Simulation of magnetic field distribution of excitation coil for EM flow meter and its validation using magnetic camera

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Abstract

Distribution of magnetic flux density in electromagnetic (EM) flow meter is significantly important for obtaining accurate flow rate. Helmholtz coils are used to generate homogenous magnetic flux density in the cross section of flow pipe of electromagnetic (EM) flow meter is presented in this paper. In this work, a simulation model with the EM module of finite element analysis software, COMSOL is built and experimental testing of the distribution of magnetic flux density is applied to verify its uniformity. A 2D magnetic camera system with 64 Hall sensors is prototyped. The magnetic field data are picked up by the National Instrument PCI 6255 data acquisition card. The results from the simulation and measurements are presented and compared in the paper. The study helps to design the electrode sensor arrays of EM flow meter. In addition to this, the distribution data of magnetic flux density are useful for the improvement of accurate flow rate of EM flow meter.

Key words Helmholtz coil, Electromagnetic flow meter, Magnetic flux density, Magnetic camera, Hall sensors

1. Introduction

Electromagnetic flow meters work using the Faraday principle, where an emf is generated by a changing magnetic flux density. The theory of EM flow meters belongs to the subject area of magnetohydrodynamics, formed from the combination of fluid mechanics and electromagnetism disciplines. Process tomography is a non-invasive imaging technique for understanding complex 3D multiphase flow processes and has been recognised as one of the most promising solutions to the measurement of multiphase flow [1, 2].

$$\nabla^2 \mathbf{U} = div(\mathbf{v} \times \mathbf{B}) \quad (1)$$

Where v is the fluid velocity vector and B is the magnetic flux density vector.

After some assumptions were made, Shercliff [1] proposed a weight function that describes the contribution of different parts of the EM flow meter measurement to the total signal. This function shows that the effect of velocity is strong near the electrodes and decreases when moving further away from the electrodes. The weight function therefore describes spatial variations in the EM flow meter sensitivity, which is a function of the magnetic flux density and the size, shape and positions of the electrodes.

According to Shercliff's weight function [1], the induced voltage between electrodes can be expressed as follow:

$$U = 2a/(\pi a^2)\iint B(x,y)v(x,y)W(x,y)dxdy \quad (2)$$

Where U is the induced voltage when electrode pair is located at various positions (x, y), B is the magnetic flux density, v is the flow velocity at each point of flow region in the pipe cross section, W is the weight value at each point of flow region in the pipe cross section and a is the radius of flow pipe.

To obtain an accurate flow rate measurement using an EM flow meter, the velocity v(x, y), at each point (x, y) of the flow pipe cross section must be accurately obtained. According to equation (2), the velocity can be calculated when U, B(x, y) and W(x, y) are known. Fortunately, the induced voltage U between the electrodes can be acquired and processed using the data acquisition system, which has been constructed for the EM flow meter. Shercliff has inferred W(x, y) when the electrodes are at positions along the pipe diameter. W(x, y) also can be numerically determined when the electrodes are located at positions parallel to coordinate axis [3]. The magnetic flux density B(x, y) is then used to calculate the flow velocity.

One method of obtaining accurate magnetic flux density B(x, y) measurements is to try to make B(x, y) uniform across the cross section of flow pipe, another more complicated method would be to calculate the magnetic flux density at each point (x, y) of the flow region.

The main aim of this paper is to model the EM flow meter using a homogeneous magnetic field, which is generated using Helmholtz coils. This magnetic field will be simulated using COMSOL FEM software and the results experimentally verified using a measurement and acquisition system with a magnetic camera. The rest of the paper is organised as follows, section 2 introduces the proposed structure of the EM flow meter. Next section 3 details the simulation model of EM flow meter, used to research the distribution of magnetic flux density. Section 4 details the construction of the experimental system with a magnetic camera, used to verify the distribution of magnetic flux density. Finally, section 5 concludes this research work and proposes further work.

2. Structure of EM flow meter and Helmholtz coil

The design of the EM flow meter is shown in Figure 1. Dimensions from an experimental setup at the University of Huddersfield were used, where the pipe internal diameter (Di) is 80mm and outer diameter (Do) is 90.7mm.

