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INFLUENCE OF MAGNETIZING FREQUENCY AND CONSTRUCTION OF PICK-UP COIL ON BARKHAUSEN NOISE

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This paper investigates the influence of the magnetizing frequency and different arrangements of a pick-up coil on the Barkhausen noise in samples of plastically deformed low-carbon steel. The strain dependence of root mean square value and power spectrum of the Barkhausen noise is explained in terms of dislocation density. The most suitable value of the magnetizing frequency for the investigated samples and used measuring system was found out experimentally.

Keywords: Barkhausen noise, tensile stress, pick-up coil, magnetizing frequency

1 INTRODUCTION

Nondestructive testing has gained in importance as a result of the rapid technological progress during the past half-century in areas such as aviation and nuclear energy. The preliminary investigations are necessary to predict any likelihood of the occurrence of structural changes and the appearance of defects, which may lead to possible failure. The Barkhausen noise method of nondestructive testing provides good sensitivity to residual stress levels and changes in microstructure of a magnetic material. The Barkhausen noise arises from the discontinuous changes in magnetization process as a result of irreversible motion of domain walls and irreversible rotation of magnetization. These irreversible changes of magnetization can be detected by sensing coil as a high frequency stochastic signal. The detected signal is influenced by external factors such as mechanical stress and fatigue. In this work, the different arrangements of pick-up coil are tested by means of measuring the Barkhausen noise in the samples of plastically deformed low-carbon steel.

2 THEORY

Most metal materials are deformed elastically only to the strain of about 5.10^{-3}. At the greater deformation the stress-strain curve is not linear and the permanent or plastic deformation arises. The physical principle of plastic deformation results from the disturbance of atom bonds and creating new ones by moving atoms to the new positions in the crystal lattice. The position of this disturbance in the crystal lattice is called dislocation. After removing the mechanical stress the atoms don't return to the original positions, but remains at new ones.

The dislocation density rises with plastic deformation. At higher deformations, the dislocations group together and form regions of high dislocation density separated by regions of low dislocation density. These dislocations act as hindrances to domain wall motion and thereby influence the Barkhausen noise. The individual Barkhausen jumps accomplished after releasing a domain wall from a hindrance tend to cluster and create large Barkhausen jumps [1]. The power spectrum of this noise provides information about correlation of individual pulses. The spectrum depends on the average number of individual pulses in large Barkhausen jump and the average time between individual pulses. Plastic deformation changes the average number of individual pulses in large Barkhausen jump due to the change of the dislocation density in the sample and also other factors, for example residual stresses and bending and changing number of domain walls in the sample.

3 EXPERIMENT

Four cylindrical rods of the low-carbon steel (Behanit, C<0.06, Mn<0.45, Si<0.15, P<0.02, S<0.02, Al<0.02%) with initial (before loading) diameter 14 mm were plastically deformed by mechanical tension. The tensile strains after unloading were 2.2, 5.4, 10.2 and 15.2 %.

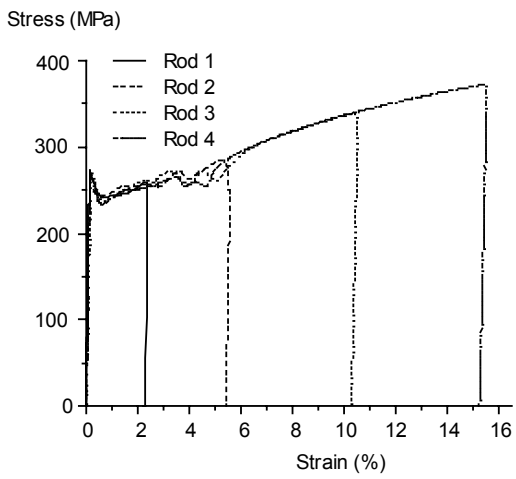

Fig. 1. Stress-strain curves of deformed samples

Computer control of loading machine preserved constant rate of strain. The loading diagrams of prepared rod samples are shown in Fig. 1. The samples were then cut by water-beam from rods in shapes of closed rings with cross-section of about 5 mm^2. They were magnetized by a

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triangular waveform magnetic field with different frequencies and constant maximum field intensity H_m=1.2 kA/m.

