

THE APPLICATION OF METAL MAGNETIC MEMORY TESTING TO THE FIELD OF THE LIFE ESTIMATION OF REMANUFACTURING BLANKS

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Abstract

The life prediction of remanufacturing blanks is one of the key techniques in the field of remanufacturing engineering. The method of Metal Magnetic Memory Testing (MMM) is a highly promising tool in the field of life prediction of remanufacturing blanks. This paper revealed the essence of MMM signals and represented its recent progress in the life prediction of fatigue crack initiation and fatigue crack propagation. A new apparatus using $H_p(x)$ signals, named RM-1, was developed. Moreover, it was used to evaluate the surface quality of a certain tank body.

Key words: remanufacturing blank; Metal Magnetic Memory testing; magnetic memory signals; fatigue crack initiation life; fatigue crack propagation life

1 Introduction

Equipment remanufacturing engineering is a new discipline founded to meet the strategic objective of the sustainable development in our country and to explore the effective ways of resource conservation and of waste equipment upgrade. It includes a series of technique measures and engineering activities to repair or modify the waste and old equipments, which is guided by a full-life periodical design and management and uses the means of the advance technologies and the production of industrialization and has the goals attaining high quality, high efficiency, saving materials and protecting environment^[1-3].

Remanufacturing is different from traditional manufacturing, which utilizes waste and old products as blank. In other words, the remanufacturing blanks are the components which have manufactured and served for some time. Prior to remanufacturing production, the life of the remanufacturing blanks must be firstly evaluated to judge whether they have adequate value to be remanufactured. Consequently, life evaluation of remanufacturing blank is one of the key techniques of remanufacturing engineering. Moreover, this research belongs to the fundamental front project of remanufacturing engineering^[4].

At present, there are three types of methods for evaluating residual life of remanufacturing blanks, such as the method of theory model calculation, the method of finite element simulation and the method of non-destructive testing^[5-8]. If the first or the second methods were used to evaluate residual life, the predicted life often rather differs from the real life under operating condition. Moreover, the individual differences

of the same kind components can not be showed if used the two methods for life prediction. In contrast, non-destructive testing can be applied to a certain special component to monitor defects variation in real-time, which has a higher accuracy of life prediction. Today, there are many mature non-destructive testing methods can be used to detect millimeter-sized defects^[9,10]. However, there are still a lot of difficulties to identify early damage in components due to a lack of measured parameters.

Metal Magnetic Memory testing is a new non-destructive method. It can find stress concentration zones in the surface of ferromagnetic components using self-emitting signals. However, the physical mechanism of the method did not be clarified completely due to its short development time^[11-13]. The magnetic memory signals are very weak, thus they can be influenced by many various interference factors. Consequently it is difficult to carry out the quantification of magnetic memory signals. It is not clear whether and how MMM is applied to the field of life prediction of remanufacturing blanks, which is a difficult and important problem in remanufacturing engineering.

2 The basic principle of Metal Magnetic Memory testing

MMM is a harvest of Russia researchers, which was firstly presented in the 50th international welding conference in 1997 and introduced into China in 1999. The technique was rapid spread and widely applied in the engineering fields^[14,15].

MMM is mainly based on the magnetomechanical effect. Weak magnetic signals are spontaneously generated in the ferromagnetic components during their operation, which can be used to find stress concentration zones. Ferromagnetic materials have magnetic domain structures and self-magnetization. When external load is applied to them, the residual magnetic induction and the spontaneous magnetization increase on the stress concentration zones of ferromagnetic materials. Thus the fixed nodes of the magnetic domains generated, thereafter they occur on the surface of ferromagnetic materials in the form of leakage field, which can be reserved after the applied load removal. The self-leakage field can memory the position of stress concentration zones, which horizontal component $H_p(x)$ has a maximum value and normal component $H_p(y)$ cross the zero point. Consequently the degree of stress concentration can be diagnosed and evaluated^[16-18]. The basic principle was shown in Fig.1.

