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Failure analysis by advanced magnetic techniques

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ABSTRACT

Now-a-days attempts are being made to use the inherent ferromagnetic properties to characterize steels. Out of all the available methods, magnetic hysteresis loop (MHL) and micromagnetic Barkhausen emissions (MBE) are relatively newer and very promising techniques in the area of component integrity and failure analysis. The MHL parameter coercivity (H_c) decreases with the tensile stress, grain size and increases with the hardness of the materials while the reverse effect is observed in case of remanence (B_r). The micromagnetic Barkhausen emissions (MBE) which are originated due to irreversible domain wall motion in the presence of alternating magnetic field are also found to be sensitive to stress and microstructure of the materials. The present paper deals with the two case studies where MHL and MBE parameters were used to analyse failure of components. The cases were (i) failure of in-service flange used in fossil power plant and (ii) premature failure of shot peened suspension spring used in automobile. In the former case MBE and MHL parameters were used to find the extent of creep damage at various positions of the component while in the latter case MBE parameters were used to evaluate the residual stresses at different positions of the spring component.

INTRODUCTION

The variation of magnetic properties of steel with stress, strain and microstructure is a subject of great practical importance. It is of special interest to those who are involved in property evaluation of in-service components by nondestructive techniques as the changes in magnetic properties due to stress, strain or microstructure can be very large. For example, permeability may be 100 times more due to strain within elastic limit or the non ferromagnetic steel may become ferromagnetic due to microstructural changes occurred during service exposure [1,2]. However, despite these large changes in magnetic properties, the techniques have not been fully realised as tools to assess the damage of in-service engineering components or to understand the cause of failure of components. Probably this is because

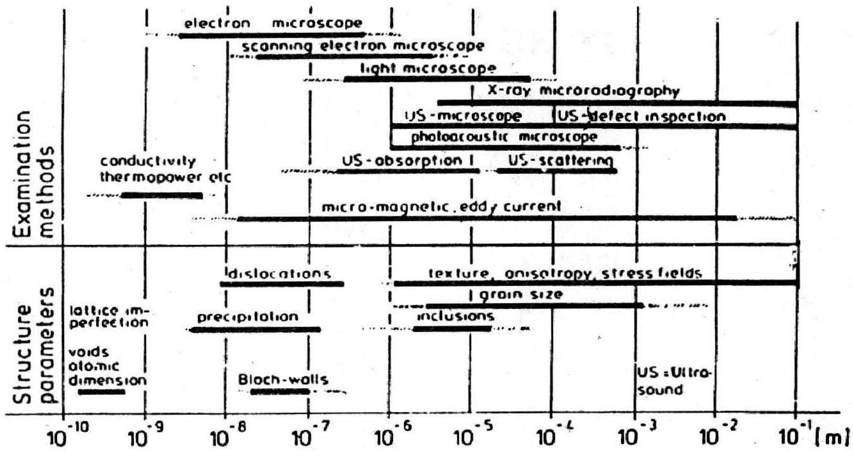

Fig. 1 : Linear dimensions of structure parameters and examination methods[8]

other techniques can be applied to a wide variety of materials and previously there was more incentive for their development. Now, however, as the limitation of other techniques become apparent, as for example, in the important area of detection and prediction of failure such as fatigue or thermomechanical degradation (creep damage), attention has focused on the capability of magnetic methods applied to steels [3,4]. There are also some difficulties in using magnetic techniques as the magnetic properties are sensitive to various factors like stress, grain size, precipitates [5,7] However, these problems can be overcome by analysing the result systematically with the prior knowledge of the dependence of each variables that the material experienced during service.

The examination methods for various types of structural parameters and their linear dimensions are presented in Fig. 1 [8]. It clearly demonstrates the usefulness of magnetic techniques for defect analysis as its covers wider range of defects. The various magnetic methods for determination of structural defects have been reviewed by Jiles [9]. However, out of all the available methods Magnetic Hysteresis Loop (MHL) and Magnetic Barkhausen Emissions (MBE) are found to be relatively new and very promising techniques for analysis of defects in engineering ferromagnetic components. While MHL represents the bulk properties, MBE gives information about the surface and/or near subsurface zone. In this presentation two case studies are discussed where MHL and MBE are used to analyze the cause of failure of components that failed while in service.

