Maciej PILOT
SILESIAN INSTITUTE OF TECHNOLOGY
10 Akademicka St., 44-100 Gliwice, Poland

Prognosing the stability of permanent magnet by investigation of Barkhausen noise

Abstract

A problem of measurement of Barkhausen noise coming from permanent magnet is investigated in the paper. This is important for correct conclusion when permanent magnet parameters are measured. Currently, Barkhausen noise is measured for soft magnetic materials for detecting material defects, for example, a microcracks and a tensions. A measurement of Barkhausen noise in permanent magnets may be useful for prognosing the stability of magnets working at duty cycles. Changes of working point of permanent magnet caused by cyclic external load can be examined in dedicated laboratory stand. In the paper first the measuring stand is presented, next the mathematical model of permanent magnet parameters is discussed and the measurement results are presented. They show that magnetoacoustic and electromagnetic phenomena are observed in the permanent magnet under test and their parameters may be measured.

Keywords: Barkhausen noise, permanent magnet.

1. Sources of Barkhausen noise in permanent magnet

The Barkhausen noise is inseparable of jumps of domain walls through barriers of a potential. They are caused by many different injuries of a material during magnetization or demagnetization of a material in an external magnetic field. Therefore, this noise is treated as a parasitic and unwanted effect in permanent magnets. The essential feature of this phenomenon is that after the cycle load the working point of a material does not return to a start point of a magnetic circuit - it draws a hysteresis loop on the *B*(*H*) plane. It means that Barkhausen noise can be helpful as a pointer to specifying the shift of a working point. In Fig 1 the shift of domain wall is illustrated. In Fig 1a the point P represents the inclusion, which is an obstacle in domain wall shift. The obstacle is overcame if external magnetic field exceeds same critical value. During this shift the Barkhausen noise is generated. Its nature is stochastic in specific range.

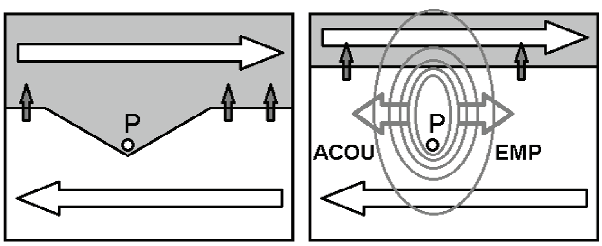

Fig. 1. Illustration of an idea for Barkhausen noise generation. ACOU – acoustic noise, EMP – electromagnetic pulse radiation

The Barkhausen noise is observed by two effects, as a surface electromagnetic noise and volumetric magnetoacoustic noise. Magnetic dipole moments of atoms in a material which rotate violently cause this state. According to [1,2], a spectrum of Barkhausen noise is between 0.1 and 100 kHz and lasts several milliseconds (as a response to jump change of external field). A frequency of the noise and a high electric and acoustic conductivity of a material make that an electromagnetic noise may be recorded on a surface of a magnet under test only, and an acoustic noise may be recorded in a whole bulk of a magnet (an electro-magneto-accoustic effect, EMA).

2. The concept of Barkhausen noise measurement

To measure signals which are generated by both components of the Barkhausen noise, the dedicated measuring stand was designed (Fig 2a). The device contains two magnets. The first magnet (1) is a one under test, it is motionless. It is placed within a detecting coil (2), and it adheres to the piezoelectric transducer (3). The second magnet (4) is movable. It is a source of external magnetic field which loads the magnet under test. It moves periodically, by cam wheel. Main part of the stand is shown in Fig. 2b.

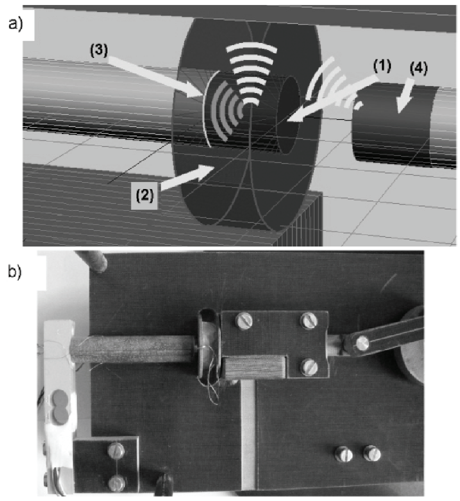

Fig. 2. The measuring stand: a) location of magnets (1, 4) and sensors (2, 3), b) external view

The procedure of loading the magnet by external field must be slow enough, to avoid the effect of inertia of domain walls. The shown measuring stand has some defects. First, the detecting coil detects noises which come from both magnets (with the magnet 2 is movable). Second, the piezoelectric transducer records all magnetoacoustic phenomena (for example these generated by microcracks).

