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The effect of changing loads affecting the martensite steel on its structure and the Barkhausen noise level

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Abstract

The intended aim of the paper is to demonstrate how changes in the Barkhausen noise (BN) intensity depend on changes in the microstructure of rotor blades of an axial compressor, ones made of the martensite steel exposed to changing loads. What has been explained is the non-linear dependence of the BN on the number of steel-deformation cycles applied on a test stand under service-loading conditions. The modification of the dislocation structure emerging in the course of steel fatigue has been presented. It has also been shown that any change in the dislocation distribution and the accompanying increase in the misorientation of sub-grains as well as the modification of retained austenite precipitates both considerably affect the BN intensity. The dependence of the BN on the blade's operation time has been compared with that of the BN on the number of service-loading cycles. It has been found that results of both the stand tests and metallographic examination can be used to determine the level of blade material fatigue in the course of operational use thereof.

Keywords: Compressor blades; Changing loads; Steel fatigue; Barkhausen noise; Dislocation structure

1. Introduction

Any object is exposed to changing loading with mechanical, heat and other loads of varying amplitudes and frequencies during its whole service life. Fatigue induced with these loads is the major cause of, among other things, failures/damages to compressors of aircraft turbine engines. Numerous research studies have been intended to deal with the fatigue cracking and fatigue damages. In spite of this and because of strongly complicated nature of the phenomenon, still open remain questions of both evaluation of the material-fatigue level and early detection of fatigue cracking in machine components. Several experimental methods that facilitate finding fatigue damages (with different reliability) have been put forward [1–9]. One of the suggested methods has been based on the Barkhausen effect and makes use of the so-called Barkhausen noise (BN). The concept of applying the BN to examine changing deformation of the steel was formulated dozens of years ago. Thus far, the question has not been thoroughly investigated and remains within the scope of interests of many researchers.

The up-to-the-present conducted research work concerning the effect of the deformation process of steel on the BN level has proved that the BN depends on values of deformations and the number of cycles. Karjalainen et al. [2,10,11] have shown the non-linear dependence of the BN on changing deformations in low-carbon steel. According to their findings, stress in the steel mostly affects the BN level. They have shown that any change in the BN level is a function of both the number of cycles and the value of load amplitude. If the maximum value of stress induced with variable loads is lower than the fatigue limit of the material, the BN level changes only slightly, if at all [10]. On the other hand, with stresses higher than the material's fatigue limit considerable changes in the BN are observable soon after the first stress cycles. Griszakow et al. [12] have also proved that the level of the BN in steel specimens changes if the number of variable loads changes.

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The changes become even more severe if the amplitude of variable loads increases. Lachman et al. [3] have shown that there is a relation between the changes in residual stresses and the BN level in welded specimens made of the S355 steel, subjected then to changing loads. As the amplitude of plastic strain kept increasing during the fatigue process, some changes in the BN level could be found.

Palma et al. [6] have presented the effect of variable stresses on the BN level in specimens made of the AISI 8620 steel containing ferrite and pearlite. They have shown that the BN level changes significantly for the range of stresses between fatigue strength and yield stress. If the induced stress exceeds the yield stress, no equivalent dependence between the material's destruction and the BN level can be found.

Softening due to variable stresses is an important feature of the fatigue process. Such a phenomenon is observed when—prior to changing load (fatigue)—dislocations are introduced in the material through plastic deformation [13–16]. During the changing deformation some change in distribution and density of dislocation occurs. In many cases this change results in the reduction of dislocation density and some decrease in strength of the material under investigation. The dislocation cellular structures due to changing load were reported by Laird et al. [13] and Murgrabi et al. [14] in steels subjected to the full—annealing process, and rolled (the output difference in the dislocation densities was considerable). The dislocation structure after applying changing load strongly depends on both the number and amplitude of cycles, Murgrabi et al. [14] and Liu [17]. For the number of cycles lower than 10^4, dislocation dipoles and loops are observed, whereas for the number of cycles higher than 10^5- slip bands. Propagation of these slip bands can result in the initiation of cracks. Roven and Nes [18] attribute crack propagation to the formation of continuous fatigue bands; therefore, they have proposed a model describing this phenomenon.