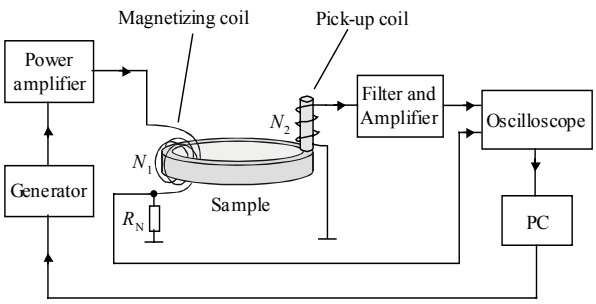

Fig. 2. The system for measuring the Barkhausen noise

A schematic diagram of the Barkhausen noise measurement system is shown in Fig. 2. Magnetizing coil N_1 with 40 turns is wound directly on the surface of the ring. Pick-up coil N_2 with 300 turns and ferrite or amorphous core placed perpendicularly to the surface of the sample (longitudinally to the strain direction) registers the Barkhausen signal. It is placed together with the sample into a shield box. In the previous arrangement, the Barkhausen signal was detected by classical toroidal coil and results of measurements were published in [2]. From application point of view this type of sensing coil is unsuitable for *in situ* nondestructive testing, therefore pick-up coils for sensing the normal component of magnetic field were used. The cylindrical ferrite core (H21) has diameter 2 mm and length 12 mm. The second core is manufactured from stacked amorphous ribbons (VITROKOV 8116) and has approximately the same cross-section and also length. The magnetic field is generated by a signal from the arbitrary waveform generator Agilent 33120A amplified by the power amplifier and led to the magnetizing winding. The power amplifier realized with OPA544 can provide maximum voltage 30 V and maximum current 2 A. LC filter used to remove quantization noise of the generator is placed at the output of the power amplifier. The magnetic field intensity in the sample is proportional to the voltage on the sensing resistor R_N connected to the first channel of the oscilloscope LT342. The voltage from the pick-up coil is led through the low noise preamplifier with the gain of 500 and the band-pass filter SR560 to the second channel of the oscilloscope. The band-pass filter with cut-off frequencies 10 Hz and 100 kHz filters the Barkhausen signal, which was measured only in one quarter of the period of the magnetization signal around the coercive field, where most of irreversible changes of magnetization occurs. This restriction increases the maximum achieved sampling frequency, which is confined by the size of storage oscilloscope memory. The oscilloscope and arbitrary waveform generator are connected to the personal computer PC through GPIB bus. The controlling program written in VEE programming environment reads the voltages from the oscilloscope and displays the Barkhausen signal.

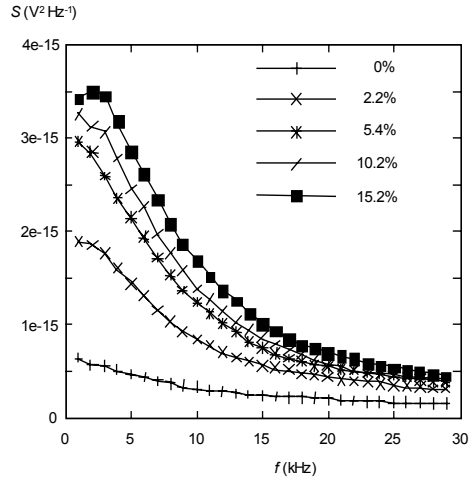

Fig. 3. Influence of the plastic strain on the power spectrum S of the Barkhausen noise at the magnetizing frequency 0.2 Hz measured with amorphous ribbon core

Different types of pick-up coil were tested by means of evaluating the power spectrum of the Barkhausen noise. Fig. 3 shows that its maximum value increases with plastic deformation because of increasing the average number of individual Barkhausen jumps due to rising dislocation density [3]. In the previous study, Iordache *et al* [4] found that Barkhausen noise energy in plastically deformed Fe-Si steel after unloading also increased at the beginning of the plastic deformation, but then started to decrease. This drop was ascribed to clustering effect of dislocations occurring at higher plastic strains, where tangles of dislocations with high dislocation density are separated by regions with low dislocation density. These tangles seems to more hinder the movement of domain walls then separated dislocations. Further, they found that Barkhausen noise amplitude of unloaded sample decreased in the whole region of plastic deformation, but for loaded sample the amplitude increased at the beginning of the plastic deformation and then decreased. This difference was ascribed to residual stresses in the sample after unloading. In our case, the maximum value of power spectrum and also root mean square value of the Barkhausen signal increases in the whole region of strain up to 15.2%. Such dependence indicates that in this case of low-carbon steel with low content of dislocations in undeformed state strained up to 15.2% the residual stresses and clustering of dislocations don't have such a significant influence on the Barkhausen signal as in Fe-Si steel [4].

