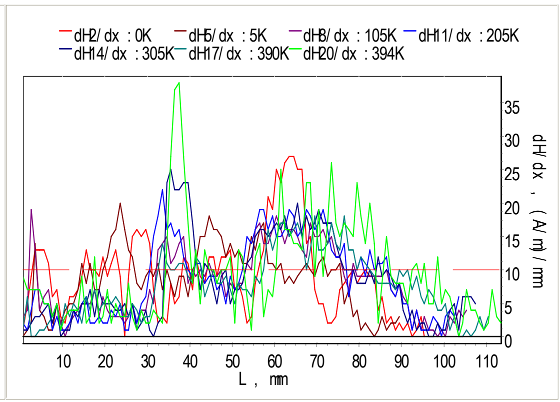

Fig6b The grads of MMMT curve on lineⅠin B-side of

Fig 6 the grads of MMMT curve in the horizon plane

3.4 The analysis of magnetic memory testing results

(1) It can be seen from the curve of the magnetic field intensity that the magnetic signals changed within the region where fatigue crack appeared. The magnetic field intensity curve concave volatility in this region. The analysis results of the magnetic memory measurement shows:

the internal magnetic field changes, while the fatigue cracks expand. Where is the crack, where the greater fluctuations in magnetic signal. Through the examination of the different locations of the four lines, it showed that the sensitivity of magnetic signal to fatigue crack is different at the four different locations, in the position where the fatigue crack initiation the fluctuations of the magnetic signal is remarkable. It can be seen that the magnetic signal changes reflected to crack in position lineⅠby comparing the changes of magnetic signals, regardless of A-side or B-side, but the magnetic signal changes is weak in the second-line position.

It can be seen from this analysis that tiny crack is an important factor to the change of magnetic field within the metal, and the change caused by tiny cracks of partial magnetic field intensity is partial effect.

(2) It can be seen from the grads of magnetic memory intensity figures that changes in rates of the magnetic signal is great in the position where the fatigue crack is. With the increase in the number of fatigue life the changes in rate of magnetic field intensity increase, and the grads of magnetic field intensity changes increase rapidly after the fatigue crack initiation.

(3) The features of magnetic field within the metal will not change generally because the existence of the Earth's magnetic field, unless there is magnetic phenomena caused by strong magnetic field. Compared the changes of magnetic field intensity in the plane vertical the geomagnetic field and the horizon plane, there is no obvious difference about the character of magnetic memory signal between them, the slight difference is that the magnetic memory signal in the plane vertical geomagnetic field is more sensitive than it in horizon plane.

4. conclusions

(1) The magnetic field intensity curve concave volatility within the region of metal fatigue cracks.
(2) Tiny crack is an important factor to the change of magnetic field within the metal, and the change caused by tiny cracks of partial magnetic field intensity is partial effect.
(3) the magnetic signal curve changes in rates is tremendous in the region of fatigue crack, with the increase of the fatigue life magnetic field intensity change rate get to be larger than before ,and the gradient of magnetic field increases rapidly after the fatigue cracks germinated.
(4) The features of magnetic field within the metal will not change generally because the existence of the Earth's magnetic field. Unless there is magnetic phenomena caused by strong magnetic field.
(5) The experiment confirmed that metal magnetic memory testing method can be used to test the accumulated fatigue damage, and it can better reflect the state of fatigue about the specimen, it has important role on promoting further research on fatigue.

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