Magneto-acoustic investigation on steel samples

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Abstract. Experiments have been carried out using yoke for energizing alternating magnetic field in the steel samples. We used acoustic emission sensors and ultrasound microphone for recording acoustic signal born in the steel material. Results of experiments clearly show the presence of Acoustic Barkhausen noise. We are introducing graphs presenting dependence of acoustic time response signal on magnetic signal (inductance) in form of Lissajous curve. It is claimed that this new method gives more insight in the material than the widely used simple RMS measurement of acoustic response.

1. Detecting Acoustic Barkhausen Effect in steel samples

Barkhausen effect is well known in the magnetic theory and practice. The Magnetic Barkhausen Noise (MBN) was first detected by Barkhausen [1] in 1919, observing cyclical magnetization in a ferromagnetic material. Changing the polarity of magnetic field in the steel, the induced magnetic field in the material describes a hysteresis. Magnetic domains in steels turn towards the driving magnetic field abruptly causing stochastic noise, which can be transferred from measured inductivity signal into an acoustic signal. However, this is just a detection technique to demonstrate the stochastic (noise) nature of the magnetic inductivity changes. The theoretical models explain this magnetic domain changes either by real turns of domains or by dislocation of domain walls. In both cases pressure wave born on the changing domain walls should also produce acoustic emission in the material, and this is called acoustic Barkhausen noise (ABN) or some literatures magnetoelastic effect (MAE). To detect MAE one need to directly detect acoustic signal born in the material. Typical sensors, which can be used for detection of MAE are the so-called acoustic emission (AE) detectors. AE sensors are typically acceleration sensors having resonance in ultrasound frequency region. We shall demonstrate in the next sections, that similar results in acoustic measurement can be achieved using ultrasound microphone.

Earlier we have noticed (see Figure 1) that ABN can be observed during low cycle fatigue test [3]. It was not our intention to investigate that, it was just a side effect of our fatigue test, since fatigue test included not only stress but also heating and cooling parallelly with tension and pression. Heat treatment was done by strong, periodic current, which produced changing magnetic field up to 4 tesla on the skin of the sample.

This led us to investigate ABN (or MAE) in test samples using yoke. On Figure 2 we present the acoustic noise detected by AE sensors on test samples from iron and stainless steel. One can clearly see the repeating ABN burst in every half period, but with larger burst in every second half period.
Figure 1. Acoustic signal and its zooming when heating with large AC current causing magnetic field in material up to 4 Tesla in Gleeble simulator for fatigue test. Details of experiment see in [3]

Figure 2. Left hand side: ABN bursts in sample made from reactor material 15H2MFA. Right hand side: in stainless steel 08KH18N10T the same yoke does not generate ABN
2. New Laboratory Experiments

2.1. Measurement arrangement
In our new laboratory experiment we used standard size steel samples for tensile test. The yoke was powered from the 50 Hz network, but the voltage was regulated by an autotransformer to produce different magnetic flux level in the sample. We were interested to find when at which saturation level Barkhausen bursts appear in the material. To measure the magnetic field, a calibrated Hall sensor was used, but it can give information only about the field around the steel plate. To get the real magnetic flux in the material we applied the old-fashioned coil technique. We installed a coil of 10 turns of wire around the tensile test sample (see No.3 on Figure 3) and a similar one around the pole of the yoke (number 4 on Figure 3). We shall see, their signals might exhibit different behavior.

![Figure 3](image)

**Figure 3.** Laboratory arrangement for experiments. 1- sample, 2- yoke, 3-coil around sample, 4-coil on the pole of yoke, 5,6,7,8 - AE sensors 9-red dot from laser vibrometer, 10- end of tube of ultrasound microphone.

Since we noticed also mechanical vibration of the yoke and the sample contacting with that, we followed vibration using a non-contacting laser vibrometer (see red dot circled with white between AE sensors 17 and 12 in Figure 3.). Originally, we intended to register ultrasound acoustic emission in the sample due to changing magnetic field using AE sensors (No. 5,6,7,8 in Figure 3). But later it was decided to test also ultrasound microphone (No.10 on Figure 3), since it is also a non-contacting method, and this is a new direction for sensing the ultrasound response.

2.2. Developing suitable measuring software
The measuring set was programmed in LABVIEW. We were able to sample ultrasound signal with sampling rate of 1 MHz, while the slow change of magnetic field was sampled parallel with 10kHz only. Software can estimate full RMS, partial RMS including short time RMS with typical averaging time of 1-5sec.

Visual examination of the signals with zooming and comparison of different types of signals with different sampling rate and different filters are all very important part for the evaluation of the events during the test. While there are low frequency deterministic components like the magnetic field itself...
and some correlated vibration of the steel plate, we have stochastic burst in very short time range, and this is rather difficult to present on the same screen and on the same figure.