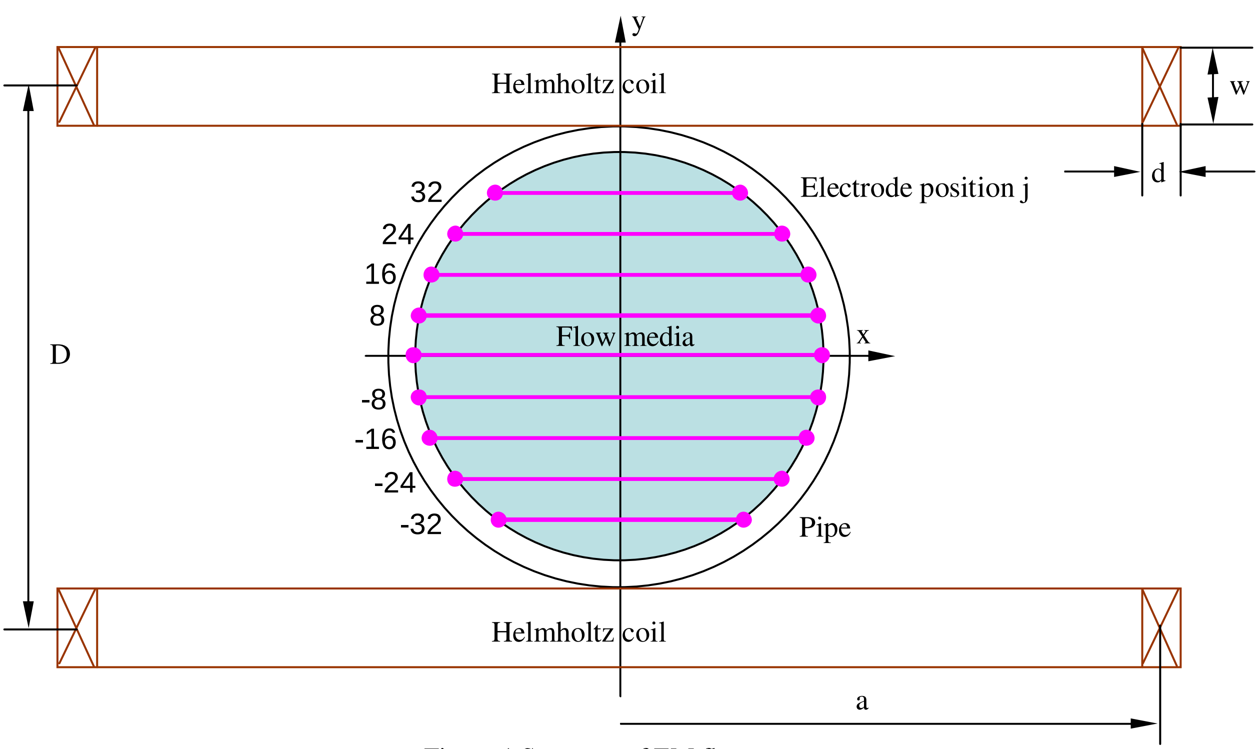

Figure 1 Structure of EM flow meter

Helmholtz coils are used as the excitation coils in the design of our EM flow meter. A Helmholtz coil consists of a parallel pair of identical circular coils spaced one radius apart and wound so that the current flows through both coils in the same direction. This winding results in a uniform magnetic flux density between the coils with the primary component parallel to the axes of the two coils. The direction of magnetic field is shown is Figure 1. From equation (2), a uniform magnetic flux density simplifies the computation of flow velocity based on induced voltage measured by the data acquisition system. The dimensions of coils are defined as follows:

- w, width of Helmholtz coil, 15.52mm
- d, depth of Helmholtz coil, 7.76mm
- a, mean radius of Helmholtz coil, (Do+w)/2=106.22mm
- D, distance between the two coils, 106.22mm

