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Effectiveness of magnetic detectors in alarm systems

***Abstract**. The paper presents results of experiments and of modelling magnetic field by means of the finite element method (FEM). The study was performed on a magnetic detector K-1 manufactured by Satel, and the results of modelling were subsequently compared to those published by the manufacturer. The study also comprises the influence of changes in selected constructional parameters of the magnet on the detecting range. The finite element method is widely applied for the description of inductive phenomena since it is well suited for the analysis of complex electrical systems and their components.*

Streszczenie.** W artykule przedstawiono wyniki badań oraz modelowania pola magnetycznego za pomocą metody elementów skończonych. Modelowaniu poddano czujkę magnetyczną K-1 firmy Satel, wyniki porównano z wynikami udostępnionymi przez producenta. W pracy zbadano również wpływ zmiany wybranych parametrów konstrukcyjnych magnesu na zasięg detekcji czujki. Metoda elementów skończonych jest powszechnie znaną i wykorzystywaną w ocenie zjawisk indukcyjnych, umożliwiającą analizę pracy skomplikowanych elementów i układów elektrycznych. **(Skuteczność działania czujek magnetycznych w układach alarmowych)

Keywords: magnetic detector, simulation, modelling, FEM
Słowa kluczowe: czujka, symulacja, modelowanie, MES

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Introduction

The study is based on an application of FEM modelling in a 2-D space. This method makes it possible to divide the region under scrutiny into triangles and to set the boundary conditions. Besides, it is possible to determine a potential or electric charge for any point within the model. The program defines the environment in which the analysis is performed. The results of computations are presented in a graphic form, representing the distribution of the scalar potential or the distribution of field intensity. The exact numerical value of potential, field intensity, surface charge, energy density and dielectric permittivity can also be obtained for any point, and linear graphs representing variation of these values can be plotted.

Objectives of the study

The main objective of the study was to determine the influence of selected properties of permanent magnets, such as kind of material or dimensions, on the characteristics of the reed switch operation. As a departure point for the study, preliminary measurements were performed in a detection system with the detector K-1. Then, interaction of the detector with the control panel Integra 128-WRL was examined, and the detector's sensitivity and operation range were determined for the closed and open reed switch. Next, some modifications of the permanent magnet were implemented, concerning the material and its geometrical parameters. To investigate their impact on the operation of the system, different variants of magnet were tested, such as different relative length (L/D), different positions with respect to the reed switch, or different properties of the magnetic material. It was then investigated how these variable parameters affected the reed switch sensitivity.

The reverse shift phenomenon in a permanent magnet – reed switch system.

In the detector system there occurs a delay in connecting and disconnecting the reed switch circuit. This phenomenon is sometimes referred to as reverse shift and affects the detector sensitivity. The reed switch sensitivity, in turn, depends on many factors, both within design and in the external magnetic field. That is why the problem under scrutiny should be analysed from the viewpoint of the reed switch construction and from the viewpoint of the permanent magnet parameters. The delay, or the shift occurs between the distance of closing H_o and opening H_r the contacts of the reed switch. The construction of some switches, such as small-size switches, or multiple-switch detectors requires that the shift *dy* has to be minimised, which affects the operating characteristics of the reed switch.

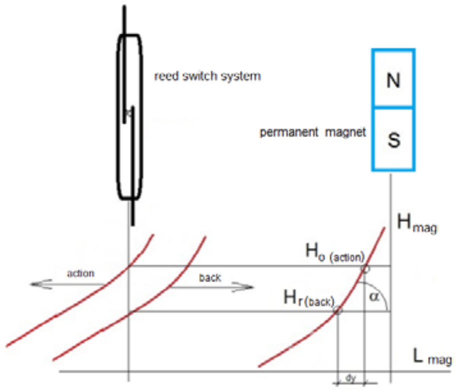


Fig. 1. Influence of the reed switch parameters and of the magnetic field gradient on the value of the reverse shift *dy*.