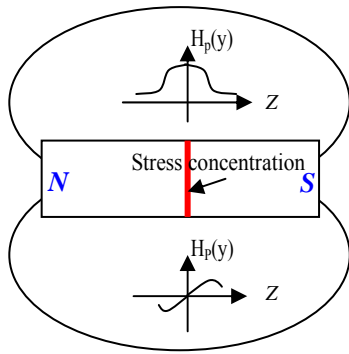


Fig. The schematic diagram of MMM method

Compared with the other non-destructive methods, MMM can detect the stress concentration zones induced by the hidden discontinuity for early damage diagnosis, which is the outstanding merit. When measuring by MMM, an external excitation magnetic field and surface cleaning applied to ferromagnetic materials are unwanted, and non-contact measurement can be used, thus the technique is particularly well suited to the site measurement. Moreover, the apparatus of MMM is very small for ease of operation. The reliability and repeatability of measuring results are very good.

3 Progress in the field of life prediction of remanufacturing blanks using MMM

In fact, MMM is still in the growth stage due to its short developing time. It only provides a qualitative evaluation criterion for detecting the site of stress concentration, furthermore, its accuracy need to be verified by other testing methods, which limits its use for the life prediction of remanufacturing blanks. Hence, further investigation of MMM, not only theoretical but also practical, was carried out by our research group.

3.1 Advance in the theoretical investigation

A lot of fundamental experiments were performed, in addition, many waste or old components of armored equipments were measured in the past few years. Consequently, the essence of MMM signals was defined and the effective approach to evaluate the life of remanufacturing blanks was determined.

3.1.1 The essence of MMM signals

The experimental results and measuring results of practical parts indicated that a stray field, induced by the factors of load, heat and magnetization, was spontaneously generated on the surface of ferromagnetic components during their manufacturing process and operation. The value and distribution of the stray field can reflect the influence of temperature, load factors. In fact, MMM signal is the signal of the stray field, which horizontal component is $H_p(x)$ and normal component is $H_p(y)$. The signals of the self stray field are ignored in the previous researches on magnetic non-destructive method. The MMM technique just utilize the ignored stray field signals to infer the degree of stress concentration.

3.1.2 Fatigue life prediction by MMM

Most of armored components are made of ferromagnetic materials, and a lot of key parts of them are subjected to different fatigue loads in type and value, thus fatigue

fracture is the main reason for their failure. The fatigue life is defined as the total cycles fatigue crack needed from crack initiation and propagation to final failure of the parts, that is, fatigue life N equals to a sum of fatigue crack initiation life N_i and fatigue crack propagation life N_p [5].

The prediction of fatigue crack initiation life is a very difficult problem in the field of non-destructive testing because the damage variation in the materials is very small prior to fatigue crack initiation. In our research the smooth specimens demagnetized by vacuum heat treatment were used and tension-tension fatigue tests were performed with constant amplitude in different stress level. The smooth specimens had clean initial magnetic state due to the effect of vacuum heat treatment. The $H_p(y)$ curves presented a good linearity after loading, thus it is easy to extract the slope coefficient K_s of the magnetic curve to analyze the relationship between K_s and fatigue cycles N . It can be found that in the early stage of the fatigue life K_s dramatically increased with the fatigue cycles increasing; in the intermediate stage K_s gradually trended to a stable value and increased slowly; in the last stage of fatigue life K_s decreased due to microcrack formed (shown in fig.2). Consequently a formula describing fatigue crack initiation life $K_s = aN^b$ was obtained, where coefficient a and b is parameters controlled by applied load [19].

