

# A novel design of the high-precision magnetic locator with three-dimension measurement capability applying dynamically sensing mechanism

Wen-Nan Huang<sup>a,b</sup>, Po-Shen Chen<sup>b,\*</sup>, Mu-Ping Chen<sup>b</sup>, Ching-Cheng Teng<sup>a</sup>

<sup>a</sup>Department of Electrical and Control Engineering, National Chiao-Tung University, Hsin-Chu 300, Taiwan

<sup>b</sup>Electrotechnology Division, ERL, Industrial Technology Research Institute, Hsin-Chu 310, Taiwan

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## Abstract

A novel design of the magnetic locator, for obtaining the high-precision measurement information of variety of the buried metal pipes, is presented in this paper. The concept of dynamically sensing mechanism, including the vibrating and moving devices, proposed herein is a simple and effective way to improve the precision of three-dimension location sensing for the underground utilities. Based on the primary magnetism of Lenz's law and Faraday's law, the functions of the amplifying effect for the sensing magnetic signals, as well as the distinguishing effect by the simple filtering algorithms embedded in processing programs, are achieved while the relatively strong noise exists. The verification results of these integration designs demonstrate the effectiveness both by precise locating for the buried utility, and accurate measurement for the depth.

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**Keywords:** Magnetic locator; Buried metal pipes; Dynamically sensing mechanism

## 1. Introduction

At the present technology, the completion information of the position databases and accuracy of maps that dealing with detailing locations of buried pipes, tubes, and wires, are critical for protecting investments and lives, introduced in Refs. [1–4]. The magnetic locator is an effective scheme of device to measure the position information of buried metal pipes by magnetic induction approaches, and the related techniques of measurement are generally owning advantages of less time-consuming, more cost-effective, and safer operation, respectively, than excavation in hazardous environments.

Several research achievements of the magnetic locator have been presented based on the special materials' utilization and schemes, respectively, described in Refs. [1,5–7], respectively. As description of Ref. [5], rubidium atoms can construct a measurement device with the sensitivity of the magnetic field of 50 pico-tesla. Appara-

tuses and computation algorithms for measuring and detecting a magnetic signature of a detectable object from a distance are patented or described in Refs. [1,8], respectively.

However, various techniques show that each has its own advantages and shortcomings. Gas, telecommunications, electricity, and water managers are devoted to look for the approaches to obtain a high-precision map-capturing device that can provide full-spectrum service to solve the problems of the buried utilities. Hence, a novel design of the magnetic locator, applying the simple and effective way to improve the precision of three-dimension location sensing for the underground utilities by dynamically sensing devices, is presented herein.

## 2. Applied primary concept of magnetism

Magnetism and the related theories are crucial for constructing the magnetic locator. The functionalities and schemes of the magnetic locators are highly affected by the deployed magnetic operation concept. In this paper, both

\*Corresponding author. Tel.: +886 3 5914268; fax: +886 3 5820050.  
E-mail address: [ps\\_chen@itri.org.tw](mailto:ps_chen@itri.org.tw) (P.-S. Chen).

Faraday’s law and Lenz’s law are applied to form the main concept of the presented design.

The simple explanation and concept for Faraday’s law is that any change in the magnetic environment of a coil of wire will cause a voltage to be induced in that coil. For the other applying magnetism law, Lenz’s law, which clearly describes that the induced voltage is formed against the above change. Eq. (1) defines the relation based on the two laws.

$$v_g = -N \frac{\Delta\phi}{\Delta t}, \tag{1}$$

where  $v_g$  expresses the induced voltage.  $N$ ,  $\Delta t$ , and  $\Delta\phi$  denote the winding turn number of the coil of the induction core, the time division, and the change of the magnetic flux flowing through the induction area. Based on Eq. (1), the induced voltage is proportional to the rate of change of the flux with respect to time for a fixed number of turn.

