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Investigation of natural gas theft by magnetic remanence mapping

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ABSTRACT

Natural gas theft causes major losses in the energy industry in Hungary. Among the non-technical losses occurring in natural gas networks, fraudulent residential consumption is one of the main factors. Up to 2014, gas meters that are most widely used in residential monitoring are manufactured with ferromagnetic moving components, which makes it possible to alter or disrupt the operation of the meters non-intrusively by placing permanent magnets on the casing of the meters. Magnetic remanence mapping was used to investigate a sample of 80 recalled residential meters and detect potentially fraudulent activity. 10% of the meters were found suspect by magnetic remanence measurement, of which 50% were confirmed to be potentially hijacked by further mechanical investigation. The details of the technique are described in this paper, along with experimental results and the discussion of the analysis of the real-world samples.

1. Introduction

Between 2010 and 2013, the yearly average of nonpayment losses caused by natural gas theft is estimated to be between $10,000,000 and $40,000,000 in Hungary. A major part of the damage is caused by small consumers. Among all investigated cases, tampering with gas meters is the most frequent charge against supposedly fraudulent consumers.

Up to 2014, the most widely used natural gas meters in Hungarian residential consumption monitoring have been of the diaphragm/bellows type. The majority of the meters were manufactured with steel diaphragms and ferromagnetic outer casings. In models that have diaphragms parallel to the outer casing surface, accurately placed and strong enough permanent magnets can disrupt the operation of the meters. Since the magnets are placed on the outer casing, the tampering is mostly non-intrusive and difficult to detect by visual inspection.

Forensic science, digital investigation, geoscience and archeology are a few of the fields that apply magnetic remanence measurements. Magnetic remanence or remanent magnetization is the residual magnetic field of an object made of a ferromagnetic material after the magnetizing external field has been removed from the vicinity of the object. There are many definitions of remanence, e.g., anhysteric remanent magnetization (ARM), which is widely studied in geoscience in order to gain insight about past geologic processes [1]. Environmental sciences apply ARM measurements for pollution source identification [2–4]. ARM was also used in conjunction with other material properties, like heavy metal concentration for mapping out pollution sources [5,6]. In archeology, historical events may be reconstructed or information on past civilizations may be gathered by observing the ARM, natural remanent magnetization (NRM) or isothermal remanent magnetization (IRM) of samples [7–10].

As for forensics and crime prevention applications, previous works described a case where remanent soil magnetism was studied for finding the source of an illegally dumped sediment load [11]. Furthermore, digital forensics routinely employ magnetic remanence measurements, e.g., for validating secure documents [12], credit cards [13] and for data recovery [14,15]. A report describes an application by which obliterated serial numbers can be re-obtained from steel casings [16].

The detection and prevention of non-technical losses is an important factor in determining the profitability of enterprises in the energy industry. State-of-the-art methods often include sophisticated mathematics or machine learning [17,18]. The authors of this study are not aware of previous attempts that employed magnetic remanence measurement in energy fraud detection.

This paper describes a method by which the in-situ detection of fuel gas theft is possible, provided that the theft was realized by tampering with gas meters by using permanent magnets. Following the description of the methodology, the results of a

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case study are presented that include the analysis of recalled residential gas meters.

2. Materials and methods

This section describes the geometry and operation parameters of the gas meters typically encountered during this study, along with the magnetic remanence measurement technique that was used to analyze them.

2.1. Typical investigated gas meters

Diaphragm/bellows type residential gas meters were encountered in various shapes and sizes throughout this study. For the sake of simplicity, the two most common geometries are used for demonstration purposes in this paper. The nominal maximum flow rate of the meters was about 6 m^3/h. The span of the inlet and outlet stubs was 110–250 mm. Most of the gas meters were manufactured after 1995 and were equipped with steel diaphragms, that replaced the aluminum parts of earlier models. The casings were also made of steel – the type of casing material was very similar in each investigated case. In typical meters, the motion of the traveling diaphragms was such that permanent magnets placed on either the front or back face of the meter casing could affect or disrupt operation. The shortest distance between the membrane and the steel casing surface was typically between 10 and 20 mm. An internal plastic casing contained the diaphragm assembly, introducing a plastic surface between the steel casing and the diaphragms. Fig. 1 shows the geometry of the outer casing and the position of diaphragms inside a typical meter.

