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A new method of analysis of breaking magnet damages in induction watt-hour meters

***Abstract**. The article presents a discussion about the problem of illegal energy consumption. One of the typical watt-hour energy meter damage is the failure of braking magnets as a result of their exposition to a high external magnetic field. Permanent magnets are very sensitive elements to this action, and their damage affects the accuracy of energy measurement. The study discusses the evaluation methods of the magnetic flux density asymmetry inside the magnet gap. The authors present statistical classification methods as identification means in the evaluation process of magnet damage.*

***Streszczenie.** Artykuł przedstawia dyskusję na temat problemu nielegalnego zużycia energii. Jednym z typowych uszkodzeń liczników energii czynnej jest awaria magnesów hamujących jako efekt ekspozycji na działanie zewnętrznego pola magnetycznego. Magnesy trwałe są bardzo wrażliwymi elementami na to działanie, a ich uszkodzenie wpływa na dokładność pomiaru energii. Omówiono metody oceny asymetrii rozkładu indukcji magnetycznej w szczelinie magnesów. Autorzy przedstawiają metody klasyfikacji statystycznej w celu identyfikacji w procesie oceny uszkodzenia magnesów. – (**Nowa metoda analizy uszkodzeń magnesu hamującego w indukcyjnych licznikach energii czynnej**).*

Keywords: induction watt-hour meter; braking magnet damage; magnetisation state; illegal energy consumption.
Słowa kluczowe: watomierz indukcyjny; uszkodzenie magnesów hamujących; stan magnesowania; nielegalny pobór energii.

Introduction

In the metrological literature, many authors focused their attention on the problem accuracy of the watt-hour meter resulting from non-sinusoidal current [1-4]. The present article discusses the problem of permanent magnet damage. The issue of illegal energy consumption is still a current problem in Eastern Europe and other parts of the world, and many techniques can be found to falsify counter energy readings as well as to prevent them [7-14].

The watt-hour meters are devices that record the real power consumption. The principle of the energy counting takes advantage of the mechanical movement of the two aluminium discs, which torque is produced by the interaction of magnetic field coming from the coil pairs: current and voltage (Fig. 1). An important part of the instrument's construction is compact systems forming pairs of permanent magnets (Fig. 2 and Fig. 3).

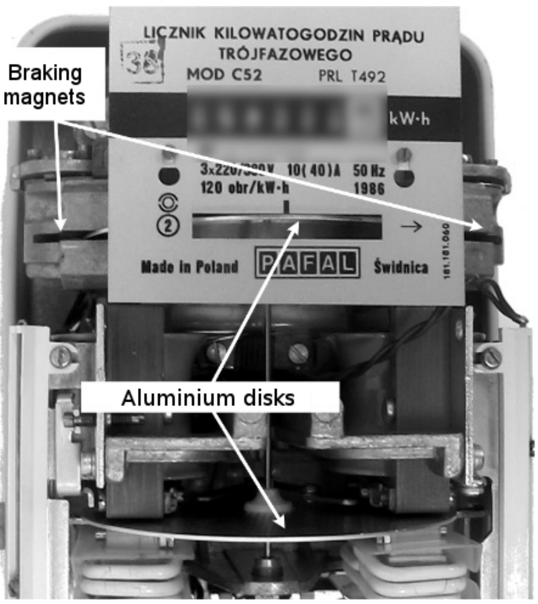

Fig.1. Three phase watt-hour meter type C52 with marked positions of the compact system of permanent magnets and the aluminium disks of the rotor

The task of the permanent magnets is to produce the magnetic flux in the gap, perpendicular to the disk surface. The accuracy of the meter is closely related to the autonomous magnetic circuits of two pairs of permanent magnets [5], [6].