### 3. Novel design concept

Fig. 1 illustrates the main structure of the novel magnetic locator that making use of dynamically sensing strategies.

This magnetic locator is composed of two magnetic sensing units, the vibration source made of piezoelectric material and its driving circuit, the related read-out components of sample/hold(S/H) devices, the data storage memory and program related to the pre-modeled characteristics of the vibration source, the proximity switches for recording judgment, and the battery sets. By definition of the Cartesian coordinates  $(x,y,z)$  shown in Fig. 1, the first magnetic sensing unit can be described further as that it includes one magnetic core with wound coil connecting to a rotation mechanism which can rotate with respect to  $y$ -axis for obtaining the signature of the buried objects. The other two cores, their counterpart coils, and rotation devices form the second magnetic sensing unit. The two

elements of the separately independent cores can indicate planner mapping direction in  $x$ -axis for deciding the precisely upward measurement position and the rotation axis is set to be  $z$ -axis.

The dynamically sensing mechanisms can provide the upgraded high-precision location information by accurate projection for the position of the pipe to the core 2 by perfect mapping upward to the ground while the maximum magnetic signal is sensed in coil 2 as the induced signal in coil 1 is zero. Meanwhile, the core 1 is rotated to the position with space orthogonal relation to core 2. Core 3 can shift position along  $x$ -axis to acquire the comparative signal for measurement distinguishing.

#### 3.1. Effects of motion and vibration

The conventional static point-to-point measurement cannot make the accuracy requirements be achieved while the relatively strong noise exists or under the conditions such as the pipe with a change of depth for near a tee or a blend, and so forth. The method for amplifying the induced signals is the effective way to improve the precision. By variable sensing orientations of the utilized devices and collection of different responses, the precise measurement of location can be achieved.

The vibration effect generated by the dynamical mechanism is focused on the change of the voltage produced by moving the core elements into or out of the original magnetic field, and the computation technique can be arranged as Eq. (2) in the form of

$$\Delta v = -N \frac{\Delta\phi}{\Delta t} \propto -\frac{d^2 \cdot ((d - \Delta r)^2 F_{lx}(t_2) - (d + \Delta r)^2 F_{lx}(t_1))}{(d + \Delta r)^2 \cdot (d - \Delta r)^2 \cdot (t_2 - t_1)}, \tag{2}$$

where  $\Delta v$  means variation of the induced voltage.  $d$ ,  $\Delta r$ ,  $F_{lx}$ ,  $t_1$ , and  $t_2$  mean depth of the object, the vibration distance,

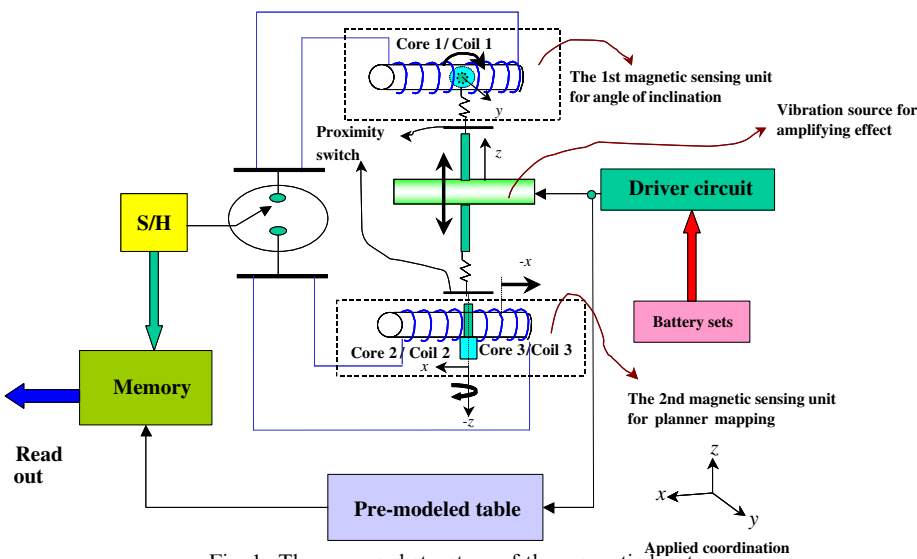


Fig. 1. The proposed structure of the magnetic locator.

the function of magnetic flux value at the medium vibration position, the time at the first measurement point, and the time at the second measurement point, respectively. The lower measurement point is sensed at time  $t_1$ .