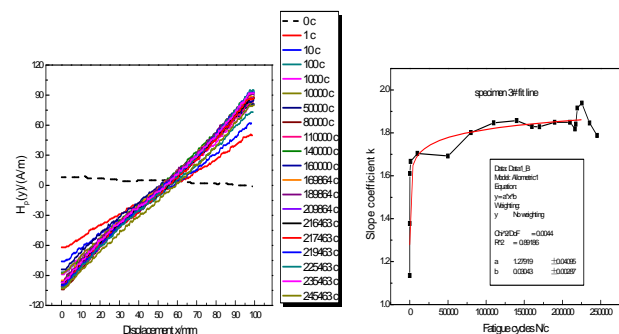


Fig.2 The distributions of $H_p(y)$ and K_s versus fatigue cycles during the fatigue tests

It should be noted that the above conclusion is obtained under the condition of the tested specimens with very clean initial magnetic state. Even if so, the variations of K_s induced by fatigue cycles increasing were still weak. Although the research result verified the feasibility of early fatigue life prediction, it is not easy to be applied directly to a special remanufacturing blank because the magnetic signals of the practical engineering component are very complicated, which are closely related to the dimension and size of the part, material composition, manufacturing process and operating conditions.

In contrast, ferromagnetic materials can emit strong abnormal magnetic signals during the stage of fatigue crack propagation, even if the specimens without clean initial magnetic state, which is very different from the weak variation of magnetic signals during the stage of fatigue crack initiation. The central crack testing (CCT) specimens were used to perform tension-tension fatigue test. Measured under the load-off condition, it was found

that the peak-to-peak value of magnetic abnormal peak increased with the fatigue crack growth^[20]. A linear relationship between the length of fatigue crack and the peak-to-peak value of abnormal magnetic peak was found (shown in fig.3). Hence the peak-to-peak value can be utilized to characteristic fatigue crack growth and the life of fatigue crack propagation can be expressed as:

$$N = \int_{\Delta H_{p1}(y)_0}^{\Delta H_{p1}(y)_c} \frac{d\Delta H_{p1}(y)}{A(\Delta K)^B}$$

3.2 Development of a new MMM instrument

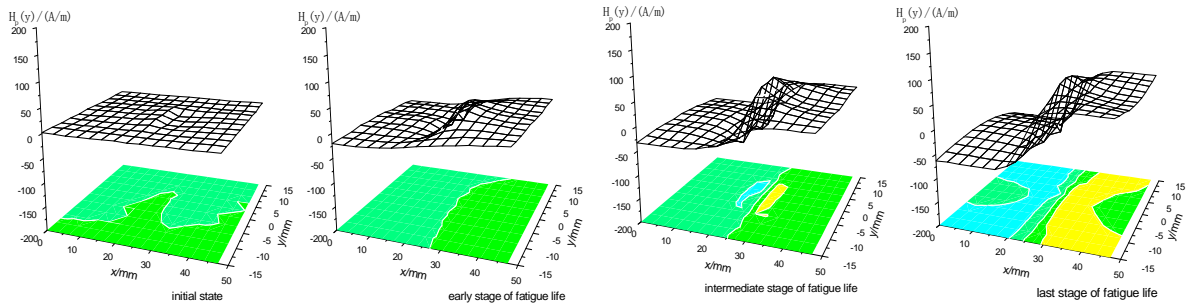


Fig.3 The variation of $H_p(y)$ signals of CCT specimens during the process of fatigue crack propagation

$H_p(y)$ signal would have a zero point jumping from a positive sign to a negative sign at the zones of stress concentration, thus it is easy to find and collect. Consequently all types of instruments only provide $H_p(y)$ signals, namely the normal component of stray field, since the appearance of MMM method. The horizontal component $H_p(x)$ is unfortunately ignored. In fact, $H_p(y)$ and $H_p(x)$ are twin parameters. They can present their distribution features respectively during the stage of fatigue crack propagation, both of which can be utilized to predict the life of remanufacturing blanks. Hence our research group developed a new MMM instrument RM-1 for measuring $H_p(x)$ signals^[21].

