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# Practical validation of flow meter design environment

***Abstract**. This paper presents process of practical verification of an automated CAD environment for the design of a primary transducer of the electromagnetic flow meter. The verified system supports numerical simulation (analysis and optimal design) of the flow meter coil for a channel of given dimensions. Results of the design were compared to the measurements performed on the prototype coil.*

***Streszczenie.** W artykule przedstawiono proces praktycznej weryfikacji komputerowego systemu wspomagającego projektowanie przetwornika pierwotnego przepływomierza elektromagnetycznego. Testowany system umożliwia komputerową symulację (analizę rozkładu pola i optymalizację kształtu cewki) dla kanału o zadanych wymiarach. Wyniki projektowania zostały porównane z wynikami pomiarów pola generowanego przez prototyp zaprojektowanej cewki. **(Praktyczna walidacja komputerowego system do projektowania przepływomierzy elektromagnetycznych)***

**Keywords:** CAD system, practical verification, numerical field simulation.
**Słowa kluczowe:** systemy CAD, praktyczna weryfikacja, numeryczna symulacja pola elektromagnetycznego.

## Introduction

Flow measurements are a well known and widely described metrological problem. The case becomes more complicated if the flow velocity in the open channel has to be measured. In such situation the relation between flow and fluid level is usually unknown, so the classic methods for flow calculation are inefficient.

In such a case only two methods can be effectively used: electromagnetic method and an ultrasonic one. This paper concentrates on some aspects of electromagnetic flow measurement method for artificial channel with rectangular cross-section, a situation that can be very often found in a wastewater treatment plants or irrigation systems. The described channel has non-conductive banks and, because of its rectangular shape, the homogenous magnetic field should be induced [1].

Measurement heads of electromagnetic flow meters for small artificial channels consist of excitation coil and a pair of measurement electrodes and they are usually built into the channel itself [2].

Example solution of such primary transducer is presented in Fig.1.

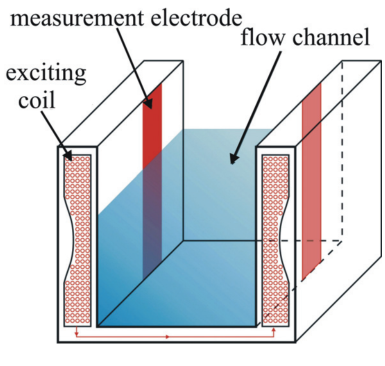


Fig. 1. Primary transducer of an electromagnetic flow meter

The main design problem is to ensure a high level of uniformity in the magnetic flux distribution across the measurement zone by a specific design of an excitation coil.

## Excitation coil

As it was mentioned above, the main design goal is to achieve homogenous magnetic field in the measurement zone and the optimal, expected field distribution at the end of the coil. In this border area magnetic field rapidly disappears which may cause disturbances in the electric field, known as border effects [3,4,5]. This effects results in the finite length of the excitation coil and may significantly reduce the measured electric signal. The simplest way to overcome that problem is to optimally extend the length of the coil in the flow direction [3].

Another problem then that should be considered during the design process is the technical feasibility to build such optimally designed coil.

The influence of the shape of the coil on the magnetic field distribution was calculated using numerical model and Opera3D software [6,7]. Two versions of the excitation coils were taken into consideration, saddle type and new double deck type. In both cases the shape of the cross-section of excitation coils was not optimized.

Finally the double deck coil type was chosen, because of favourable character of the resulting magnetic field distribution. The model of such coil is presented in Fig.2.

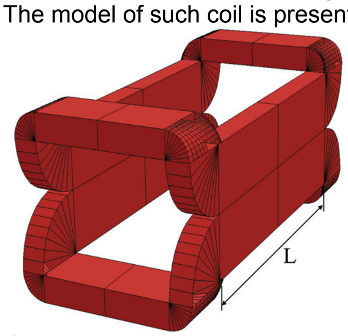


Fig.2. Model of a double deck coil

The application of double deck coil, which is basically two identical saddle type coils connected back to back, makes the winding process much easier. This coil type has a working part L, parallel to the bank of the channel and upper joints that go above and below the channel. As a result from technological point of view this coil is easier to make than a saddle type one.

The division of the number of turns between two identical coils decreases the total length of the upper joints by half. As a result, the double deck coil with the same length of working part L as an equivalent saddle type coil is shorter by the length of single upper joints.

Additionally, the magnetic field distribution in the measurement zone is more homogenous for the double deck coil and the mean value of the magnetic flux density is also higher (for the same magnetomotoric force).