What are MHL & MBE?

When a ferromagnetic material is subjected to a cyclic magnetic field, the magnetic induction value depends on the strength and direction of the applied field resulting in a hysteresis loop as shown in Fig. 2. The characteristic parameters of

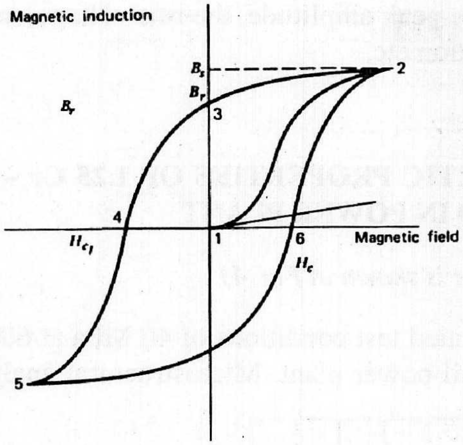

Fig. 2 : Magnetic hysteresis loop showing important properties, B_r, remanence; B_s, saturation induction; H_c, coercivity

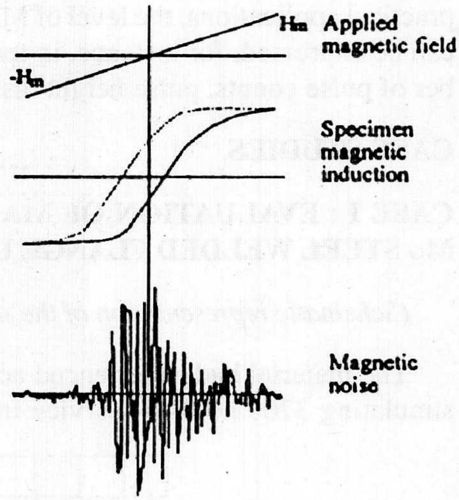

Fig. 3 : Magnetic Barkhausen Emissions (MBE) signal for half magnetizing cycle

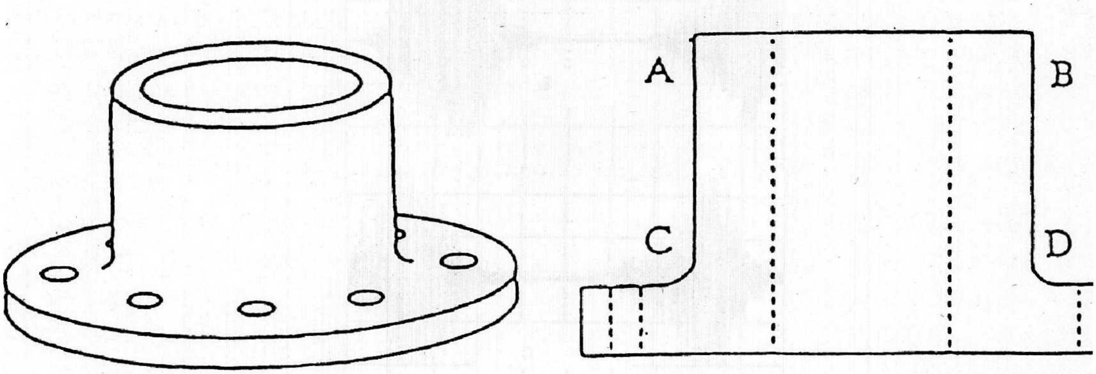

Fig. 4 : Schematic presentation of creep damanged sample

the magnetic hysteresis loop are coercivity (H_c), remanence (B_t), initial permeability (μ_i), maximum differential permeability (μ_{max}) etc. which are also shown in Fig. 2. Ferromagnetic materials consists of magnetic domains, separated from each other by domain walls. The net magnetization of the bulk material is the average of the magnetization within all domains. In the demagnetized state, it will be zero. If the domain wall is made to move by the magnetizing field, the magnetization within the area swept by the wall will change to other direction, generating an electrical pulse. In bulk sample when all individual wall moves and pulses generated are bunched, a burst type signal, called Magnetic Barkhausen Emissions (MBE), emitted

[10]. Fig. 3 shows how one MBE burst is created for a magnetizing half cycle. Fc practical applications, the level of MBE signal can be quantified in several ways.] can be expressed, for instance, in terms of peak amplitude, the rms voltage, num ber of pulse counts, pulse height distribution etc.