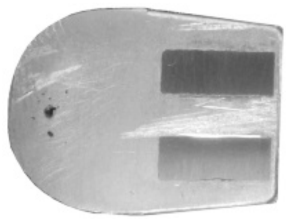

Fig.2. View of the compact permanent magnet system from the air gap side

The economic situation in Eastern Europe and the rising prices of electricity caused an increase in the number of cases of illegal energy consumption. In Poland a basic problem is the intentional falsification of the amount of energy consumption. Dishonest customers have found many methods of falsification and incorrect energy registration in the measuring system. The most popular method has been to slow down the rotation of the aluminium disc (Fig. 1 and Fig. 2). One of the methods is exposition to an external magnetic field [7-10]. In the literature one can find some articles focused on the metrological aspect of intentional illegal magnetic exposition of watt-hour meters [11-14].

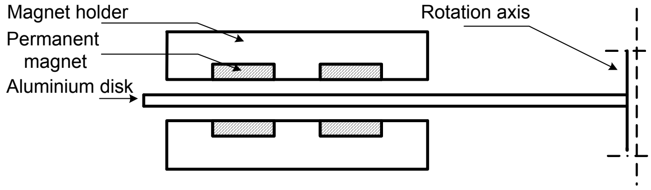

Fig.3. Position of the permanent magnets and rotational disk in the compact braking magnet system

As a result of magnetic field exposition, which comes from permanent magnets, the braking torque is produced. The watt-hour induction meter under consideration uses the AlNiCo (Aluminium, Cobalt, Nickel alloy) permanent magnets. Their residual magnetisation causes the presence of the magnetic flux density inside the gap in the range value from 220 mT up to 260 mT. Important elements of the system are four solid permanent magnets arranged in pairs and their task is to produce the eddy currents in the disk volume and finally the producing of the braking torque. It follows that the accuracy of the instrument as a device recording the electric energy consumption is closely related to the level of magnetic induction in the air gap of autonomous magnetic circuits composed of two pairs of a compact system of magnets. The external magnetic field acting on the watt-hour energy meter leaves a trace of its operation not only in the braking magnet system, but also in the ferromagnetic components of the meter such as the meter cover, mounting screws fixing the cover as well as magnets, the disk axle [15].

Experimental environment

To study the effect of external magnetic field on the level of induction in the gap of a compact system of braking magnets, they were exposed to a magnetic field created by a neodymium magnet with a diameter of 70 mm and a height of 30 mm. Undamaged braking magnet systems were placed at different distances from the magnetic field source using a magnet holder (Fig. 4)

The experimental procedure carried out in the present research was identification of the normal component magnetic field distribution inside the gap of the permanent magnet compact system (Fig. 2). The testing procedure consisted of measuring the values at equal interval in the central plane, located parallel to the surface of the magnets (Fig.5). A Regular square mesh has been defined on the selected surface with the XY moving table and their nodes points were marked to measure the normal magnetic flux density value (Fig. 5).

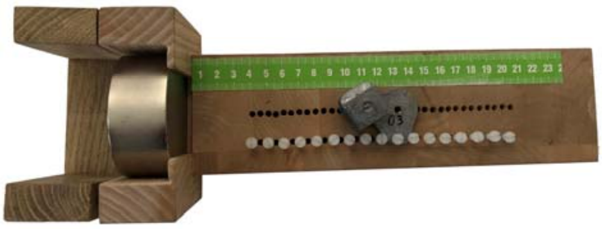

Fig.4. The fixture for testing braking magnets with a choice of changing their distance from the source of the field