## Design of the excitation coil

The coil was designed using own software package FMDT (Flow Meter Design Tool). It is an integrated graphical environment for the design and optimization of electromagnetic flow meters for open channels with rectangular cross-sections and electrically insulated banks.

It consists of the following main modules: coil generator, flow analyzer, evolution optimizer (genetic algorithms), deterministic optimizer (Leveberg-Marquartd algorithm) and graphical user interface which integrates all aforementioned modules into one consistent design system.

Using the presented software the double deck excitation coil was designed for rectangular flow channel measuring W=0.127 m of width and H=0.11 m of depth, assuming the length of measurement zone D=0.05 m. In the initial stage of the project the current density of 0.25 A/mm$^2$ was assumed, and the desired value of the vertical component of mean flux density was $B_y$=1.5mT. The working section of the coil (parallel to the channel) was divided into 10 segments. The snapshot of the main window of FMDT software after coil optimization is presented in Fig.3.

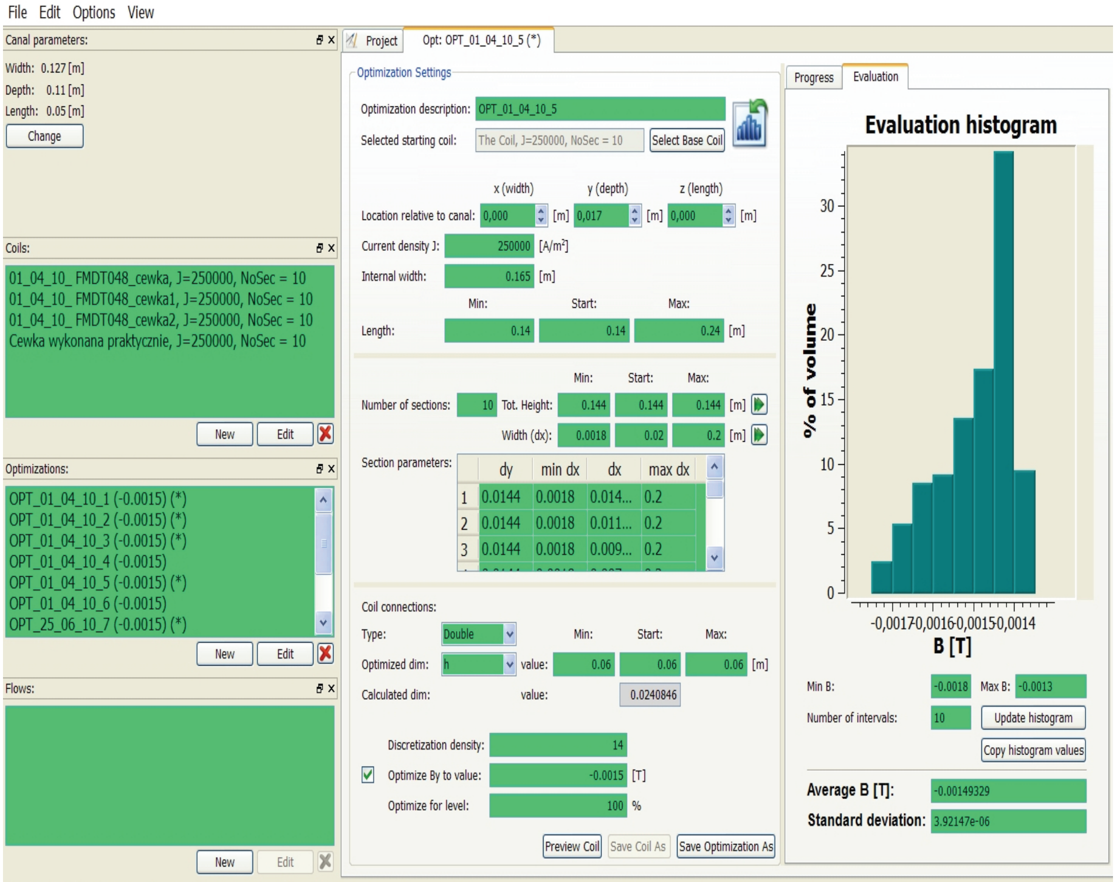


Fig.3. Main window of FMDT software

a) b)

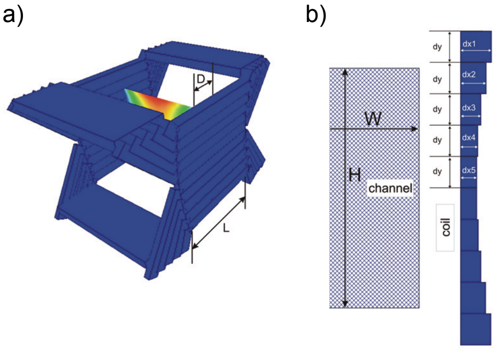


Fig.4. 3D view of the coil a) and its cross-section (for the single side of the channel) b)