In the operating system of the detector K-1 (the magnet acts with its lateral field upon the reed switch) the reverse shift can be represented as

(1) $$d_y = \frac{H_O - H_r}{tg\,\alpha} \quad [mm]$$

with the coefficient k_r of the reed switch resuming its neutral state

(2) $$k_r = H_r / H_O$$

the shift becomes

(3) $$d_y = \frac{H_O(1-k_r)}{tg\,\alpha} \quad [mm]$$

The value and the character of the magnetic field actuating the reed switch depend on the dimensions of the magnet, its energy and the mutual position of the two elements in the detector system. The figure below presents a possible distribution of the magnet active zones (connecting - A and disconnecting - B) in a position parallel to the reed switch.(Fig. 2.) The point at which the reed switch is actuated and the point at which it is disconnected depends not only on the material of which the contacts are made but also on the remanence and magnetic coercivity value of the magnet.[1]

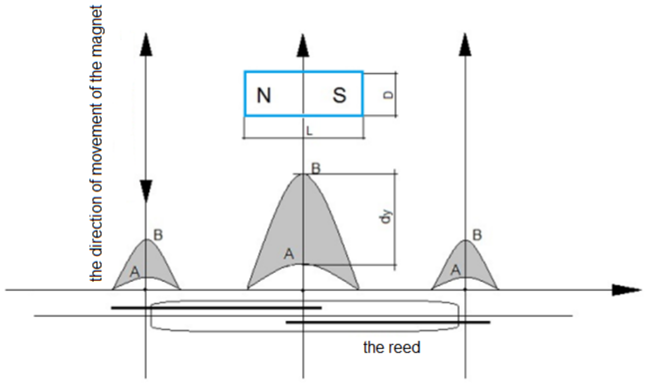


Fig. 2. Actuating the reed switch by means of a permanent magnet in a system with a parallel movement of the magnet with respect to the longitudinal axis of the reed switch.

Design and technological parameters of the magnetic detector K-1 Satel

This simple detector utilises the phenomenon of magnetic field originating from a neodymium magnet mounted on a mobile element, such as a door or a window, and acting on an element actuating an electric circuit, i.e. a reed switch, mounted on a stationary element, such as a frame. These elements are typically mounted on doors and windows in building protection systems but it has to be noted that magnetic detectors can be applied in all kinds of alarm systems controlling the operation of various devices. When introducing new variants of the above mentioned subsystems into the market, a manufacturer commissions tests on the basis of which the usefulness of particular variants in particular operating conditions can be classified. The technical ratings for the sensors K-1, K-2 and K-3 are included in the documentation of the company Satel available at their web site by the symbols 123_pl 04/07. The operation of the detector was verified empirically in order to establish the distance between the magnet and the reed switch required for the correct operation of the detector. In the several tests conducted, it was shown that the reed switch contacts close when the distance is 19 to 20 mm, and open when it is 27-28 mm.[3,5]

Fig. 3. Detector K-1

Selected technical parameters for the magnet N38 with the dimensions 4x20 mm at the temperature 26,5^{o}C are as follows:

a) Magnetic properties of the material N38: remanence induction B_r=1,24 [T], coercivity H_{CB}=907,4 [kA/m], coercivity H_{CJ}=1096,1 [kA/m], magnetic energy density $(BH)_{max}$=292,47 [kJ/m^3]

b) Physical properties: density ~7,5 [g/cm^3], Vickers hardness (HV) ~600 [kG/mm^2], resistivity ~144 [μΩ x cm]

c) The magnetisation along the height direction means that one circular surfaces of the magnet constitutes its north pole and the other circular surface is the south pole (on the basis of the data issued by: Laboratorio Elettrofisico Engineering, Measuring Equipment IS-300).

Next, on the basis of the above stated catalogue data the object was modelled by means of the FEM in order to represent the magnetic field surrounding the magnet. The computations involved three steps: preparation of input data, computations proper and result analysis (Table1).