The vibration frequency is chosen for distinguishing under considerations of materials of the detected objects, the range of distance, and the level of background noise signals, respectively. Eq. (3) depicts the sensing signal amplifying factor for obtaining the enlarged change rate of the magnetic flux based on Faraday’s law and Lenz’s law while the measurement is set to be operated in the two vibration end-points actuated by the proximity switches.

$$A_{mp} = \frac{1}{\Delta t} = \frac{1}{t_2 - t_1} = 2 \cdot f, \tag{3}$$

where  $A_{mp}$  means signal amplifying factor.  $f$  denotes the vibration frequency.

### 3.2. Simple filtering algorithms

Two simple data transformation algorithms, expressed in Eqs. (4), (5), respectively, with distinguishing capability by data compressing as well as by enhancement, are applied in the processing program of this magnetic locator

to deal with the signal coupling problem which needs less consuming time.

$$[A_F] = \ln[A], \tag{4}$$

$$[B_F] = e^{[B]}, \tag{5}$$

where  $[A]$  and  $[B]$  mean the original sensing signals recorded in matrix form.  $[A_F]$  and  $[B_F]$  express the transferred signals after being processed by the filter techniques.

### 4. Experimental setup and demonstration

Verification for the proposed design is performed using software of Ansoft Maxwell EM under settings of regular electricity pipe used by Taiwan Electricity Co., with interior power line of signal frequency of 60 Hz and RMS current value of 250A, respectively.

Two verification results are shown in Figs. 2 and 3, respectively. As shown in Fig. 2 with conditions of  $M_1 = 30$  cm,  $M_2 = 2$  cm, and  $d = 30$  cm, respectively, signal of coil 1 can be sensed in an observable value (RMS 703.2 mA) which means that at least one other pipe exists near the measurement position. As shown in Fig. 3

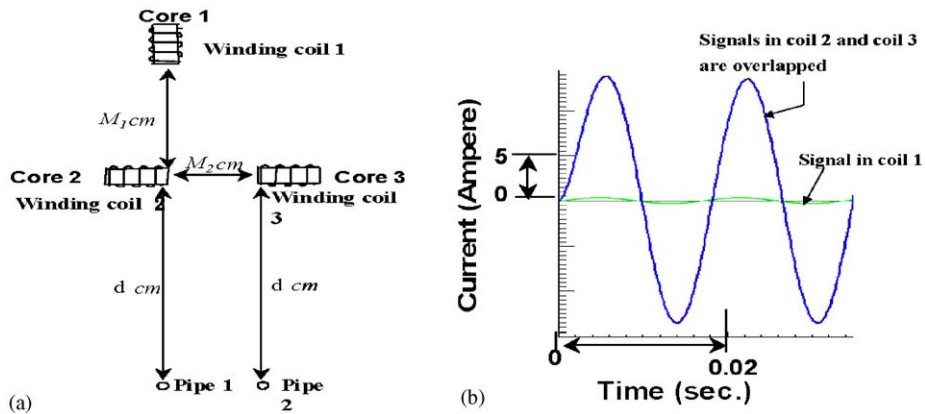


Fig. 2. Verification result for upward measurement position: (a) transient scheme; and (b) induced signals.