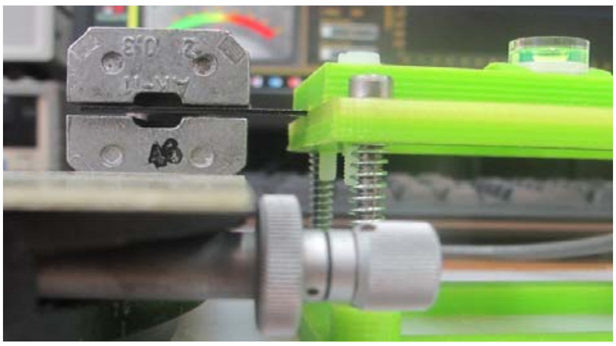

Fig.5. Measurement setup

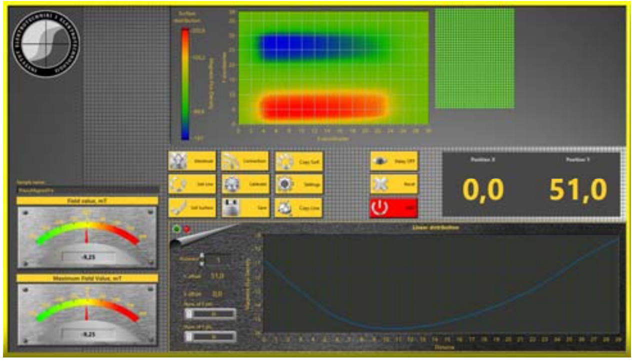

Fig.6. Application of a computer measuring system for scanning the space of a compact system of permanent magnets

For testing the magnetic field in the magnetic gap, a computer measuring system was developed (Fig. 6), which was connected to the LackeShore421 magnetic field meter and to the MNT-4E02-VG measuring probe, whose measuring range was up to 3 T.

Results and discussion

The main problem presented in the research is identification of the watt-hour meter damage in the verification process. The results of the magnetic flux density distribution in the gap of the permanent magnet compact system are presented in Fig. 7, which makes possible the comparison of the surface maps in the undamaged (1) and damaged slots (2-8).

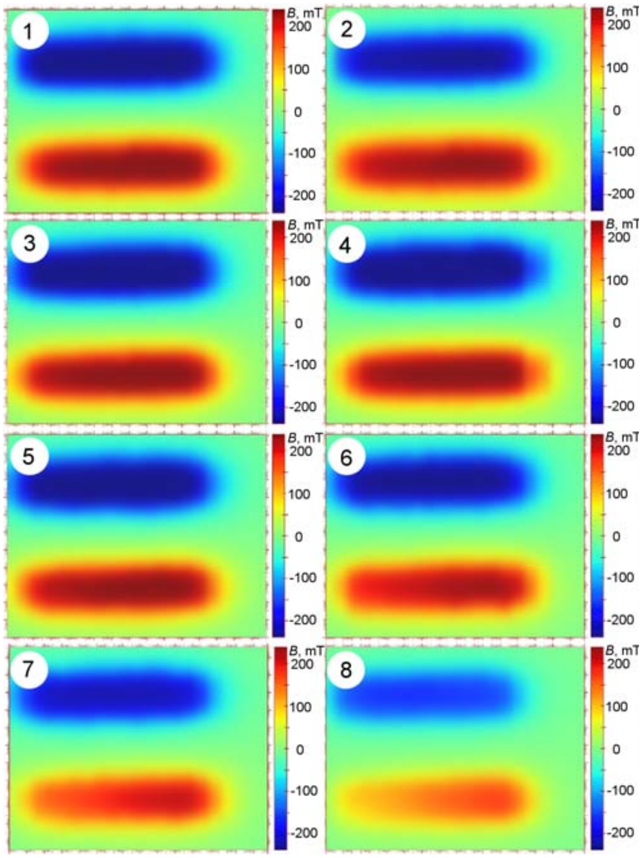

Fig. 7. Distribution of the magnetic induction in the gap of compact system of permanent magnets, for distances: 1) without field exposure, 2) 165 mm, 3) 135 mm, 4) 85 mm, 5) 55 mm, 6) 35 mm, 7) 25 mm, 8) 15 mm from the face of a neodymium magnet with a diameter of 70 mm and a height of 30 mm

It is clearly visible that in the undamaged part the distribution of the magnetic flux density is symmetrical while in the case of the damaged one unsymmetrical distribution is observed. Likewise, the maximum magnetic induction and its average value are lower in the range from 40% up to 60%. The nonlinear statistical model allows to create some probability classes and returns the required information of damage origin. The algorithm of classification procedure is an application of machine learning theory.

The proof of magnetic field exposition to the watt-hour energy is the distribution of the magnetic flux density in the gap of the permanent magnet compact system. It is clearly visible that in the undamaged permanent magnet compact system the distribution of the magnetic flux density is symmetrical in the slot, while in the case of the damaged one unsymmetrical distribution is observed.