The mean value of magnetic flux density in the measurement zone of the channel was 1.49 mT after coil optimization, with standard deviation reaching 0.039 mT. The histogram was used in order to perform quantitative analysis of magnetic field uniformity. Histogram shows the values of magnetic flux density ***B*** in the whole volume of the measurement zone. An example histogram is presented on the right side of Fig.3 and it shows the percentage of flux density values that fall into eight ranges between min and max value. Histogram data can be used for a quick comparison of different coils. The best case is when the most of the values are around the desired magnetic flux density ***B*** assumed in the design.

The 3D view of the designed coil and the cross-section of the working section are presented in Fig.4. The optimized coil is symmetrical with respect to the height of the channel and it has the form of two identical coils with 5 segments of different thickness each. The calculated dimensions of the coil are presented in Tab. 1. The parallel, working section of the coil L is 0.14m long.

Table 1. Calculated coil dimensions

| Segment number | Height, dy [mm] | Width, dx [mm] |
|---|---|---|
| 1 | 14.4 | 14.0 |
| 2 | 14.4 | 11.6 |
| 3 | 14.4 | 9.2 |
| 4 | 14.4 | 8.0 |
| 5 | 14.4 | 7.4 |

## Laboratory model of the coil

Both coils, upper and lower were wound on a special mould made by the authors. Each coil was made using copper wire 1.8 mm in diameter. The wire is covered with two layers of durable lacquer which can withstand up to 200 degrees Celsius. Furthermore the wire can be bent to the right angle with the radius equal to wire diameter.

The coil consists of several layers of wire immersed in epoxy resin and insulated by insulating board, as shown in Fig.5b.

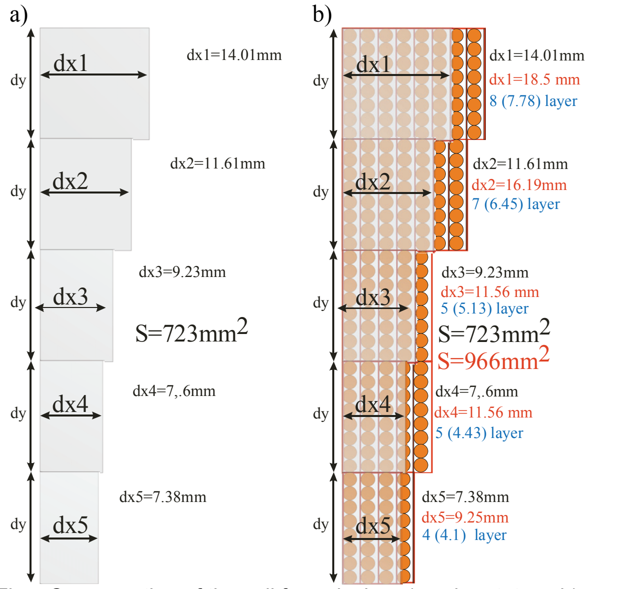


Fig.5 Cross section of the coil from design a) and prototype b)

The calculated profile of the coil (Fig.5a) was slightly modified during practical realization of the model (Fig.5b). The thickness is discretized due to the integer number of turns and chosen wire diameter. The active cross-section was diminished as the copper wire is only part of it, the rest being epoxy resin and insulating board.

## Laboratory tests of a prototype coil

The laboratory tests and measurements of magnetic field distribution inside the designed excitation coil of electromagnetic flow meter were performed on a test stand shown in Fig.6.