The hardware of RM-1 instrument include magneto-dependent sensor, advance conditioning panel, main conditioning panel, power, data acquisition card, computer, application software and wires. The magneto-dependent sensor, advance conditioning panel

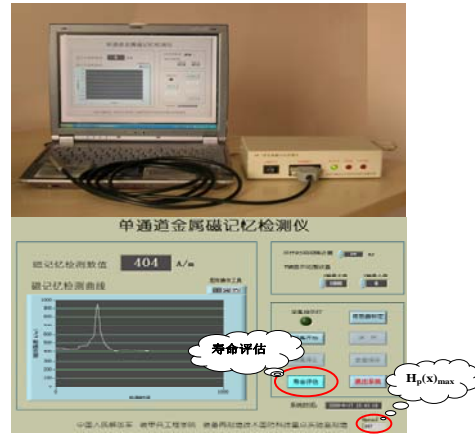


Fig.4 The appearance of a RM-1 MMM instrument and its face panel

and signal wire constitute sensing probe; the main conditioning panel, the data acquisition card and power constitute the host machine of the RM-1 instrument; the computer and the application software constitute the calculating control module. The software program of RM-1 instrument is written by a programming tool LabVIEW. Moreover, a life prediction module is added into the RM-1 instrument based on the experimental results. According to the measured $H_p(x)$ signals it can be determined that a ferromagnetic part is in the stage of fatigue crack initiation or in the stage of fatigue crack propagation, and then its residual life can be predicted. The appearance of the instrument and measuring surface are given in Fig.4.

3.3 A example in the application

When a tank or a armored vehicle driving, its body is loaded through a crawler and a loading wheel due to uneven road surface. A fatigue crack will be initiated in the stress concentration zones of the body. With the service time increasing the fatigue crack will grow gradually, which is a potential menace for the safety of the tank. Fig.5 gave a fatigue crack on the stress concentration zone of the body of a certain tank. Four measured lines were arranged along the direction of

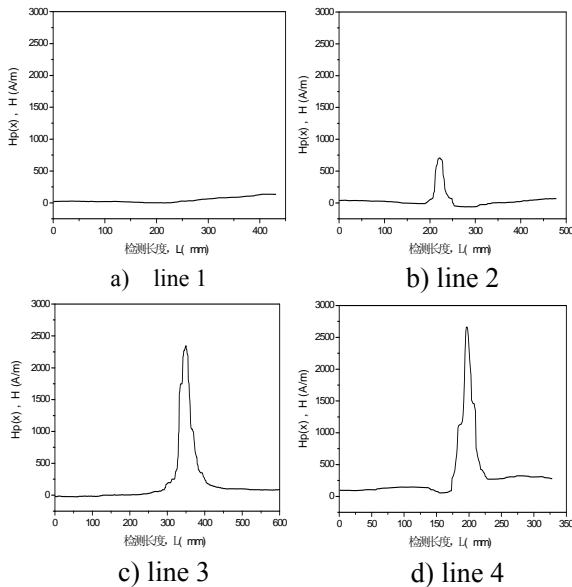
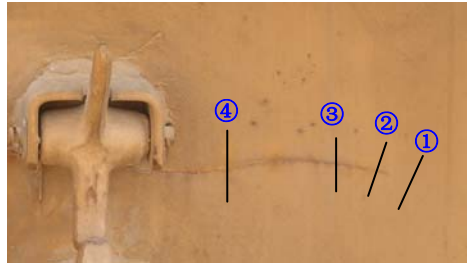


Fig.5 The distribution characteristics of $H_p(x)$ signals on the surface of tank body

fatigue crack propagation. It can be seen that the $H_p(x)$ curves showed a peak on the positions existing fatigue crack. The nearer the fatigue crack front, the smaller peak value the measured line displayed. Then the peak disappeared on the site without fatigue crack. Hence the damage degree on the different sites of the tank body could be evaluated according to the $H_p(x)$ signals. When all the measured results were studied analytically and synthetically, the residual life of the tank body was obtained.

4 Conclusions

As a new non-destructive method MMM testing attracted a lot of interests in the field of non-destructive methods at home and abroad. However, the study of life prediction of remanufacturing blanks by MMM has just begun. A longer time is needed to establish a good predicting model for a specific ferromagnetic component. To meet this objective, more researches should be done to further clarify the internal physical mechanism of MMM on one hand; on the other hand, MMM signals of specific samples of remanufacturing blanks should be collected and be analyzed to find a suitable parameter evaluating damage degree, only by means of this approach the theoretical model may be perfectly combined with the specific component.