The next and new method of symmetry evaluation was calculation of the symmetry angle (Fig. 8). To this end, a computer application that determined the axes of the magnets was developed. In the next step, the maximum and minimum points were searched. As a result, a straight line was defined. Finally, the angle between a straight line perpendicular to the magnet axes and the determined straight line going through extreme points was calculated. The nonzero value is the determinant of the asymmetry.

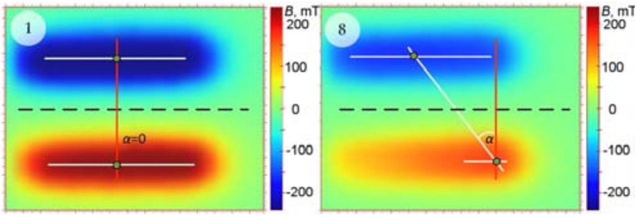

Fig.8. Magnetic flux density distribution B in mT with marked extremum points in the gap of the permanent magnet compact system 1) undamaged slot, 8) damaged slot after external magnetic field exposition for the distance from the field source equal to 15 mm, the red line being perpendicular to the magnet axis

An additional procedure of calculating asymmetry is the mean value of the magnetic flux density. Considering the magnetic flux density distribution in the undamaged permanent magnet compact system one can expect that the mean value is zero. In a damaged permanent magnet compact system a nonzero mean value of the magnetic flux density is observed.

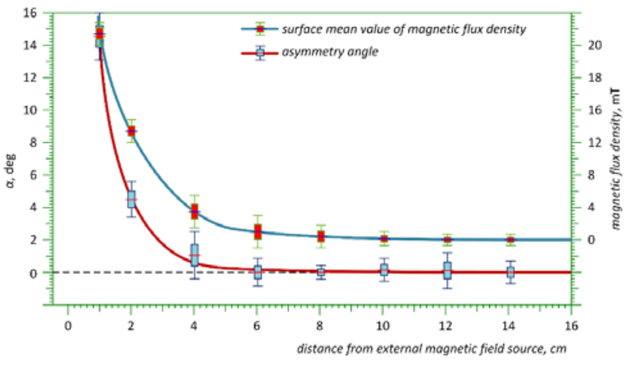

Fig.9. The results of value calculation: red line – the asymmetry angle and blue line – the surface mean value of magnetic flux density in the air gap of the permanent magnet compact system

The graph presented in Fig. 9 shows the dependence between distance from a permanent magnet compact system and the external magnetic field source (neodymium magnet). A correlation between the asymmetry angle and the mean value of the magnetic flux density can be noticed.

The analysis of both line graphs (red line for unsymmetrical angle, blue line for mean value of the magnetic flux density) shows that in the infinity they tend towards the zero value. A limit distance value is approximately 8 cm, where a nonzero value is observed. When the distance from the magnetic field source was decreased, both values (unsymmetrical angle and the mean value of the magnetic flux density) increased up to 16 deg and 30 mT respectively.

Testing the magnetic field on the surface of the meter cover and on its edges may be an additional argument indicating the influence of an external magnetic field. It is advisable to perform a statistical analysis based on a set of results for each element of the cover, examine the conditions of fitting to a normal distribution using parametric or nonparametric significance tests.

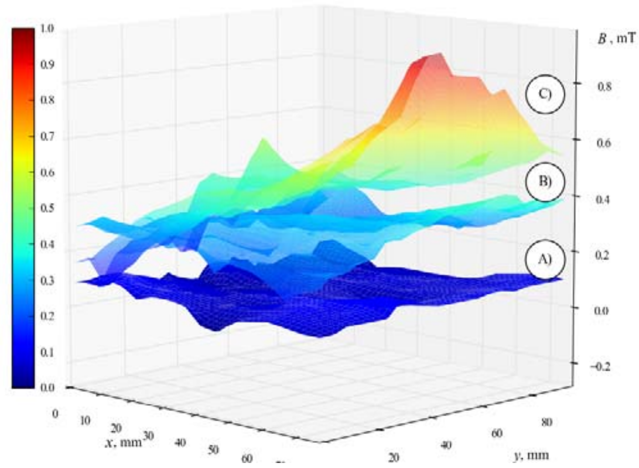

Fig.10. Distribution of the normal magnetic induction component on the left side surface of watt-meter enclosure cover: A), reference meter without magnetic field exposure B) tested meter, C) reference meter exposed to the magnetic field of a neodymium magnet