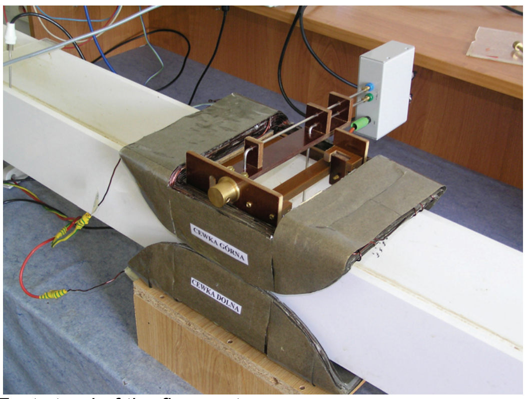

Fig.6 Test stand of the flow meter

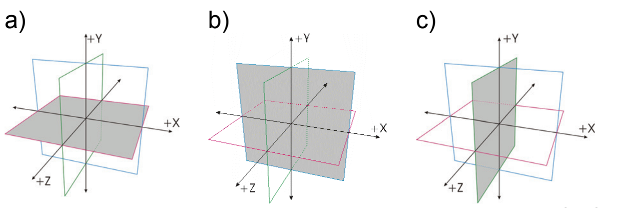


Fig.7 Planes XZ a) XY b) and YZ c) selected in 3D space for field visualization

The magnetic flux density in the measurement zone of the coil was measured using Bell 5180 meter. Taking into account measurement range, accuracy and flux density values, the calculated measurement error was 0.03 mT. The coils were connected in series and supplied from DC power supply, drawing such current to obtain assumed mean value of magnetic flux density of 1.5 mT. Because the wire was then only a part of the total cross-section of the coil, the current density has to be increased from the projected 0.25 A/mm$^2$ to 0.39 A/mm$^2$. Measured mean value of magnetic flux density was $B_0$=1.496mT in the measurement zone and the standard deviation reached $\sigma$=0.058mT. The measured values of flux density in 3D space are visualized on 2D plots, showing field distribution in XZ, XY and YZ planes, as shown in Fig.7.

The field distribution on XY plane (Fig.7b), perpendicular to the bottom of the channel and located in the middle of the measurement zone (defined by the electrodes) is presented in Fig.8. The plots show the flux density values as a function of a distance from the center of the channel, for different values of Y coordinate (again with respect to the center of the channel).

It can be seen that quasi-parabolic relation was obtained, with good symmetry in X axis, but slightly asymmetrical in Y axis. This can be seen by comparing field distribution 40 mm above (Y=40) and below (Y=–40) the centerline of the channel (Y=0). The differences are small, a couple percent of flux density value. Similar magnitude of asymmetry exists in X axis.

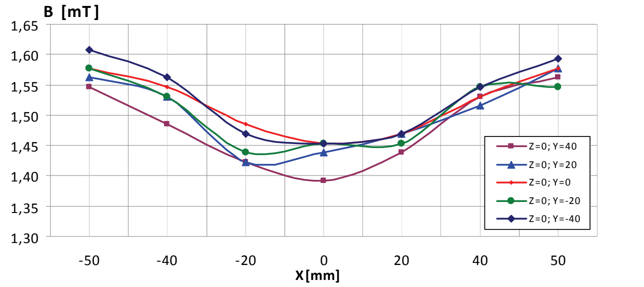


Fig.8 Magnetic flux density on XY plane in the centre of the channel (Z=0 cm), along different lines (Y=var.)

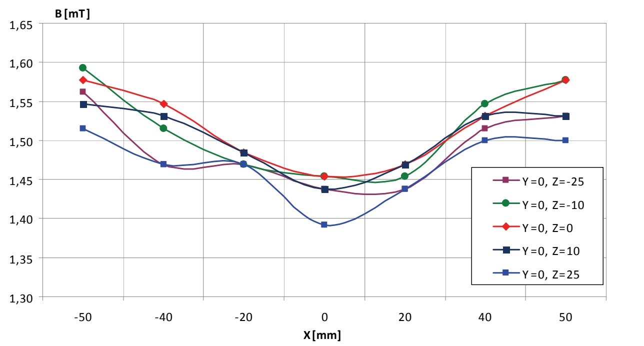


Fig.9 Magnetic flux density on XZ plane in the centre of the channel (Y=0 cm), along different lines (Z=var.)

The field distribution on XZ plane (Fig.7a), parallel to the bottom of the channel and located in the middle of the measurement zone is presented in Fig.9. The plots show the flux density values as a function of a distance from the centre of the channel, for different values of Z coordinate (again with respect to the centre of the channel). The plots show the magnetic flux density changes as the distance from the electrodes increases in both directions. Again, some symmetry can be observed, as the plots Z=25 and Z=–25) are compared.

The field distribution on YZ plane (Fig.7c), perpendicular to the bottom of the channel and parallel to the fluid velocity vector is presented in Fig.10. The plots show the flux density values as a function of a distance (in Z axis) from the center of the channel, for different values of Y coordinate.

The measurement results revealed very similar values of flux density, slightly smaller than the mean value. By comparing the field distribution for both ends (Y=40 and

Y=–40) it can be seen that the measured values are inside the margin defined by standard deviation and the resolution of a flux meter.

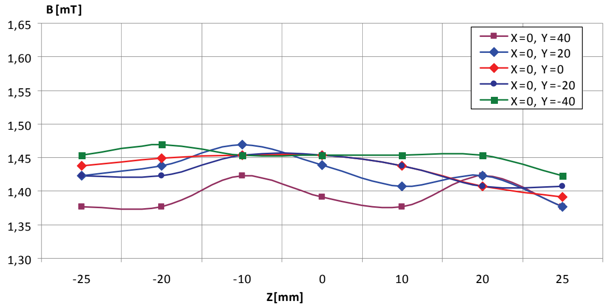


Fig.10 Magnetic flux density on YZ plane in the centre of the channel (X=0 cm), along different lines (Y=var.)

