

Advanced Techniques for the Measure of Microstructure and Residual Stress in Components Subject to Rolling Fatigue

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ABSTRACT

Demands on loaded, rotating components, e.g., bearings, shafts & gears continue to escalate. Modern manufacturing strategies require improvements in traditional measurements and process control tools.

Traditionally residual stress examination in bearings was accomplished with depth profiles obtained using X-Ray diffraction (XRD) and electrochemical layer removal. More recently Barkhausen Noise Analysis (BNA) has proven itself in the evaluation of microstructure as well as surface residual stress in ferromagnetic materials. Traditional BN analysis parameters have been used for fixed measurement depths, usually near the surface.

This study is an examination on a set of as-hardened and ground bearing rings manufactured with variations in processing. The Barkhausen signal was analyzed to yield information about a range of depths. XRD & BNA depth profiles were gathered and they correlate well. This allows a calibration of the BN signal to the residual stress. It is proposed that BNA can be used for quick, non-destructive assessment of residual stress depth profiles.

INTRODUCTION

Current manufacturing processes for rotating components, specifically those subject to rolling fatigue, often include multiple instances of surface grinding and heat treatment. These processes introduce a multitude

of complex changes to the microstructure of the component, including residual stresses.

Residual stresses impact the fatigue life of components as they play a role in the total stress exerted on the component. The total stress exerted on a component is the sum of all external and internal stresses, including internal residual stress. Traditionally, surface residual stresses can be evaluated non-destructively using XRD methods or BNA. In order to measure stresses below the surface and through the depth XRD must be complemented by electrochemical layer removal, thus destroying the component. It is possible, however, using advanced techniques in BNA, to estimate subsurface stress features non-destructively.

MAIN SECTION

RESIDUAL STRESS MEASUREMENTS VIA X-RAY DIFFRACTION – X-ray diffraction uses two well known principals to effectively use the inter-atomic spacing between a specific crystallographic plane as a strain gauge and allow the calculation of the planar residual stress stored in the surface using linear elastic values.

The first such principal is Bragg's law that relates the diffracted peak position (θ) to the inter-atomic spacing (d) as well as the wavelength of the incident radiation (λ).

$$n\lambda = 2d \cdot \sin\theta$$

The values of the wavelength and peak position are known for the selected crystallographic plane. In this

case CrK α radiation and the Fe 211 plane at a 2 θ value near 156°. This allows for small changes in the peak position to reflect changes in the d-spacing in the surface plane as measurements are taken in the positive and negative directions relative to normal (ψ); effectively measuring the strain.

The second principal is Hooke's law that relates the Modulus of Elasticity (E) and the strain (ϵ) to the stress (σ) by assuming that the stress normal to the plane is zero ($\sigma_z = 0$) and that the d-spacing can be used as a measure of strain. The relationship between d-spacing and stress uses the Modulus of Elasticity, Poisson's Ratio (ν) and (m) the slope of d vs $\sin^2 \psi$ plot.

$$\sigma_{\psi} = \left(\frac{E}{1 + \nu} \right) m$$

This equation in conjunction with cross correlation methods to determine peak translation and multiple exposures through the positive and negative ψ range allows for the precise and repeatable measurements of residual stress on nearly any crystalline material.

FUNDAMENTALS OF THE BARKHAUSEN EFFECT –
The Barkhausen Effect is a micromagnetic phenomena observed in ferromagnetic materials undergoing magnetization. As a ferromagnetic sample is magnetized and demagnetized the net magnetization of the sample changes in relation to the applied external magnetizing field; this process is hysteretic in nature. The Barkhausen Effect occurs during this hysteretic process as the magnetization of the sample changes with respect to the applied magnetic field in discrete “steps” as opposed to a smooth, continuous transition (see Figure 1).

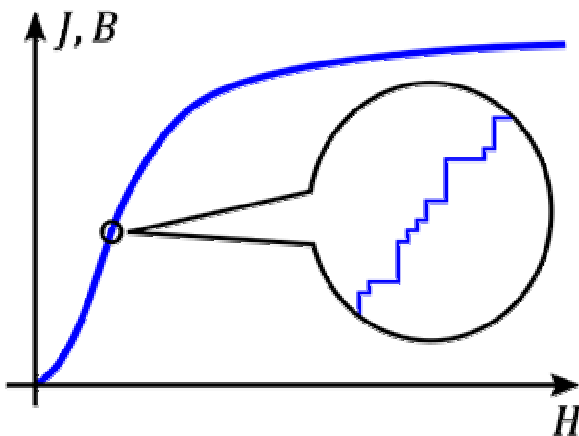


Figure 1^a – Magnetization (J) or Magnetic Flux Density (B) with respect to applied field strength (H)

It is the presence of these discrete steps in the magnetization-applied field (J,B-H) relationship that result in Barkhausen noise. These jagged steps are the product of rapid discontinuous changes in the magnetization of the sample which is a consequence of changes in the size and orientation of magnetic domains [1].

The net magnetization of a ferromagnetic material is the sum of the magnetization of all its magnetic domains. Magnetic domains are small sections or patches within a sample that contain billions of magnetic dipoles oriented in the same direction [2]. Each magnetic dipole is essentially an atom acting as a bar magnet. Ordinarily magnetic domains are randomly oriented, resulting in zero net magnetization. In the presence of an applied field (or a permanent magnet), however, these bar magnets begin to align with the direction of the applied field. Entire domains align rapidly (see Figure 2) and, sometimes, assimilate into neighboring domains. When all domains have been assimilated into one the sample is magnetically saturated.

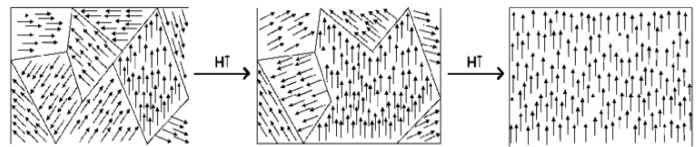


Figure 2^a – Resizing and reorienting of domains as a result of applied field H

Each rapid change in domain magnetization is a result of the rapid change in the magnetization of billions of atoms, thus producing the aforementioned steps or jumps in the net sample magnetization. The consequence of these jumps is a burst of electromagnetic noise, or Barkhausen noise.

Barkhausen noise can be analyzed by inductively measuring the changing magnetization of a sample, usually while applying an alternating magnetic field. When an alternating magnetic field is applied the sample emits a stream of Barkhausen noise bursts as the applied field continuously changes.