The distribution of noise density is similar to a normal Gauss distribution. It is shown in Fig. 3. This one is the result of statistical simulation in an Matlab program which bases on the Preisach model. The weight function is given by [2]:

$$\mu(\alpha,\beta)=\frac{M_S}{2}\cdot\frac{e^{\frac{\sqrt{\alpha^2+\beta^2}-\delta_1}{\tau_\mu}}-e^{-\frac{\sqrt{\alpha^2+\beta^2}-\delta_1}{\tau_\mu}}}{e^{\frac{\sqrt{\alpha^2+\beta^2}-\delta_1}{\tau_\mu}}+e^{-\frac{\sqrt{\alpha^2+\beta^2}-\delta_1}{\tau_\mu}}}, \qquad (1)$$

where:

M_S - magnetization in saturation,
τ_μ, δ_1 - parameters, known by measurement,
α, β - parameters of the magnetic hysteron state.

According to the simulation, a magnet manifests the largest noise density near the coercion point. Therefore at this point the process of loading by an external field must be appropriately slow so as the jumps of a walls follow the field. Otherwise, the phase and density of noise may be changed, because of inertia effect. It may change a measurement result. A cam wheel pushes the piston and modulates a velocity of the magnet 2 (which forces the magnet under test).

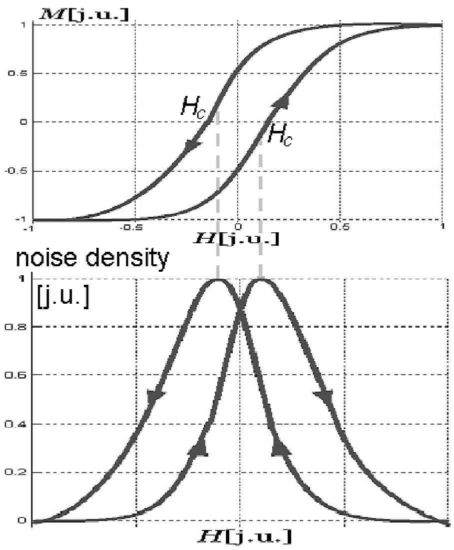

Fig. 3. The Preisach model: a) major hysteresis loop; b) noise density distribution

A simulation of the Preisach model does not show a tendency of a movement of a minor loop, in spite of the fact that the magnetic materials, which are loaded by an external field, show a systematic moving of this minor loop [3,4]. Some authors [5] have obtained a similar effect of moving a minor loop, however they suggest that this is an effect of coming in the boundary condition space by a working point during a simulation and it may be the effect of cumulating the error of simulation. The measurement and simulation results are shown in Fig. 4.

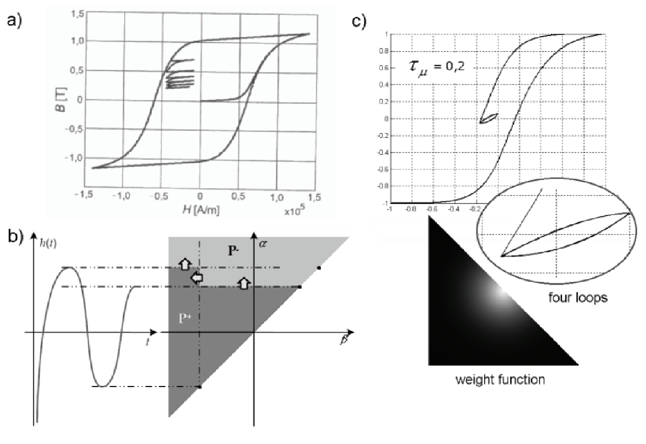

Fig. 4. a) Measurement results [3], b) Preisach plane, c) simulation results (four minor loops)

If there exists the effect of movement of a minor loop in permanent magnets in a strong external field, the questions are: how long (how many cycles) does this process last and will magnets be demagnetized fully or will their working point stabilized at a some point which is characteristic for their magnetic circuit. Long-lasting investigations which are connected with cyclic loading of a magnet under test by an external magnetic field will help to answer these questions. The second magnet which is identical to the first one (identical dimensions, density of energy and from the same production run) is the source of this external field in the designed measuring stand. Thanks to it a simultaneous investigation of the influence of rotary magnetization on a magnet under test is possible. Moreover, the same stand imitates better the working conditions existing in industrial applications of magnetic devices.