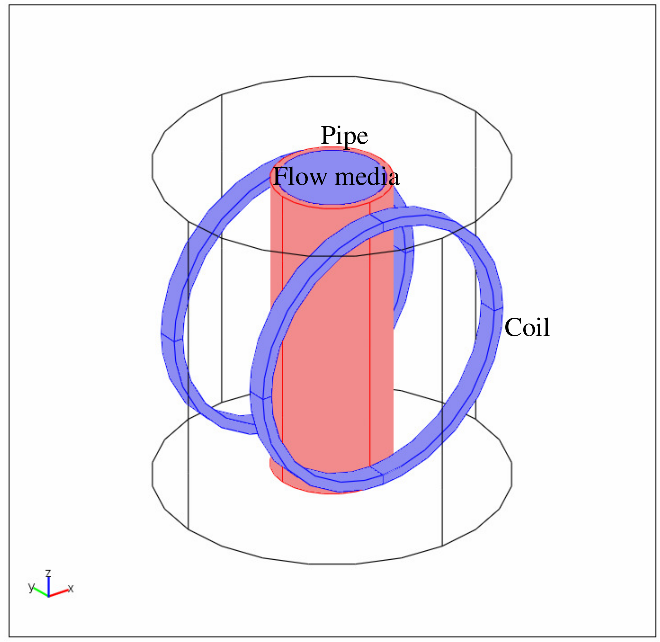

Figure 2 3-D simulation model in COMSOL

3. Simulation result of magnetic field distribution

In order to determine the distribution of magnetic flux density in the EM flow meter using Helmholtz coils, a 3D simulation model was built in the FEM package COMSOL. The model includes the polytetrafluoroethylene (PTFE) pipe, the Helmholtz coils and the flow media, as shown in Figure 2. The outermost cylinder in the figure was used as a boundary to limit the computation area of the simulation model. The material of Helmholtz coils is copper (conductivity = 5.998e7S/m). The current density in each coil had a value of 3.32e6A/m^2.

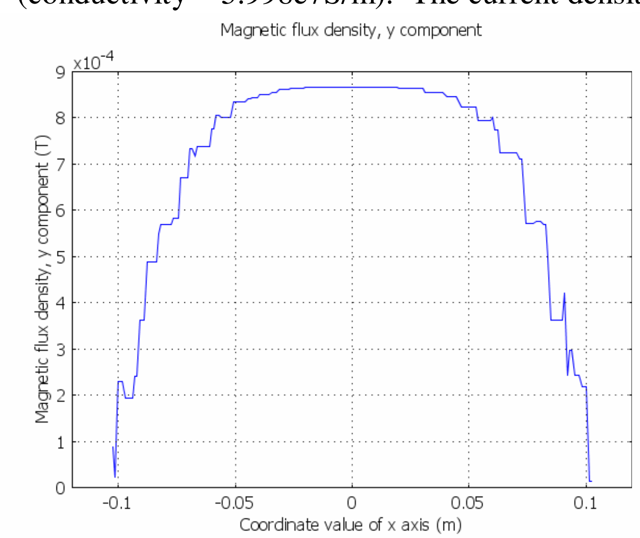

Figure 3 Distribution of magnetic flux density along x axis where y=0 and z=0

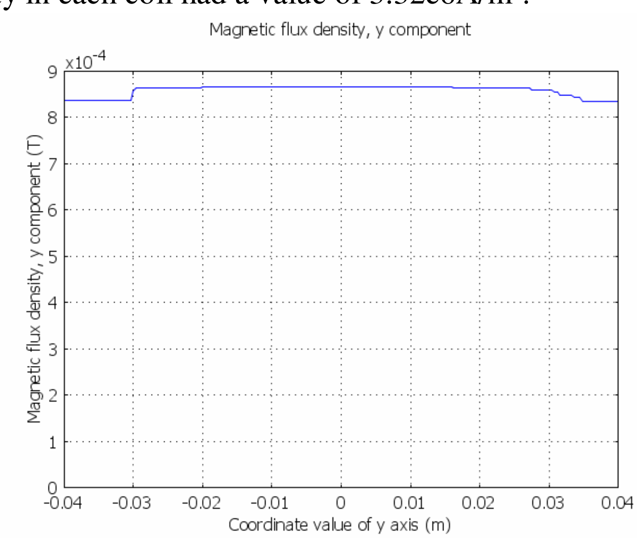

Figure 4 Distribution of magnetic flux density along y axis where x=0 and z=0

The simulation model was solved using a time harmonic stationary solver. Firstly, the distribution of magnetic flux density along x-axis in the z=0 plane was calculated, shown in

Figure 3. The x-axis range was set to the internal diameter of the coils (-102.34mm to 102.34mm). The values of magnetic flux density vary between 0.3 and 8.7Gauss from -102.34mm and 0mm along the x-axis. There is a large increase between -102.34mm and -40mm, and then the magnetic flux density remains virtually constant between -40mm to 0mm. The distribution of magnetic flux density is symmetric about x=0. This shows that the magnetic flux density along x-axis is almost uniform in the range of the flow region as shown in Figure 3. Figure 4 shows the distribution of the homogeneous magnetic flux density along y-axis. Its values are almost 8.7Gauss between -40mm and 40 mm on the y-axis.