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References

- [1] B.S Xu, S.C Liu, R.H Li, J.K Yao. "The basic approach and the prospect of the waste and old electromechanical products generating resource", *Chinese surface engineering*, 17, pp. 1-6(2004)
- [2] B.S Xu, W Zhang, S.C Liuu. "Remanufacturing Technology for the 21st century". *Proceedings of the 15th European Maintenance conference*, March, 2000 in Gothenburg, Sweden:335-339
- [3] B.S Xu. "Developing remanufacturing engineering to promote circle economy". *Chinese equipment engineering*. 40, pp.7-9(2005)
- [4] B.S Xu. "The theory and technique of equipment remanufacturing engineering". Beijing: National defence industry publishing house,2007
- [5] C.Y Chen. "Fatigue and fracture". Wuhan: Huazhong university of science and technology publishing house, 2002
- [6] S.Suresh. Fatigue of materials. Beijing: National defence industry publishing house, 1993
- [7] J.B.Ibsø, H.Agerskov. An Analytical Model for Fatigue Life Prediction Based on Fracture Mechanics and Crack Closure. *J.Construct.Steel Res.* 37, pp. 229-261(1996)
- [8] K.C.Liu, J.A.Wang. An energy method for predicting fatigue life crack orientation and crack growth under multiaxial loading conditions. *International Journal of Fatigue*. 23, pp. 129-134(2001)
- [9] J.W Li, J.M Chen. Nondestructive handbook. Beijing: Mechanical industry publishing house,2002
- [10] Jack Spanner, Greg Selby. Sizing stress corrosion cracking in natural gas pipelines using phased array ultrasound. *NDE Engineering*. 22, pp. 68-71(2002)
- [11] J.L Ren, J.M Lin. Metal Magnetic Memory Testing. Beijing: Chinese electric power press, 2000
- [12] LI Lumimng, HUANG Songling, WANG Xiaofeng, et al. Stress induced magnetic field abnormality. *Trans. Nonferrous. Met. Soc. China*. 13, pp. 6-9 (2003)
- [13] S.L HUANG L.M Li, K.R Shi, et al. Mangetic field properties caused by stress concentration. *J. CENT. SOUTH. UNIV. TECHNOL.* 11,pp. 23-26(2004)
- [14] A.A Doubov. A study of metal properties using the method of magnetic memory [J]. *Metal Science and Heat Treatment*. 39,pp. 401-402(1997)
- [15] A.A Doubov. Screening of weld quality using the magnetic metal memory effect. *Welding in the world*, 41, pp.196-198(1998)
- [16] A.A Doubov. The method determining the limit state of metal materials by means of leakage field gradient on the stress concentration zones. *Nondestructive conference in Chinese*, Jiangsu suzhou,2003
- [17] A.A Doubov. A Technique for Monitoring the Bends of Boiler and Steam-Line Tubes Using the Magnetic

- Memory of Metal[J]. Thermal Engineering. 2001, 48(4): 289~295
- [18] A.A Doubov. Express method of quality control of a spot resistance welding with usage of metal magnetic memory[J].Welding in the World. 2002, 46: 317~320
- [19] L.H Dong. Basic research on the life prediction of ferromagnetic materials in remanufacturing engineering. Doctor dissertation of academy of armored forces engineering, 2008
- [20] Dong Lihong, Xu Binshi, Dong Shiyun, et al. Monitoring fatigue crack propagation of ferromagnetic materials with spontaneous abnormal magnetic signals, *International Journal of Fatigue*. 30, pp. 1599-1605(2008)
- [21] Dan Wang. A new method and instrument of Metal Magnetic Memory Testing for residual life

estimation of remanufacturing blanks. Doctor dissertation of academy of armored forces engineering, 2008

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