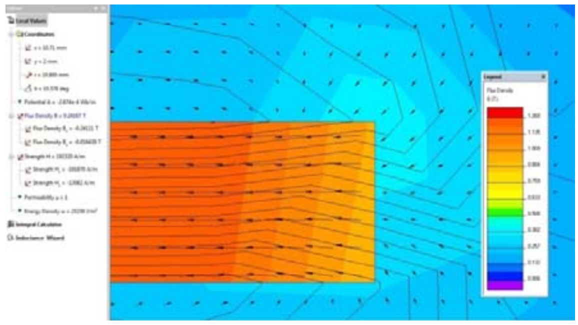


Fig. 4. Analysis of magnetic induction B in the region of one of the poles of magnet N38 [source: developed by the authors]

The modelling process was based on the particular steps. Generally speaking, when the research problem was formulated, the programme enabled simulation in a specific operating environment, material properties were defined, such as electric and magnetic properties, the shape of the element tested was represented and boundary parameters for edges, vertices and blocks were defined. Subsequently, computations were performed and the results obtained were presented graphically. On the basis of the simulations performed it can be stated that the value of magnetic induction near the edge of the magnet pole along the axis *x*, given as ~0,360 [T] by the manufacturer (maximum value) diverges from the value actually obtained in the test ~0,246 [T] (Graph 1). Since the value given by the manufacturer is defined as the maximum value, the one obtained in the simulation should also be considered correct. Then, the magnetic field surrounding the lateral surface of the magnet (the lateral symmetrical *y*) was examined. The shape of equipotential lines enabled observations of the distribution of B and H at specific places surrounding the object. The values of B and H were determined along a line symmetrical to the lateral surface for the length L = 19mm (closing the reed switch contacts) and for L = 27mm (opening the reed switch contacts) (Table 1).

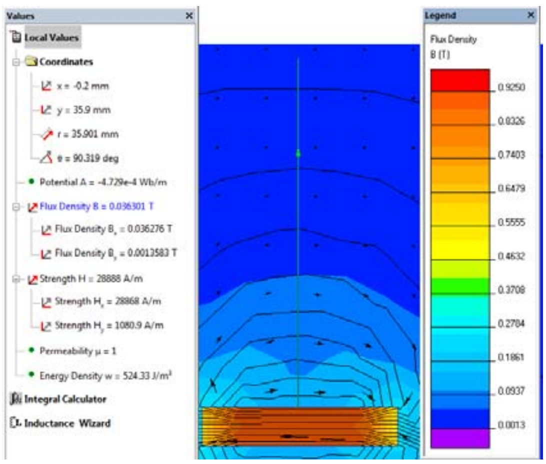
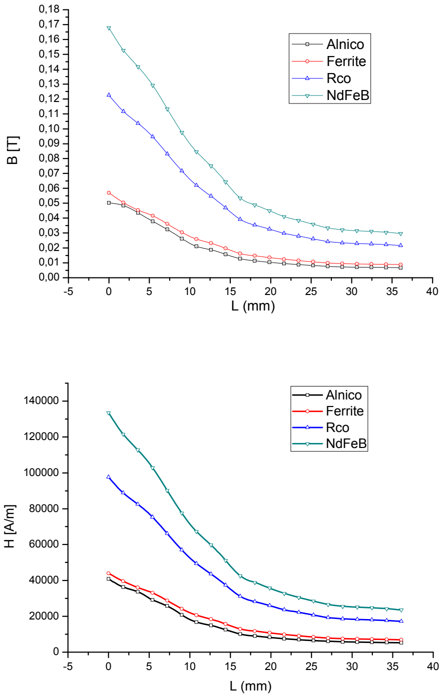