Figure 5 shows the distribution of magnetic flux density in the cross section of flow pipe where z=0. Although the magnetic flux density values vary from 8.35Gauss to 8.75Gauss, the distribution can be seen to be relatively uniform.

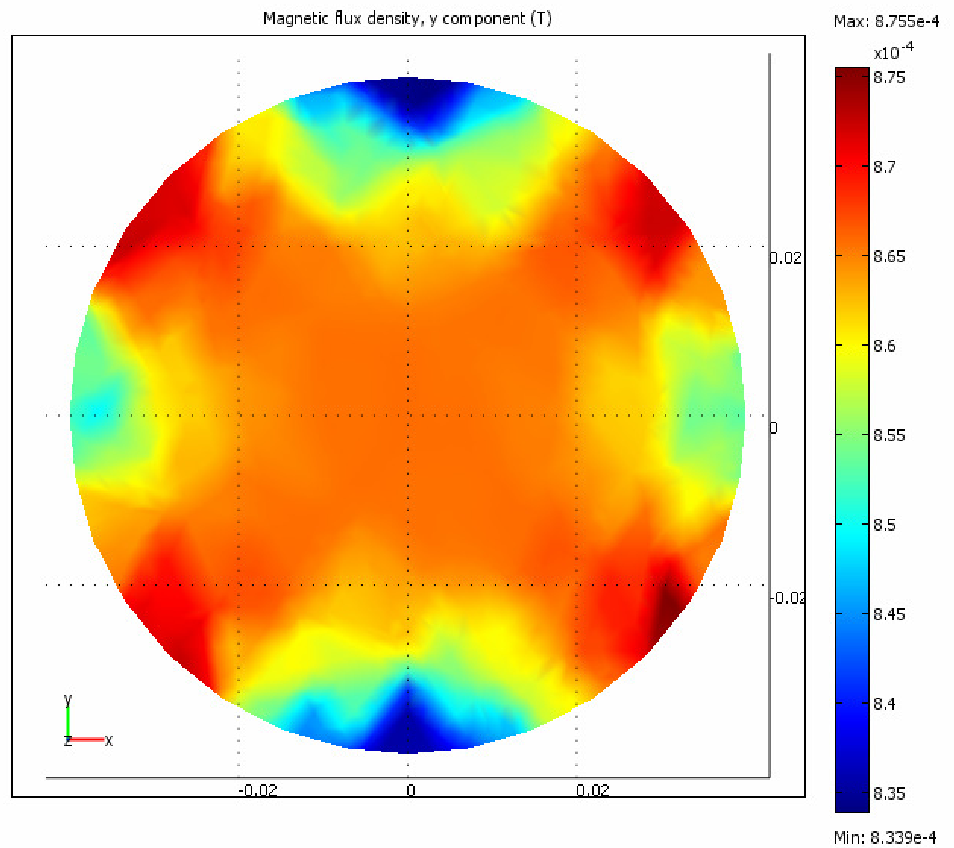

Figure 5 Distribution of magnetic flux density in the flow cross section where z=0

4. Measurement system and test result of magnetic field distribution

In order to verify the distribution of magnetic flux density, an experimental system has been constructed at Newcastle University as shown in Figure 6. An Agilent 33250A Function Generator was used to generate a sine wave excitation signal for the Helmholtz Coil, which was then amplified by a N4L LPA05B power amplifier. A Thurlby 1504 true rms multimeter was used to monitor the current in coil. The National Instruments PCI 6255 data acquisition card (750kS/s with 80 analog input channels) was used to acquire signals from the magnetic camera, which consisted of 64 (8×8 array) Hall sensors and signal amplification circuitry. Finally, the acquired data was processed using a data measurement software application.

The Mechanical Workshop at Newcastle University constructed the Helmholtz coils, shown in Figure 7, used in the experiment. They were wound with 200 turns of 22 SWG (0.71mm diameter) copper wire. In practice, the width of Helmholtz coils is 15.52mm and the depth is

7.76mm. The medium diameter of coils is 106.22mm. The practical Helmholtz coils are shown in Figure 7.