Figure 4. A typical representation of the time signals with periodic, slowly changing components (magnetic Hall and coil-green and yellow, vibration velocity-blue), stochastic components and bursts (from AE sensors. white, purple and azure).

It is worth to pay attention to the slowly changing curves on Figure 4. The green one is the direct signal from coil around the pole of yoke. It is proportional to the inductivity, which is the derivative of the magnetic field. Due to hysteresis between the magnetic field and its induction in the steel there is not linear dependence between the field and inductivity. However, if the field is far from saturation, then the inductivity (and also its derivative, which is the measured current from the coil), will follow more or less the sinusoidal variation of the energizing 50Hz voltage applied on the yoke (see also the right side of Figure 2, where we were far from saturation due to smaller permeability of the stainless steel). In the experiment presented on Figure 3 we had coil on the pole of the yoke (green line on Figure 4) and another coil around the sample (yellow line). Obviously, the inductivity in the sample went near to saturation, since the cross section of the sample was much smaller, than the cross section of the yoke. Since the current from the coils is the derivative of the inductivity, in the next Section we calculate the real magnetic field, as well as from the velocity signal (blue line) we calculate the real displacement.

2.3. Directly measured signals and calculated ones

Many physical signals can be sampled and measured directly, presenting them as their dependence on time. For example, a simple coil around the sample or the pole of the yoke will produce current proportional to the magnetic flux derivative. If one would like to present the change of the magnetic field in time, then one must integrate that derivative dependent as it is shown on Figure 5.

One can clearly see that the time dependence of inductivity is not sinusoidal, even though the yoke was powered using fully sinusoidal 50Hz current, as we have explained that in previous Section. Comparing the acoustic emission signals with calculated inductivity (see Figure 6) we can see that strong
emission occurs when there are fast changes of the inductivity, when the signal is the steepest crossing zero value.

![Graph showing signal from coil wounded around sample and B_calculated via integration](image)

**Figure 5.** Left hand side: The directly measured voltage drop on the input of ADC from the current of coil wounded around the sample, which is proportional to Right hand side: the time derivative of magnetic flux and B_calculated via integration from that.

![Graph showing signal of AE28 and measured velocity of vibration](image)

![Graph showing B_calculated via integration and Displacement calc. from velocity](image)

**Figure 6.** Correlation with the 50Hz magnetic disturbance is clearly seen on AE signals

**Figure 7.** Vibration signal measured by contactless laser vibrometer and displacement calculated from that.

This proves that this is a kind of Magnetic Acoustic Emission. It is also possible to estimate displacement signal from the measured velocity (see Figure 7.). However, if we want to see better resolution of acoustic signal of Figure 6, then we lose the behaviour of the magnetic field, since showing the burst in time of acoustic signal we cannot connect to the slow change of the magnetic signal.

2.4. New presentation of the measured signals

Due to high frequencies, relatively short records contain too many samples, therefore observation and comparison of time signals are rather difficult. We are introducing a Lissajous technique where we present direct dependence of acoustic signals on magnetic signal.
One can see in Figure 8 that the maxima are in the peaks and on the halfway of the magnitude of changing magnetic field, while a smooth characteristic trajectory was formed from the displacement versus magnetic field measured by the coil wounded around the Sample (Figure 9).

2.5. **Possibility to use ultrasound microphone to detect acoustic emission**

On Figure 3, we marked by number 10, the end of an aluminium tube pointing toward the sample. This tube plays the role of a waveguide, leading to a Dodotronic 250 type ultrasound microphone, which samples the acoustic noise with 192kHz rate.

![Image of filtered signal](image1.png)

**Figure 10.** High passed filtered signal(upper) from the total signal(down) of the ultrasound microphone exhibits burst of acoustic emission
One can see (Figure 10), that using adequate high pass filtering we can present the burst in ultrasound frequencies. This method is a noncontact method and opens new dimensions in measuring weak AE vibration in the material reaching its surface. The long waveguide-tube ending near to the surface ensures lower disturbances from environment. Contemporary microphones with built in ADC of 16 or even 24 bits opened the possibility to follow the dynamics of high frequency part of the sound signal even if its magnitude is ten thousand time less than that of the low frequency components. Meanwhile any contacting transducer attenuate and distort the sound component, while noncontacting methods have much less influence if at all.

3. Summary and plans
We investigated the acoustic signals born in the steel plate-samples due to changing magnetic field. The main goal was to find responses in ultrasound frequency range. Two main results of our investigation are as follows: It is possible and even advisable to use ultrasound microphone as contactless sensors to detect acoustic emission instead of AE sensors. Direct dependence of the measured response signal on magnetic field can be better used to characterize the stochastic dependences than a comparison of directly measured time signals or their frequency domain presentations.

Magnetic field changes must be much slower to observe and characterize effect of magnetic domain and/or displacement effects. We plan to improve our detection method using higher frequency and sampling time for acoustic signals.

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References
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