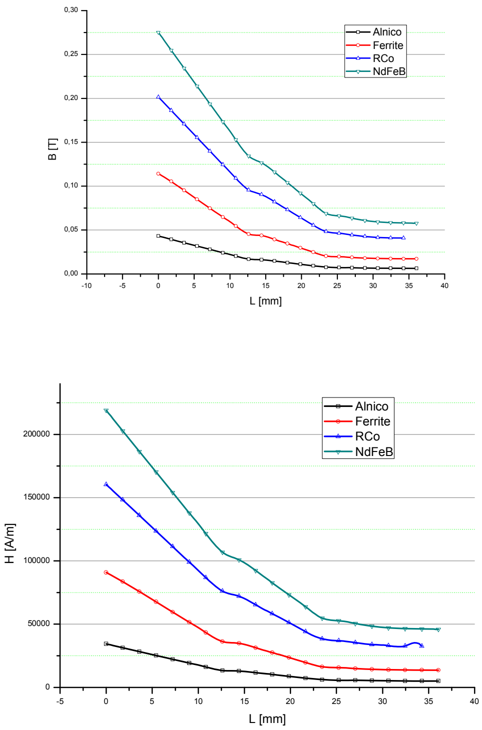
Fig. 5. The example for N38 - region of the magnetic field analysis with respect to the lateral symmetrical *y* of the model, D=4mm (magnet diameter), L=20mm (length), L/D=5 and the temperature 26,5^{o}C. [source: developed by the authors]

Table 1. Results of B, H computed with respect to the symmetrical *y* for which the reed switch changed its state for N38.

L [mm]	19	27
B [T]	0,0363	0,0250
H [A/m]	28868	19922



Graph 1. Values of the magnetic field induction B and magnetic field intensity H in the models examined; L/D=5.



Graph 2. Values of the magnetic field induction B and magnetic field intensity H in the models examined; L/D=1,25.

Depending on the technology of production, permanent magnets can be classified into three main types; cast, sintered and bonded, i.e. magnetic composites. Another classification is based on the type of magnetic material used: Alnico magnets, ferrite magnets, and magnets made of rare earth metal alloys. Each of these groups of magnets has different physical characteristics. In the subsequent part of the study, the detector operation was modelled for different types of permanent magnets, both with respect to the materials and to dimensions.[2,4]

Table 2. Selected magnetic properties of the materials tested.

Magnet type	Alnico	Ferrite	RCo	NdFeB
Production method	Sintered (1)	Barium ferrite-sintered (2)	$SmCo_5$ – sintered (3)	Compression-molded and bonded, anisotropic (4)
B_r [T]	1,050	0,400	0,925	1,28
H_{CB} [kA/m]	62	170	710	907
H_{CJ} [kA/m]	62	170	2000	995
$(BH)_{max}$ kJ/m^3]	31	30,0	170	302
μ_r	1,1	1,10	1,03	1,09

The next step in the study was to examine a response of the detector sensitivity to variation in magnet dimensions. For this purpose, all the magnet types were used in the modelling again, with doubling the diameter and decreasing the length. The dimensions were assumed as L=8mm, D=10mm. The variation in the lateral magnetic field distribution is represented in Graph 3, the conclusions are stated below.

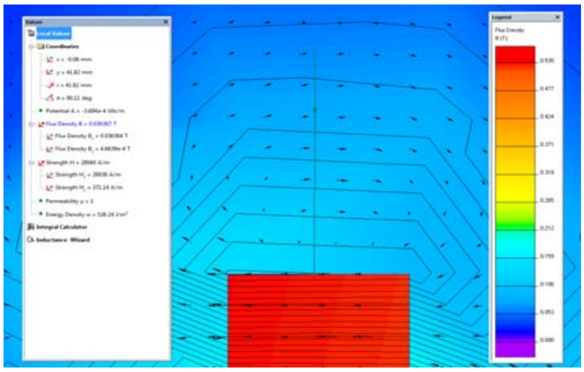
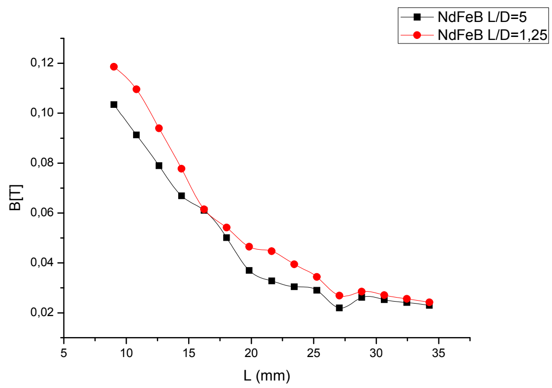


Fig. 6. Computations and distribution of the magnetic induction B and of magnetic field intensity H obtained with respect to the line *y* for NdFeB; the dimensions are D = 8mm, L = 10 mm (L/D=1,25), the temperature is 26,5^{o}C.