2.2. Magnetic remanence measurement

Magnetic remanence was measured by using a hand gaussmeter, type MAGSYS Magnet Systeme HGM09, supplied with a polarity indicator. The measurement was based on the Hall effect.

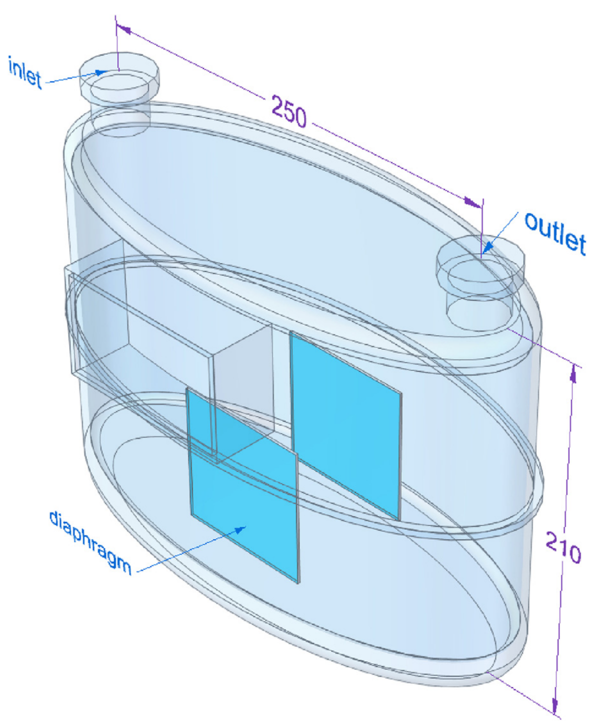

Fig. 1. A typical geometry of gas meter casings and the position of diaphragms inside. Approximate dimensions are in mm.

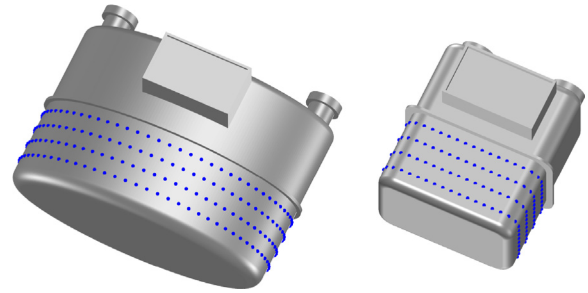

Fig. 2. Sampling grid for surface magnetic remanence measurements. Note that the sampled surfaces extend over the back sides of the casings as well. The most typical meter geometries are shown.

The portable meter was operated in DC mode, with a range of ± 10 mT and a resolution of 1 μT.

For most of the investigated gas meters, the distribution of surface magnetic remanence was approximated by point measurements. The point measurements sampled the surface on a rectangular grid with a resolution of 1 cm × 2 cm (meaning that the sample points were 1 cm apart in the circumferential direction and 2 cm apart in the height direction of the meters). In every case, the complete circumference of the meter casing was sampled, but only the lower portion of the full height. The sampled surface was determined by considering the positions of the internal diaphragms and the configuration of magnets that had the strongest effect on the operation of the meter. Fig. 2 shows the sampling points.

2.3. The acquisition of supporting data

Surface magnetic remanence measurements provided information about the external magnetic fields that the meter casings might have come into contact with. However, based on magnetic remanence data alone, it is difficult to infer whether the operation of the meter was disrupted or affected by the magnet in any way. The reason for this is that the external force exerted by the permanent magnets might be negligible compared to the pressure force acting on the diaphragms. Furthermore, even if detected, the placement of a permanent magnet on the meter casing does not necessarily imply criminal intent. For these reasons, collecting more information about the history of the investigated gas meters was found necessary.

It was hypothesized that if a permanent magnet exerted a force strong enough to disrupt the operation of a gas meter, the moving diaphragms would at some point come into contact with the inner surface of the internal plastic casing and leave abrasion marks. This hypothesis was tested in separate tests and was found to hold reasonably well in most cases. Based on this preliminary information, it was possible to collect additional evidence by investigating the internal surfaces of the meter casings. The surfaces was searched for abrasion marks, scratches or indentation. Digital photographs were taken of the investigated internal surfaces.

3. Results and discussion

Two distinct experiments are described in this section. The first experiments served to provide “ground truth” data that related the strength of the permanent magnets to both gas meter operation and the observed magnetic remanence in the meter casings. The real-world samples of the second part were analyzed based on information obtained a priori in the magnetization tests.