The influence of the core material on the Barkhausen signal is illustrated in Fig. 4. This figure shows that the core manufactured from stacked amorphous ribbons with approximately ten times higher initial permeability than ferrite core provides larger magnitude of the Barkhausen signal and increased signal to disturbing noise ratio than ferrite.

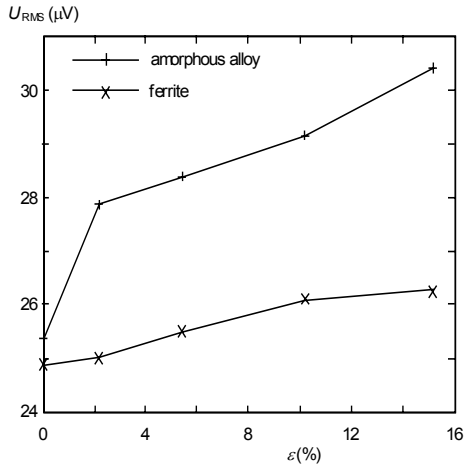

Fig. 4. Influence of the plastic strain ε on the RMS value of the Barkhausen noise for different cores at the magnetizing frequency 0.2 Hz

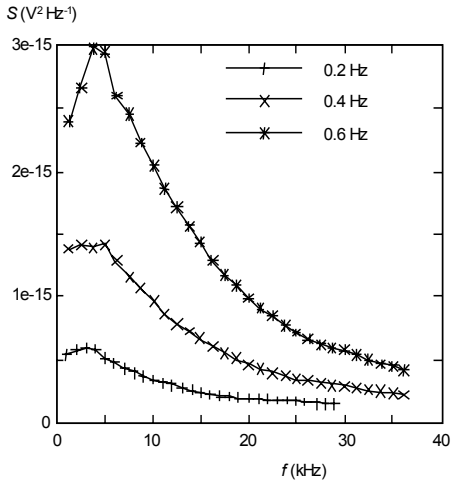

Fig. 5. The power spectrum S of the Barkhausen signal for the 15.2% strained sample at magnetizing frequencies 0.2, 0.4 and 0.6 Hz measured with ferrite core

The spectrum of the Barkhausen noise also changes with the magnetizing frequency because of overlapping the independent pulses at different positions in the sample [3]. Figure 5 shows the dependence of the power spectrum on magnetizing frequency at the strain 15.2%. The increasing magnetizing frequency at constant maximum field intensity causes the increasing the number of pulses per unit time and therefore raising the influence of overlapping. So the maximum value of the power spectrum increases with the magnetizing frequency. It follows from this that the increasing the magnetizing frequency can enlarge the magnitude of the Barkhausen signal. However, large magnetizing frequency causes the decreasing the change of the Barkhausen signal with plastic strain and therefore also the sensitivity of the measured parameters on the plastic strain. On the other hand, the Barkhausen signal is small at low magnetizing frequencies and therefore it is very disturbed by the spurious noise. Thus optimal magnetizing frequency for this measuring system is about 0.2 Hz at the maximum field intensity H_m = 1.2 kA/m.

4 CONCLUSIONS

Different arrangements of pick-up coil were tested on the samples of plastically deformed low-carbon steel at several magnetizing frequencies. To enlarge the magnitude of the Barkhausen signal and improve signal to disturbing noise ratio, it is suitable to use a core with high initial permeability. The increase in root mean square value of the Barkhausen noise with plastic strain is due to dislocation multiplication. The increasing magnetizing frequency causes increasing the number of Barkhausen jumps per unit time and therefore raising the maximum value of the power spectrum.

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