In order to compare the designed coil with the manufactured prototype, the flux density values calculated by FMDT software were presented on the same plot with the measurement data. Fig.11 shows the calculated and measured magnetic flux density between the electrodes in the XY plane, in the middle of the channel (at zero values of Y and Z coordinates).

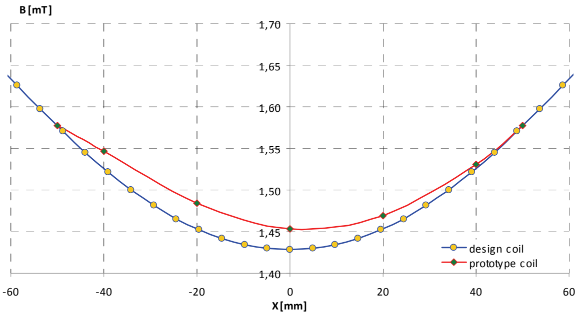


Fig.11 Magnetic flux density on XY plane in the centre of the channel (Z=0 and Y=0)

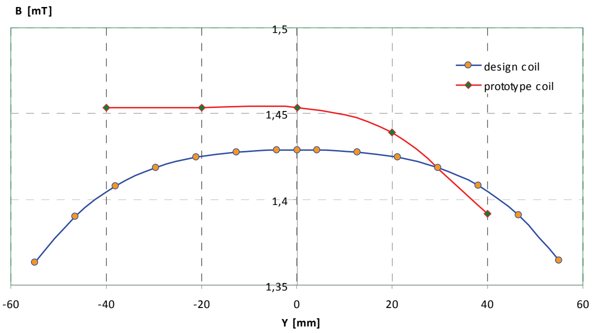


Fig.12 Magnetic flux density along Y axis in the middle of the channel (X=0 and Z=0)

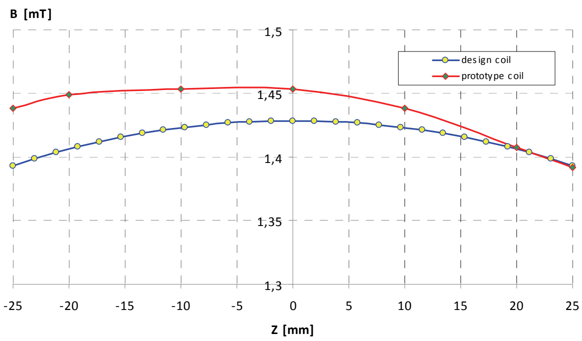


Fig.13 Magnetic flux density along Z axis in the middle of the channel (X=0 and Y=0)

It can be seen that both fields are symmetrical and the obtained distribution of the magnetic field in the prototype coil is close to the calculated one. The field distributions in the centre of the channel, along its height are slightly different for the projected and prototype coils (Fig.12).

The differences are within the margin of measurement error, but slight asymmetry of field distribution in the prototype coil is clearly visible. Magnetic flux density above the center (Y=40) is smaller than below (Y=–40). Similar situation can be observed along Z axis, as presented in Fig.13. Comparison of calculated and measured values revealed some differences and asymmetry with respect to the plane defined by the electrodes (Z=0). Again however, the differences are below measurement error margin.

## Summary

The prototype coil induces the magnetic field that fairy well corresponds to the results of numerical calculation and optimization. Unfortunately the field is not uniform in the declared measurement zone, and the standard deviation (which can be treated as a measure of that non-uniformity) reaches $\sigma$=0,058mT for the mean value of flux density $B_0$=1,496mT. During the design a slightly smaller standard deviation $\sigma$=0,039mT was assumed for the same mean value of flux density. Quasi-homogenous field distribution obtained for the whole volume of the coil is the proof of the proper choice of the coil shape. Double deck coil, due to joints over and below the channel, moves the area where the field quickly disappears further away from the measurement electrodes.

Slight asymmetry in the magnetic field distribution is caused by some manufacturing imperfections. The whole manufacturing process is well documented and such errors will hopefully be eliminated in future realizations.

The real-world influence of the differences between calculated and obtained field distributions on conversion characteristics of a flow meter will be investigated, when the whole simulator of such a flow meter will be completed. This simulator will be capable of calculating the output signal for a given flow profile. The final verification will be conducted by the determination of real conversion characteristics on a laboratory model of a flow channel.

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