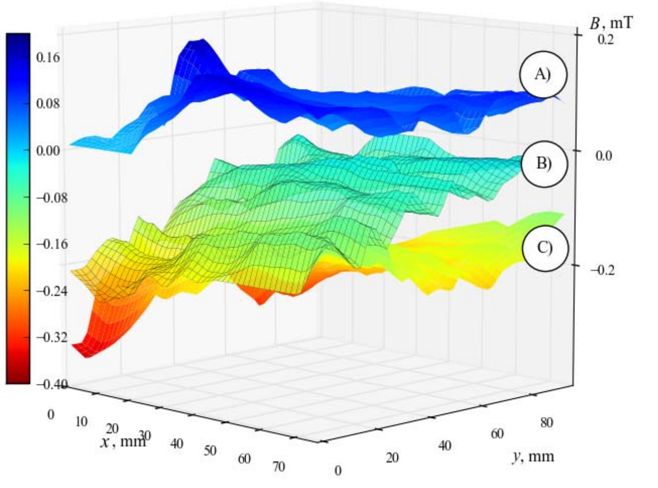

Fig.11. Distribution of the normal magnetic induction component on the right side surface of watt-meter enclosure cover: A), reference meter without magnetic field exposure B) tested meter, C) reference meter exposed to the magnetic field of a neodymium magnet

The test consisted in determining the magnetic induction distribution normal to the cover surface and the induction distribution on the edge of the open cover. This is the part of the cover that adheres to the base of the meter cover through the gasket. Surface scanning was performed on a geometric grid every 0.5 cm, linear scanning every 1 cm. In areas of difficult access or arcuate shapes, scanning was carried out with technically possible accuracy. The measurement results are shown in figures 10, 11, 12. These results indicate an increased value of residual magnetization of the cover edge and the tested surfaces of the watt-meter enclosure relative to the reference watt-meter. This is an important premise indicating that the ferromagnetic enclosure of the tested watt-meter has been exposed to an external constant magnetic field. A quantitative assessment of the magnetization state of the watt-meter enclosure cover can be obtained by subjecting the measurement results to a statistical analysis.

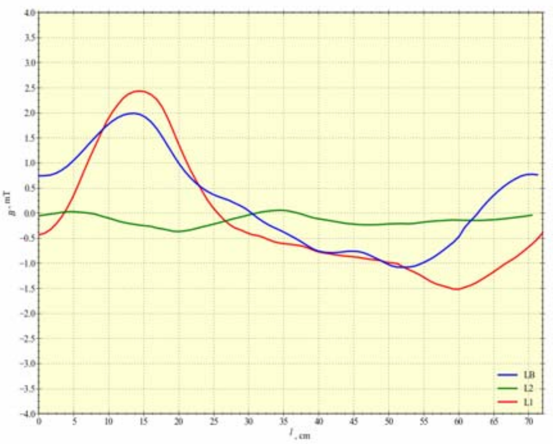

Fig.12. Distribution of magnetic induction along the edge of the enclosure cover for watt-meters: L1 - reference meter exposed to neodymium magnet field, LB - tested meter, L2 - reference meter without magnetic field exposure

Conclusions

Currently, for registering electricity, many consumers still use induction meters that are not protected against the influence of strong external magnetic fields. This makes it possible to use these fields, produced for example by a permanent magnet, to distort the meter's readings while consuming energy. The external magnetic field, appropriately directed, produces an additional braking torque that slows down the disk rotation. However, it leaves an asymmetry of the magnetic flux density distribution in the permanent magnet gap and the reduction of the extreme and the average values of magnetic induction for pairs of the left- and the right-hand magnets. In the experiment process the authors proved that the defined unsymmetrical angle value and the mean value of the magnetic flux density are significant parameters in the evaluation of the energy meter calibration procedure. The effect of permanent impact is noticeable as a result of approaching the magnetic field source at a distance of 8 cm or less from a permanent magnet compact system.

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