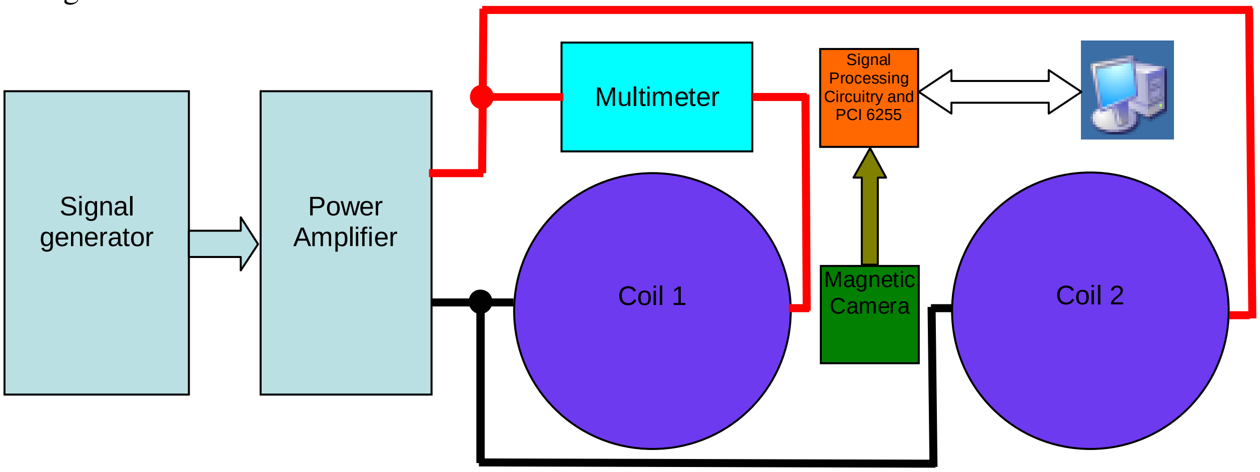

Figure 6 Diagram of experimental system

The magnetic camera was made of 64 Hall sensors and their signal amplification circuits. The arrangement of 64 Hall sensors in the circuit board was shown in Figure 8. The left picture in Figure 8 is the practical Hall sensor array of magnetic camera. The right part is the arrangement of 64 Hall sensors and their numbers.

In the experiments, the sine-wave excitation current in each coil is 472mA, with a frequency of 100 Hz. The magnetic flux density between the Helmholtz coils was measured using the magnetic camera. The magnetic flux density measured using Hall sensor 1 along x- and y-axes is shown in Figures 9 and 10 respectively.