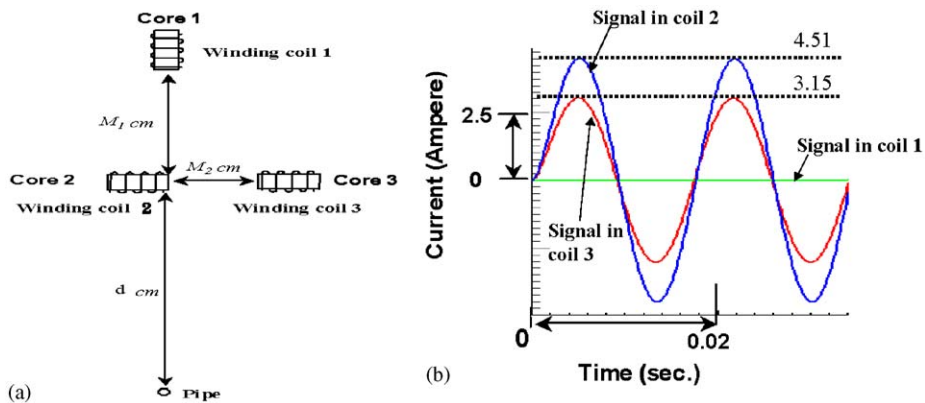


Fig. 3. Verification result for the depth measurement: (a) transient scheme; and (b) induced signals.

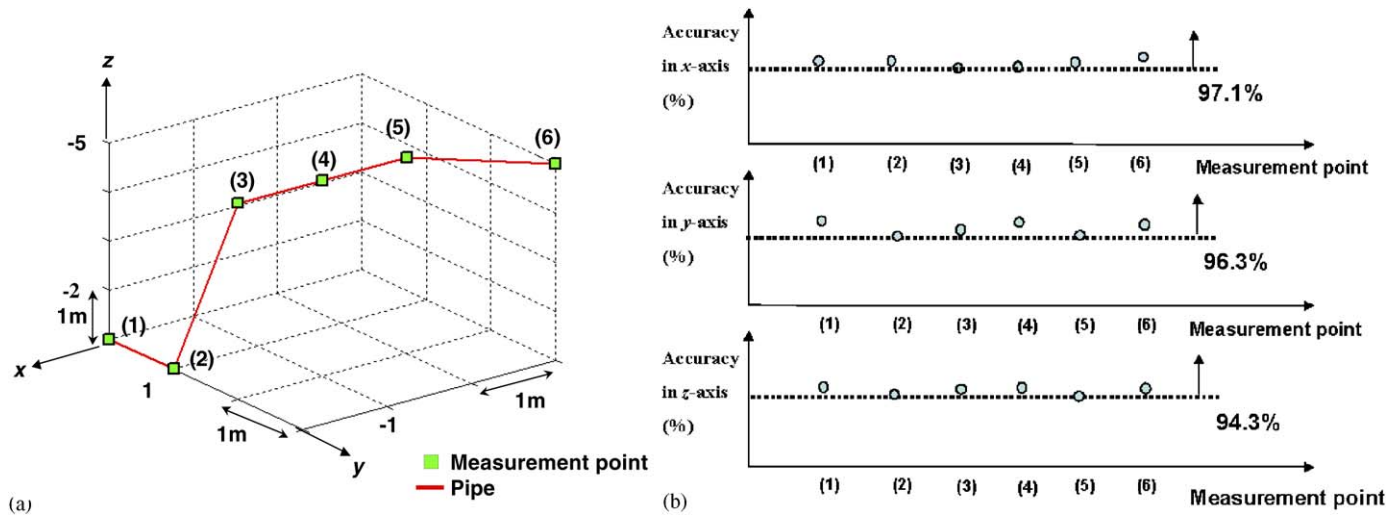


Fig. 4. Verification result under condition of depth change: (a) testing setup; and (b) measurement accuracy.