3. Measurement results

The measurements are divided into non filtered, digitally filtered and filtered by analog filters (using a dedicated electronic circuit). Shapes of characteristics from both sensors (non filtered) are shown in Fig. 5. It can be seen that the signal from the detecting coil is strongly disturbed and the signal from the piezoelectric transducer has such a large value that the Barkhausen noise is completely invisible at this stage.

It should be noted that the signals have very similar shapes in spite of the fact that they come from two sensors which are of different type. One can observe atypical disturbances (see Fig. 6.) when the characteristics are zoomed. However, it is seldom observed and it is initiated by the start an engine forcing the cam in the stand. Probably it is a typical uncontrolled magnetoacoustic effect (EMA).

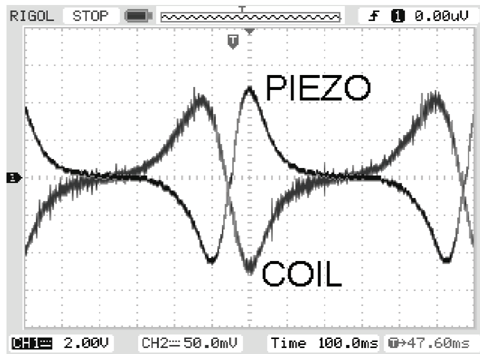

Fig. 5. Measurement signals from both sensors (non filtered)

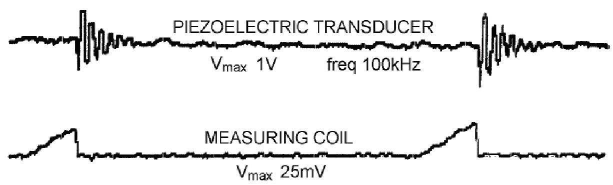

Fig. 6. An accidental and uncontrolled EMA disturbance

The atypical disturbances may be initiated by any minimal jumping friction between the magnet under test and the detecting coil. The EMA noise from the piezoelectric transducer can be extracted by a differential method by subtracting the filtered signal from the original one. The result of this operation is shown in Fig. 7. The both signals differ slightly only so in the Fig 7 they overlap. In the Fig. the difference signal is extremally gained to see any changes.

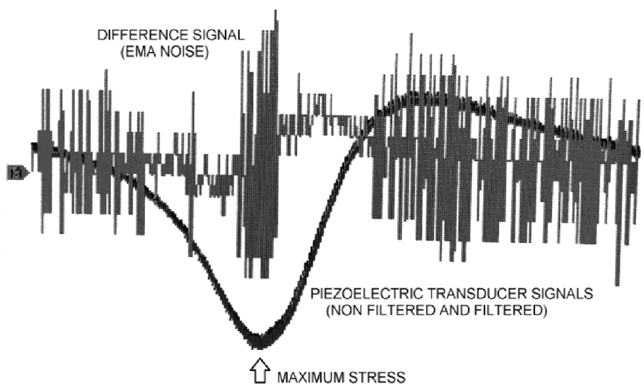

Fig. 7. Noise extraction from a piezoelectric transducer

According to Fig. 7., the maximum of noise is close to the maximum of magnetic stress (and mechanical stress) and during relaxation of magnetization. This lasts considerably longer than loading a sample by an external field. The profile of this noise may suggest that it is a Barkhausen noise.

So, if a permanent magnet generates a Barkhausen noise during loading by an external magnetic field, it is a proof that the field of a magnet is disturbed. This may mean that the working point of a magnetic circuit will draw minor loops of hysteresis and it will never return to the initial point (when loading will be switched off). A lack of the return of this point to the initial point should be observed as a non-zero integral of a certain function of the Barkhausen noise because the moving working point on the *B*(*H*) plane is closely related with the generation of the Barkhausen noise.

The measured signal from the piezoelectric transducer, when there was used an analog high pass filter (HPF), is shown in Fig. 8.

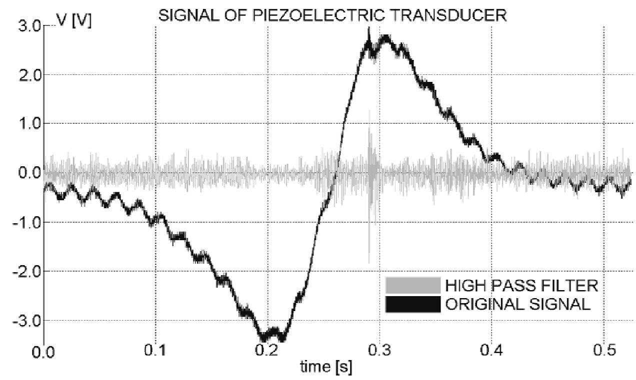

Fig. 8. The signal from the piezoelectric transducer (HPF filter)

The original signal includes a high level of disturbances from the power network (mainly 50 Hz) but a third order Bessel filter eliminates this problem. However, the noise is observed in the second half of the signal in this measurement. It may mean that this noise is not a Barkhausen noise in spite of the fact that it is repeatable and correlated with the signal from the piezoelectric transducer. The frequency spectrum of this signal is presented in Fig. 9.