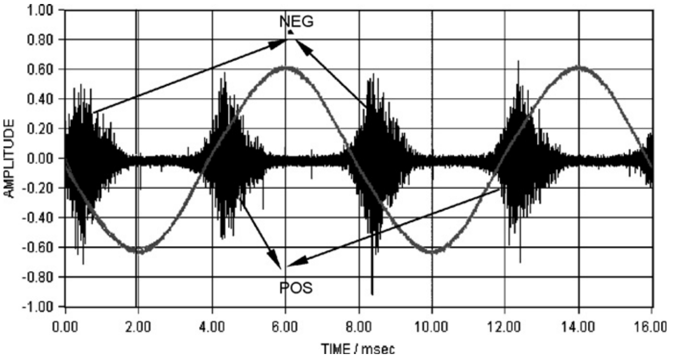

Fig. 1. The Barkhausen effect signal and a magnetising current signal (sinusoidal) taken from the μSCAN software. Negative (NEG) and positive (POS) impulses are marked in the figure.

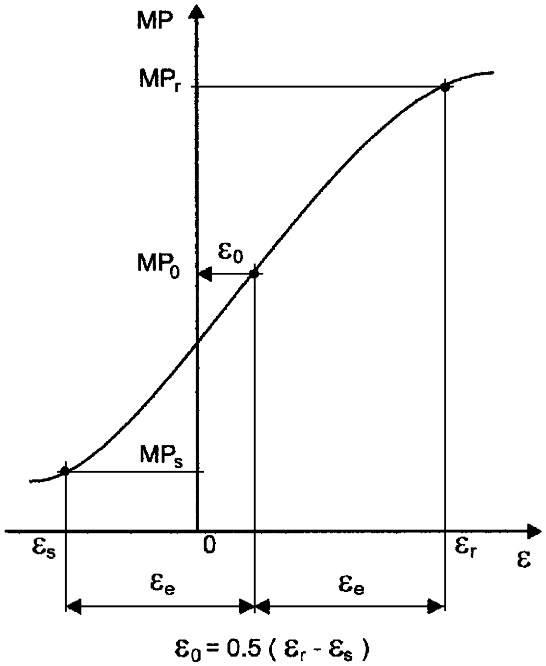

Fig. 2. Magnetoelastic parameter MP versus strain ε of the ferromagnetic material: ε_0—zero strain, ε_r—tensile strain, ε_s—compressive strain.

2. The essence of the Barkhausen noise

External magnetic field forces changes of directions of magnetisation of magnetic domains in any ferromagnetic material. Any such a change results in the displacement of domain walls to keep internal energy thereof as low as possible. The crystal lattice affects configuration of domains, whereas the magnetic structure—properties of the crystal lattice. Magnetisation of the ferromagnetic material, i.e. the changing of directions of magnetic vectors of domains could be decelerated or stimulated directly by mechanical stresses and indirectly by structural defects that either arrest or facilitate displacements of domain walls.

Voltage pulses recorded in the coil while magnetising the ferromagnetic material are information on the intensity of changes in strength of the internal magnetic field of the ferromagnetic material, induced with movements of domain walls (Fig. 1). Any change in strength of the magnetic field of the ferromagnetic material proceeds rapidly, when a group of domain walls relocates abruptly and rapidly, overcoming the force of inter-atomic interactions within the crystal lattice. The internal magneto-static and magneto-elastic energy of domains reaches then the highest level, and rapid increase in strength of the internal magnetic field induces voltage pulses in the applied coil. These pulses are called the BN. The number and the amplitude of these pulses correlate with the intensity of displacement of domain walls. They enable determination of the direction of deformation (Fig. 2).

Measurements of the BN have been gained in the form of a quantity called the 'magnetoelastic parameter' (MP), which corresponds to the mean value of the effective voltage of the BN measured in the course of several subsequent cycles of magnetising the ferromagnetic material.