CASE STUDIES

CASE I : EVALUATION OF MAGNETIC PROPERTIES OF 1.25 Cr – 0.: Mo STEEL WELDED FLANGE USED IN POWER PLANT

(Schematic representation of the sample is shown in Fig. 4)

The material had experienced accelerated test conditions of 40 MPa at 600°(simulating 3700 hours of service in fossil power plant. Microstructural analysi

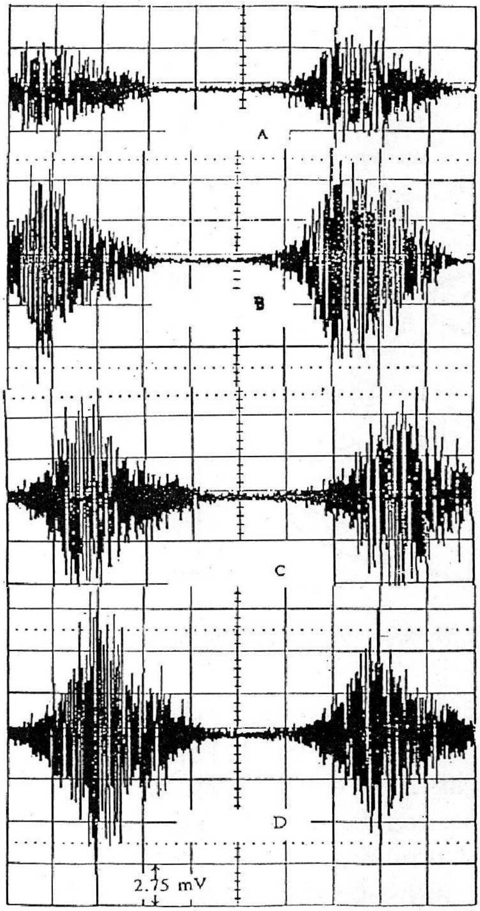

Fig. 5 : Magnetic Barkhausen emission (MBE) signals at various measured positions

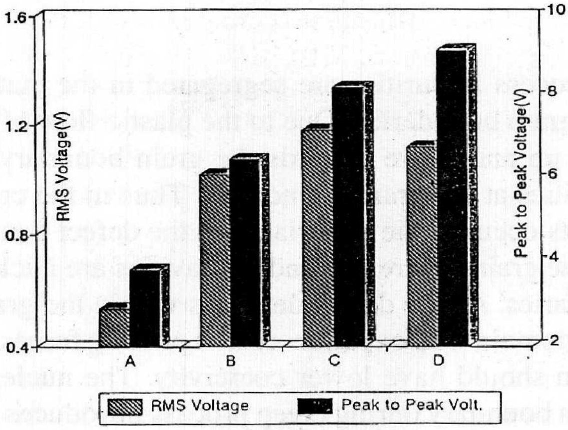

Fig. 6 : Barkhausen parameters at different measured position

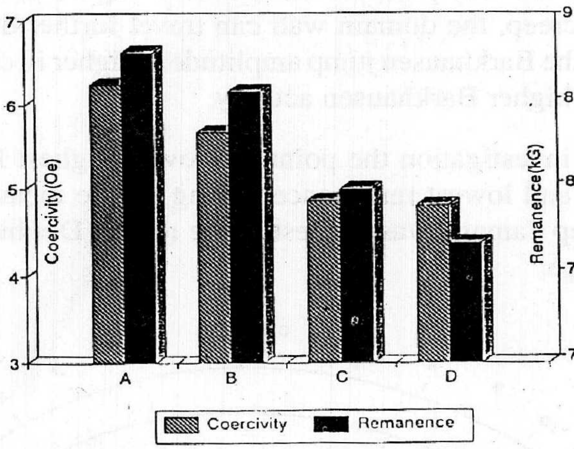

Fig. 7 : Magnetic Hysteresis loop parameters at different measured psotion

revealed that the material was early stage of creep damage. Most of the failure occurred close to the point D.