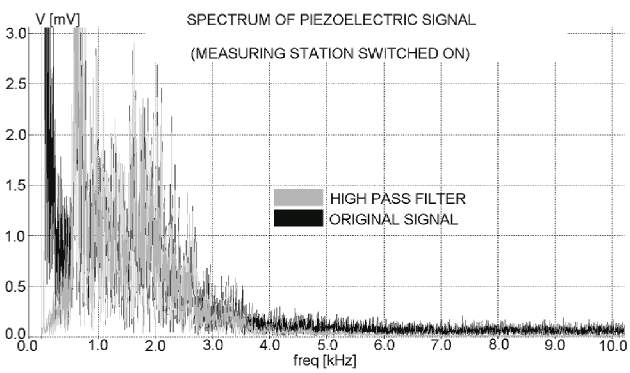

Fig. 9. The FFT spectrum of the signal from the piezoelectric transducer

In Fig. 9. one can see how the HPF filter separates the low frequency signal which is generated by the movement of the magnet. The high level of the signal is between 0.7 and 4.0 kHz and it is not connected with the level of the background (disturbance) because the background is under 0.5 mV. The spectrum of the background is depicted in Fig. 10.

The main component of the background is a signal 50 Hz, the remaining part is high-frequency electromagnetic noise. Non-shielded parts of the sensor react on this noise.

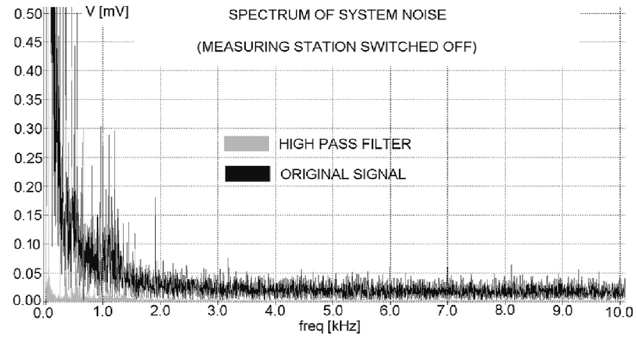

Fig. 10. The FFT spectrum of the background (a stand is switched off)

The signal generated in the detecting coil, measured under the similar conditions (the HPF filter is on), is presented in Fig. 11.

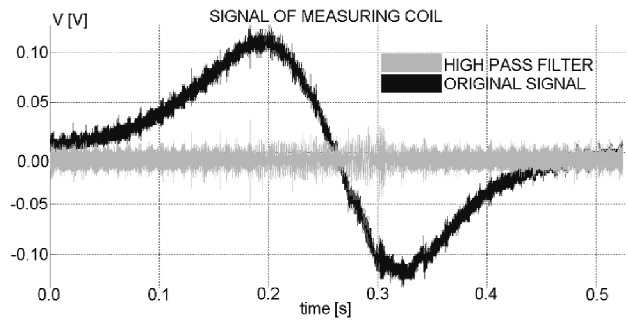

Fig. 11. The signal generated in the detecting coil (analog HPF filter is on)

The signal is very similar to the previous one but the participation of disturbances is considerably larger. Fig. 12 shows the spectrum of the signal.

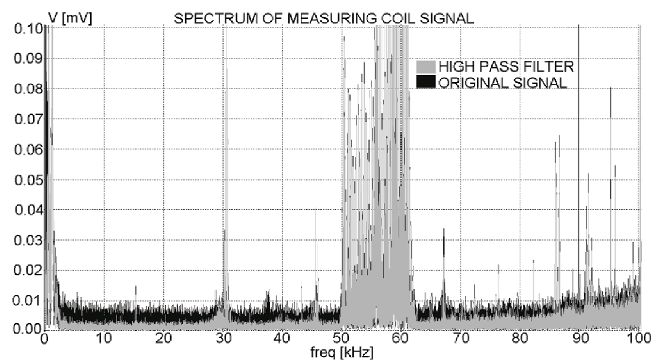

Fig. 12. The FFT spectrum of the signal from the measuring coil

This spectrum is nearly the same as the spectrum of disturbances when the stand is switched off (Fig. 13.)

