Design and development of a new magnetic sensor for stress measurements

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Abstract. This paper describes the design and the development of a new magnetic sensor for stress measurements using the magnetic Barkhausen noise and the magnetic permeability techniques in ferromagnetic steels. Both techniques together, become an important non-destructive technique, due to its exceptional material and stress characterization capabilities. The correlation of the two methods was investigated. Conclusions were derived based on the experimental results.

1. Introduction
The Barkhausen effect has become an important Non-Destructive Technique, which can be used in order to evaluate ferromagnetic materials. It was discovered in 1919 by the German physicist Heinrich Barkhausen, who wrapped a wire around a ferromagnetic material. He noticed that, under the influence of a varying magnetic field, a sound was heard from a speaker, which was connected to the coil. The sound was similar to static noise, which led to the name “Barkhausen noise” [1]. The Barkhausen signal can be used as a method of Non-Destructive Testing of materials, since it can provide useful information about the structure and the properties of the ferromagnetic materials [2-4].

2. Theoretical background
The magnetic materials consist of magnetic regions, called domains, the boundaries of which are called domain walls. Each domain is characterised by a magnetization vector. Under the influence of an external magnetic field, the magnetization vector of each of the domains rotates, in order to point in the same direction with the vector of the external magnetic field. As a result, the domain walls move and the magnetic domains change their size.

If we place a coil near or around the sample during the magnetization process, we will be able to record an electrical signal. The signal is abrupt and it is caused by the small and not continuous movement of the domain walls, due to the external magnetic field. This signal is called “Barkhausen Noise” and is affected by the properties and the various impurities and structural imperfections of the sample [5-9].

3. Measuring procedure
A basic concept of the measuring procedure includes the transfer of an alternating electrical signal from a source to an excitation coil, the conversion of the electrical signal to a magnetic flux, which

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propagates through the tested material, the reconversion of the magnetic signal to an electrical signal, the amplification and the filtering of the output signal and finally, the recording of the processed signal.

The coils are usually wrapped around a U-shaped core [10-28]. The excitation coil is wrapped around the core’s body, while the pickup coil is placed in the free space between the two legs of the electromagnet. As a result, when the electromagnet is placed on the tested material, a closed circuit is created, which forces the signal to travel through the sample and be affected by its properties. The electromagnet described above is called “single yoke arrangement” (figure 1).

![Figure 1. The single-yoke arrangement.](image)

Using this information, it is possible to detect deformations induced by mechanical stresses [29], monitor the fatigue of a material [30] and inspect its structure [31].

4. Development of the magnetic Barkhausen sensor

4.1. The arrangement
The chosen arrangement includes a signal generator which produces the excitation signal, an electromagnet with the suitable excitation and pickup coils, electronic amplification and filtering circuits, a power supply for the operation of the electronic components and an oscilloscope to display the output signal. In order to construct the sensor, we chose the single-yoke design.

4.2. The electronic circuit design
The signal amplification and filtering was possible due to a printed circuit board (PCB), which was designed and constructed in our laboratory. This electronic circuit includes a preamplifier, a low pass and a high pass filter (figure 2).

The preamplifier circuit amplifies the output signal of the pickup coil. The Texas Instruments DRV134 and INA163 differential amplifiers were used for this purpose, due to their low noise performance. The amplification factor (gain) of the input signal can be set from 2 to 200 times.

Two Texas Instruments OPA209 operational amplifiers were also used, in order to construct the high pass and the low pass filters. The high pass filter was designed to block the signal frequencies which are lower than 2 kHz and additionally, to amplify the signal 10 times. Similarly, the low pass filter blocks the frequencies which are higher than 100 kHz and amplifies the signal 10 more times. The filters were designed as second-order Butterworth filters.

As a result, the output signal was amplified by a total of 20000 times and it was limited in the range of 2-100 kHz, which is commonly chosen, in order to eliminate the ambient noise [32,33].

4.3. Development of the sensor
A printed circuit board was designed in order to include the electronic circuit above. The electronic circuit was printed on a photosensitive board, which was exposed to ultraviolet radiation.

The electromagnet was made using a U-shaped electrical steel core. Two connected in series excitation coils of 200 windings were constructed, using a Ø0.5 mm copper wire. Between the two legs of the electromagnet, the pickup coil was placed, which consisted of 600 windings, made of a
Ø0.1 mm copper wire. In order to achieve the optimum contact between the pickup coil and the various test samples, a spring was placed between the yoke and the pickup coil.

![Electronic circuit design](image)

**Figure 2.** The electronic circuit design.

5. Experimental results

In order to test the constructed arrangement, we used a low carbon steel plate as a sample. Using a triangular 13 V, 2 Hz waveform as an excitation signal, we were able to record the Barkhausen noise signal obtained by the pickup coil, after its amplification and filtering (figure 3). We were, also, able to plot the output/input signal ratio versus input (figure 4), which indicates the effect of the induced magnetic field to the magnetic permeability of the tested material.

![Input signal and Barkhausen noise](image)

**Figure 3.** The input signal and the Barkhausen noise signal of a low carbon steel plate versus time.

![Correlation](image)

**Figure 4.** Correlation between the magnetic permeability and the induced magnetic field.

6. Discussion - Conclusions

The results mentioned above indicate that the developed sensor can be used effectively in order to obtain the magnetic Barkhausen noise signal of a tested material. Using the acquired data, it is possible to correlate the magnetic permeability of the sample with the induced magnetic field. As a result, we can use the magnetic Barkhausen sensor in order to study both the Barkhausen noise signal and the magnetic permeability of a material.

Furthermore, we conclude that it is possible to develop a magnetic Barkhausen sensor and the necessary electronic components with relatively low cost. However, the sensor’s very weak output signal in conjunction with the ambient noise, make it too difficult to capture and process the data. Thus, it is necessary to design and construct the appropriate electronic circuits, in order to amplify the signal and eliminate the noise through its filtering.
The selection of the electronic components and the design of the electronic circuit was based on the elimination of the ambient noise and the best possible signal amplification, without adding extra noise to the processed signal, through the components. As a result, it would be useful to further improve the electronic circuits, mainly through the implementation of higher cost components, in order to maximize their performance. It is also encouraged to conduct measurements using various amplitude and frequency ranges of the excitation signal, as well as different types of samples of ferromagnetic materials. Finally, it should be noted that the constructed sensor arrangement consists of some laboratory devices, such as the function generator, the power supply and the oscilloscope, which help in error reduction, but, on the other hand, complicate its outdoor operation. As a result, it would be useful to develop a completely portable device, which will be able to include all the necessary electronic and electromechanical equipment, without compromising its performance.

7. References

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