Graph 3. Comparison of the magnetic induction B distribution with respect to the line *y* for NdFeB L/D=5 and L/D=1,25.

Table 3. Reed switch operating states for positions A and B of the magnet (Fig.2) [mm]

Magnet type		Alnico	Ferrite	RCo	NdFeB
L/D=5	Closing contacts A	2	9	18	19
	Opening contacts B	4	14	25	27
L/D=1,25	Closing contacts A	3	10	20	23
	Opening contacts B	6	16	28	31

Discussion

The experiments described above lead to the following observations and conclusions:

– the value of magnetic induction obtained in the simulations is subject to error, resulting mostly from the following factors: error in modelling – the mathematical model applied does not sufficiently correspond to the reality, error due to inaccurate assumptions concerning the material, error in interaction of the object with the external world, error in representing the space - the space taken into account in computations does not fully correspond to the real space occupied by the object examined;

– the value and character of the magnetic field intensity necessary to actuate the reed switch by means of a moving magnet depend on the dimensions of the magnet, on its energy and the mutual position of the magnet and the reed switch;

– a magnet of small dimensions and high coercivity is characterised by high field gradients (the higher the volumetric density of magnetic energy, the smaller dimensions of the magnet are necessary);

– anisotropic magnets are characterised by higher fluxes and remanence than isotropic magnets of the same dimensions;

– in real exploitation conditions, the actual parameters can diverge from those given by manufacturers in technical ratings, it is practically impossible to obtain identical elements;

– high-energy magnets made of rare earth metals produce several times higher magnetic force than ferrite or alnico magnets of comparable dimensions, owing to that rare earth metal magnets can be of smaller dimensions;

– the analysis of magnetic fields of ferrite and alnico magnets indicated that it is not advisable to apply them in the detector system since the distance required to actuate the reed switch would be too small, the only exception being RCo and NdFeB magnets which are capable of effectively actuating the reed switch;

– magnetic field lines of a flat magnet are located on a plain surface, whereas magnetic field lines of a high magnet have upward orientation. practically then, the value of magnetic field intensity measured at a certain distance from the magnet will be higher for a high magnet;

– the change from L/D=5 to L/D=1,25 for a NdFeB magnet renders the equipotential lines *b (h)* more convex, which in turn affects the value of the reverse shift *dy*;

– it was observed that when the position of the magnet centre is changed by less than 5mm with respect to the reed switch centre, the operation of the latter is affected faster for L/D=1,25 than for L/D=5;

– the choice of the magnet material with respect to the parameters investigated can be practically implemented for reducing the size of the detector, for developing dedicated solutions or drives of various kinds for actuating the reed switch (magnetisation, shunts, pole pieces), and for ensuring stable operation and reliability of reed switches;

– high coercivity materials should be applied mostly in open magnetic circuits. the choice of a magnet type to be applied in a detector should not be based only on the volumetric density of magnetic energy and magnet's dimensions but it should also reflect external factors, such as demagnetising external magnetic fields and susceptibility to parameters changes due to environmental factors;

– fem modelling makes it possible to develop a model affording a good compromise between computational accuracy and cost of time spent on modelling, computing and analysing the results;

– analysis of the magnetic field produced by magnets of various coercivities makes it possible to develop compact reed switches with short magnets of small dimensions;

– by determining the values of magnetic fluxes and induction in various segments of the magnetic circuit it is possible to obtain values of electromagnetic forces acting on the contacts in the reed switch, to analyse optimisation of the connector circuit as well as of the permanent magnet and its functional parameters.

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