Results

The magnetic properties were measured at four different positions A, B, C and D. Fig. 5 shows MBE signal waveforms at the measured locations at a magnetizing field amplitude of 30Oe having 8 Hz frequency. Figs. 6 and 7 represent the MBE and MHL parameters at A, B, C, and D. Experimental results demonstrate that the Barkhausen activity is more at the region CD compared to AB and it is maximum at D. Both the remanence and coercivity are found to be low at the CD region compared to AB.

Discussion

In the creep process impurities are segregated in the materials and these migrate towards the grain boundaries. Due to the plastic flow of the materials, dislocations also build up and move towards the grain boundary. This accumulation slowly causes cavities at the grain boundaries. Thus in the creep process two microstructural effects occur in the materials: (a) the defect density (impurities, dislocations) inside the grains decreases and (b) cavities are nucleated and developed at the grain boundaries. As the defect densities within the grains decreases in the creep process, the domain wall experiences less pinning forces. Therefore the creep damaged specimen should have lower coercivity. The nucleation and growth of cavities at the grain boundary during creep process introduces local demagnetizing fields in the vicinity of the cavity, and this results in a decrease of remanence in creep damaged specimens. Barkhausen emissions are caused by irreversible domain wall movement in the presence of an alternating field. As the defect density decreases during creep, the domain wall can travel further distance without pinning forces. Thus the Barkhausen jump amplitude is higher in creep damaged specimen, resulting in higher Barkhausen activity.

In the present investigation the point D showed highest Barkhausen activity, lowest coercivity and lowest remanence among all the measured points. Hence, the degree of creep damage was highest at the region D which was the cause of failure of the flange.

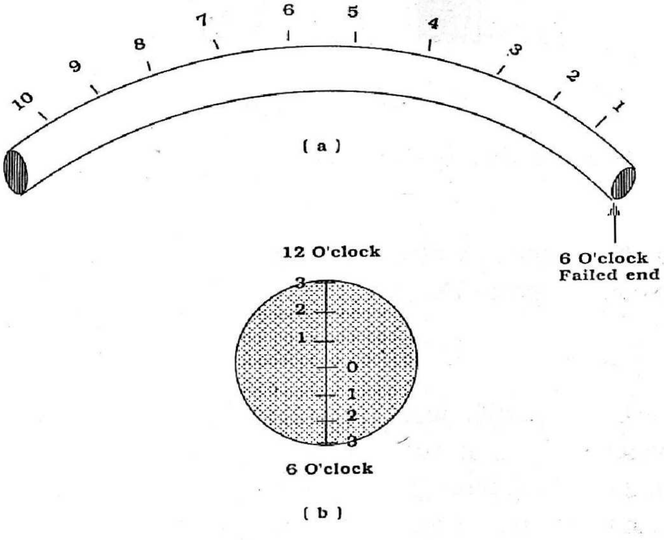

Fig. 8 : (a) Schematic presentation of the short peened spring showing different points (1 to 10) where MBE measurement was taken and (b) cross sectional view of spring section shwoing different points where XRD study was done