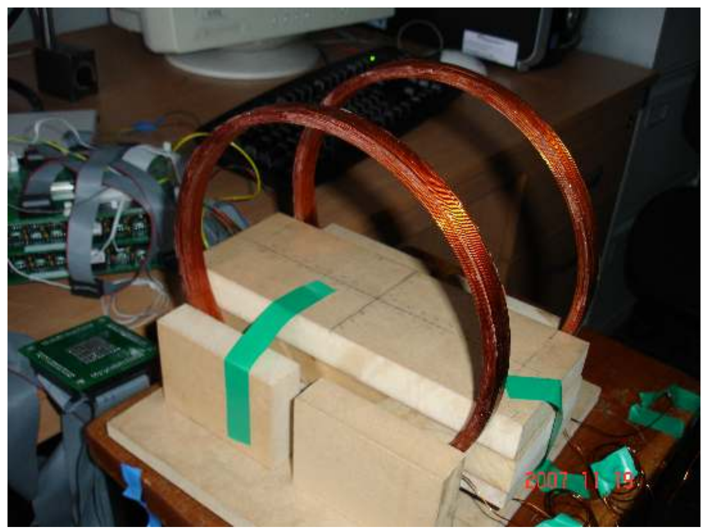

Figure 7 Practical Helmholtz coils

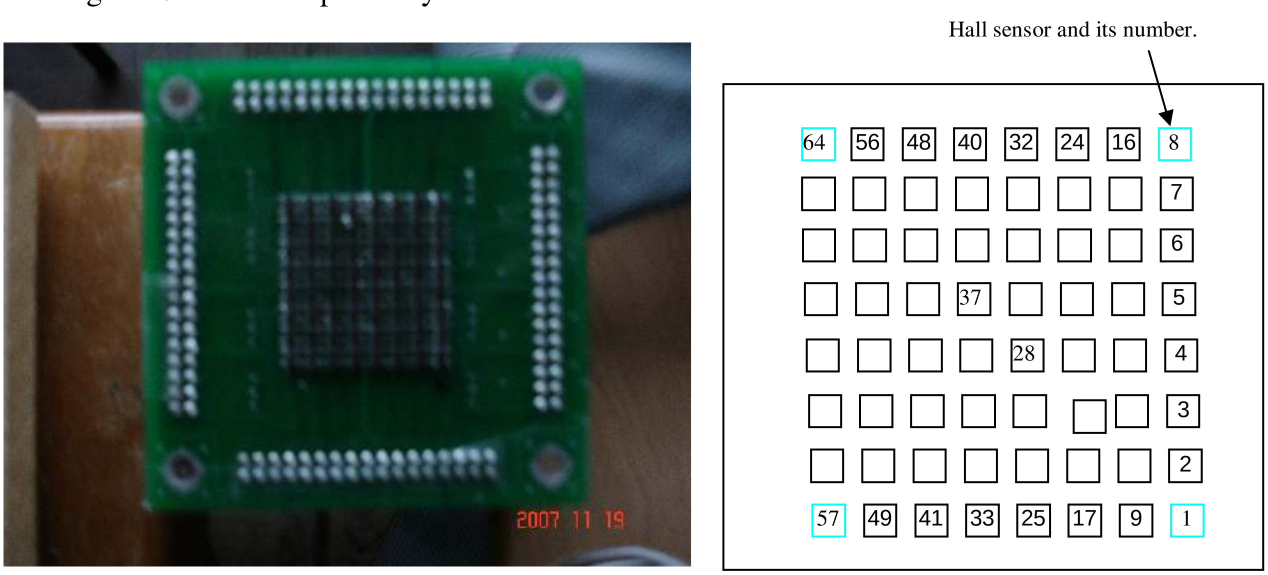

Figure 8 Hall sensor array of magnetic camera

Based on the above method for measuring magnetic flux density with individual Hall sensor of magnetic camera, the 2D distribution of magnetic flux density in the flow cross section can be measured by 64-Hall-sensor array.

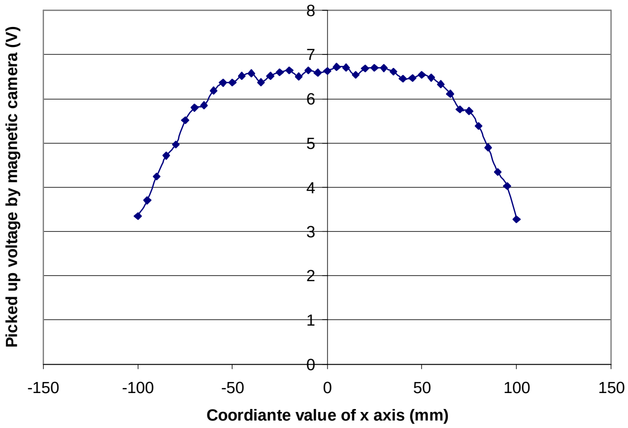

Figure 9 Experimental results of distribution of magnetic flux density along x axis

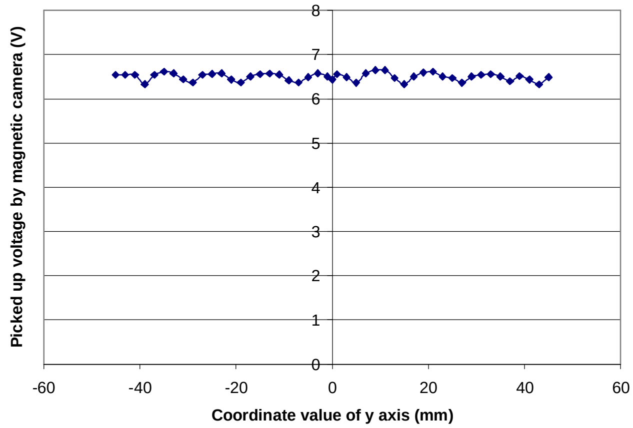

Figure 10 Experimental results of distribution of magnetic flux density along y axis

5. Conclusions and further works

Based on the simulation results and experimental results, we can conclude that the distribution of magnetic flux density in the flow cross section of flow pipe is almost uniform. Helmholtz coils can be configured in EM flow meter to generate uniform magnetic flux density. Therefore, the inverse solution of flow velocity in equation (2) will become much simpler. On the other hand, the simulation work and experimental tests prove that magnetic camera can be used to measure the distribution of magnetic flux density in the area of flow cross section to get as accurate as possible value of magnetic flux density. The further work is to improve the experimental measurement system of magnetic camera and its data processing program.

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