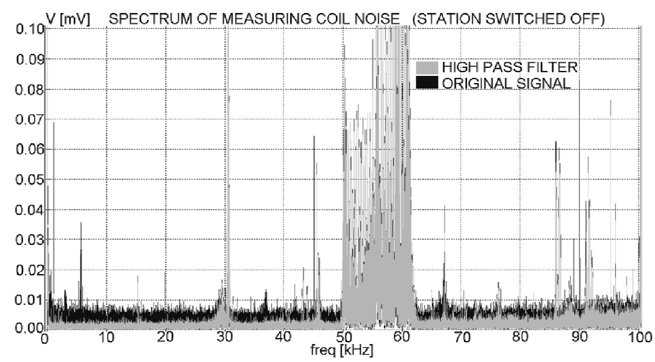

Fig. 13. The FFT spectrum of disturbances of the signal generated in the detecting coil

However, in the range between 0.6 and 4.0 kHz the spectrum has a similar shape as the signal from the piezoelectric transducer. It is shown in Fig. 14.

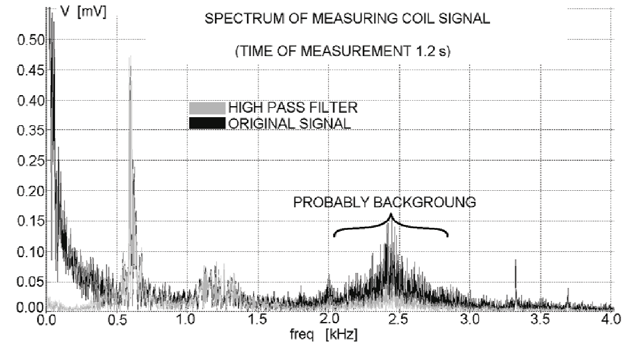

Fig. 14. The FFT spectrum of the signal generated in the detecting coil

In the previous version of the measuring circuit the low pass filter (LPF) with differential circuit was applied. However, the spectrum of signal was contained too much low-frequency components. It is shown in Fig. 15.

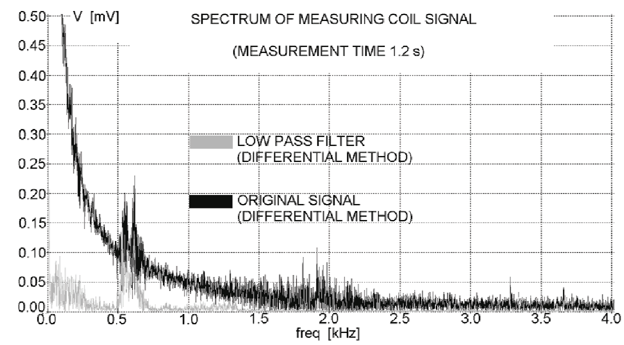

Fig. 15. The FFT spectrum of the signal generated in the detecting coil (LPF filter and differential method applied)

How one can see, the character of spectrum is similar, but additional harmonics are observed. It may be a consequence of the phase shift in filters and it may disturb the measurement results.

4. Conclusions

By analysing the results of measurement, we can deduce that permanent magnets, which are loaded by an external magnetic field, generate a Barkhausen noise. This situation is similar to the soft magnetic materials in spite of the fact that there is no magnetizing of the magnet (the intensity of the external field is lower than intensity of the coertion). It may cause systematic partial demagnetizing of magnets.

If this process stabilizes in time, initial and artificial aging of magnets which are built-in in a destination device may be necessary – so the manufacturer of this device should apply this procedure. Otherwise, sold devices will be systematically degraded. This situation may be dangerous for human health or life.

5. References

[1] Piech T.: Badania magnetyczne, wykorzystanie efektu Barkhausena. Biuro Gamma, Warszawa 1998.

[2] Stupakov O., Melikhov Y.: Influence of magnetizing and filtering frequencies on Barkhausen noise response. IEEE Transactions on magnetics, vol. 50, No. 4, April 2014.

[3] Mazgaj W.: Wyznaczanie rozkładu pola magnetycznego w materiałach magnetycznie miękkich z uwzględnieniem histerezy i anizotropii. Politechnika Krakowska, Kraków 2010.

[4] Torre E. D.: Modeling of magnetizing processes. Proceedings of the IEEE, vol. 78, No. 6, June 1990.

[5] Wac-Włodarczyk A.: Materiały magnetyczne, modelowanie i zastosowania. Politechnika Lubelska, Lublin 2012.

Received: 10.04.2017 *Paper reviewed* *Accepted: 02.06.2017*

Maciej PILOT, MSc, eng.

A research assistant at the Department of Measurement Science, Electronics and Control of the Silesian University of Technology, Poland. Interests: magnetism, energy and application of permanent magnets.

e-mail: Maciej.Pilot@polsl.pl