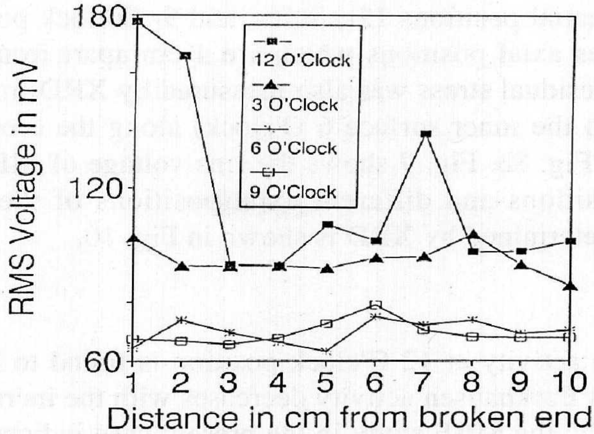

Fig. 9 : RMS voltage at different position of the spring section

CASE II : FAILURE OF SHOT PEENED SPRING

The material under investigation is shot peened suspension spring which failed during service in an automobile. The diameter of the spring rod is 10 mm and the spring section under study is part of the spring having diameter ~80 mm. The spring material confirms to medium carbon steel (C –0.57, Mn–0.82, Si–1.83 in wt. %). the schematic representation of spring section is presented in Fig. 8. Visual observation showed that the crack started from the inner diameter of the spring and extended to the outer surface.

Results

MBE measurements at a magnetizing frequency of 120 Hz were taken at four

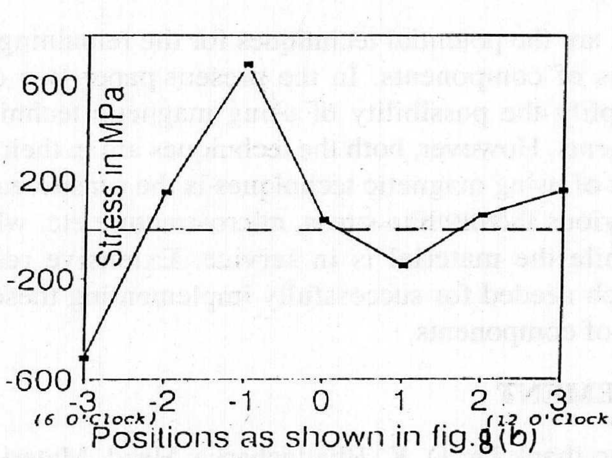

Fig. 10 : RMS voltage at different position of the spring section

different circumferential positions 12-, 3-, 6-, and 9- O'clock position facing the fail end, and various axial positions which are 1 cm apart from the fail end as shown in Fig. 8a. Residual stress was also measured by XRD from the outer surface (12 O'clock) to the inner surface 6 O'clock) along the cross section of the spring as shown in Fig. 8b. Fig. 9 shows the rms voltage of MBE signal at four circumferential positions and different axial positions of the spring section. Residual stress as determined by XRD is shown in Fig. 10.

Discussion

The Barkhausen activity at 12 O'clock position is found to be higher than 6 O'clock position. As Barkhausen activity decreases with the increase of compressive stress in steel [11], the MBE study in the present case indicates that the compressive stress at the inner diameter (i.e., the arc covering 3- 6- 9- O'clock positions) of the spring section is higher than the outer one (9- 12- 3- O'clock positions). XRD results also corroborates the MBE results that the compressive stress in 6 O'clock position in higher than the 12 O'clock position. It also indicates the existence of high tensile stressed (~ 700 MPa) region at the subsurface close to the inner surface of the spring section where the compressive stresses are maximum. Microstructural investigation revealed that the material is tempered martensite with high ratings of oxide inclusions [12]. The existence of excess inclusions makes the materials inherently bad. It appears that the nonuniform distribution of the compressive stress in the service exposed spring section and the presence of high tensile stress at the subsurface near the inner diameter may initiate the cracks in the interface of the inclusions and matrix.

CONCLUSIONS

MHL and MBE are the potential techniques for the remaining life assessment and failure analysis of components. In the present paper two case studies are discussed to exemplify the possibility of using magnetic techniques for failure analysis of components. However, both the techniques are in their infancy. One of the major problems of using magnetic techniques is the sensitiveness of magnetic parameters with various factors like stress, microstructure etc. which can change simultaneously while the material is in service. Extensive research work is, therefore, very much needed for successfully implementing these techniques for structural integrity of components.

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