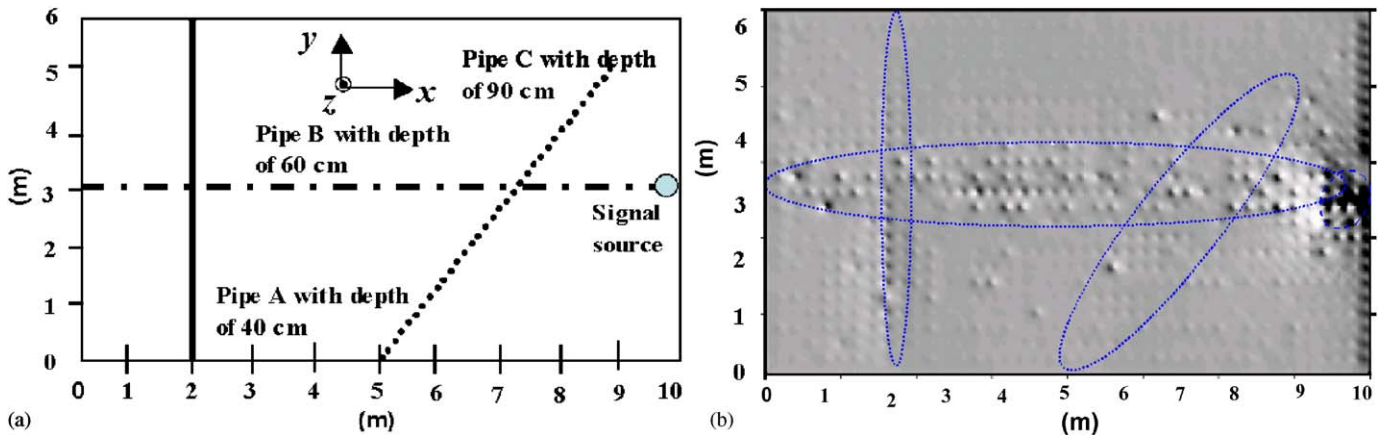


Fig. 5. Experimental arrangement and measurement results: (a) allocation of target pipes; and (b) induced signal level contour.

with  $M_1 = 30$  cm,  $M_2 = 25$  cm, and  $d = 50$  cm, respectively, the peak sensed signals of coil 3 to coil 2 closes to 0.7. In this case, the distance between cores 2 and 3 equals half of the depth of the pipe, and this relation can be applied to be a criterion to determine the depth of the pipe.

Fig. 4 shows the verification result for the depth change. It is clear from Fig. 4(b) that the accuracy of location detected by the proposed novel magnetic locator can be higher than 97.1%, 96.3%, and 94.3%, respectively, with respect to the coordinate axes.

The on-spot experimental setup with outdoor test arrangement uses I-type cores with material of 3C90 for construction of the prototype magnetic locator system. A dynamically sensing mechanism is composed by a piezo-electric machine with maximum vibration frequency of 30 kHz, two rotation motors, and a gear set with spiral axis. Three buried pipes of diameter of 1.6 cm composed by metal of compound of Fe–Al with thickness of 2 mm are allocated in different depths. An extra signal source is also

set to provide the noise source with frequency of 65 kHz of DC current value of 8 mA. The measurement operation is chosen to sense and record per 25 cm in  $x$ – $y$  swing plane by recording angle of  $0^\circ$ ,  $45^\circ$ , and  $90^\circ$ , respectively. Software of Surfer is selected to perform the measurement results by signal contour. Fig. 5 shows the experimental results based on the detection of the magnetic locator with regular subsurface soil. It is obvious that the sensing information provided by the proposed scheme of the magnetic locator with the simple algorithms owns distinguishing capability and can be applied in three-dimension measurement.

## 5. Conclusions

The integration concepts of the dynamically sensing mechanisms and the specific allocations of wound cores have apparently provided the effective solution which allows users to precisely locate a buried utility, and measure its depth accurately. The proposed approaches,

including mechanisms of movement and vibration as well as the effects by the filtering algorithms, can obviously improve the precision of measurement and own the advantage of ease of implement.

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