International Journal of Applied Electromagnetics and Mechanics 15 (2001/2002) 349–352
IOS Press

Magnetic sensor signal analysis

Yukiyasu Shigeta*, Seiji Hayano and Yoshifuru Saito
College of Engineering, Hosei University, 3-7-2 Kajino, Koganei, Tokyo 184-8584, Japan

Abstract. In the present paper, we propose a method of analysis for the magnetic sensor signals. Based on the physical characteristic value such as a time constant of the electric circuits, our methodology tries to work out an equivalent characteristic value reflecting the physical property of the target metallic material [1–3]. Our smart magnetic sensor developing is to recognize a datum from the signal database. This is applied to the space domain signal cognition. As a result, this paper reports that the equivalent characteristic value is an extremely useful quantity in order to examine the physical nature of the target.

1. Introduction

To prevent the accidents caused by the defects of metallic materials, non-destructive testing has an important role. So, we are exploiting a magnetic sensor. This paper proposes a method of the magnetic sensor signal analysis. Our method is how to extract the intrinsic physical characteristics included in the sensor output signals. Since it is difficult to extract any of the physical characteristics from the magnetic sensor signal, we extract the single characteristic value representing an entire physical characteristic of the target from the magnetic sensor signal. This characteristic value is called the Equivalent Characteristic Value (ECV in short) by this paper to cope with it to the characteristic value of physical system. Let us consider that a given signal is a solution of an initial value problem, and then the characteristic value of system dominates the property of output signal. And we derive a three-dimensional complex locus comprising the real and imaginary parts of the ECV. As a result, it is revealed that each of the targets can be recognized by means of the three-dimensional complex locus along with least squares.

2. Magnetic sensor signal analysis

2.1. Prototype of the magnetic sensor

To verify the operating principle of our sensor, we have worked out an initial test sensor shown in Fig. 1. When AC current flows through an exciting coil in Fig. 1, AC magnetic field is formed. A search coil located above the exciting coil can detect this AC magnetic field. 33 th induced voltages at equi-spaced position have been measured with the search coil in the interval 0.5 cm. Table 1 lists various constants of the exciting and search coils.

*Corresponding author: Yukiyasu Shigeta, College of Engineering, Hosei University, Japan. Tel.: +81 42 387 6200; Fax: +81 42 387 6200; E-mail: shigeta@ysaitoh.k.hosei.ac.jp.

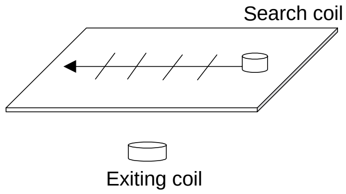

Fig. 1. Schematic diagram of a signal measurement in a space domain.

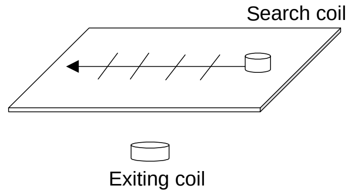

Fig. 2. Transient current of a R-L series circuit.

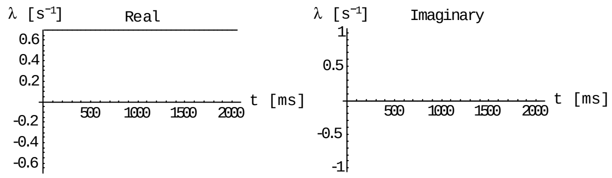

Fig. 3. Equivalent characteristic values evaluated by applying Eq. (2) to the current in Fig. 2.

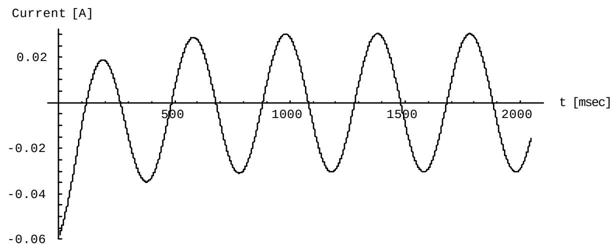

Fig. 4. Transient current of a R-L series circuit when impressing AC voltage.

2.2. ECV (*Equivalent Characteristic Value*)

2.2.1. ECV of an electric circuit

When DC voltage is impressed to an R-L series electric circuit with zero initial current, Fig. 2 shows a typical response current.

Let us sample the current in Fig. 2 with period , then current in the time can be approximately expressed by Eq. (1).

$$i_{n\Delta t} = i_{(n+1)\Delta t} + \left[i_{(n-1)\Delta t} - i_{(n+1)\Delta t}\right] \varepsilon^{-\lambda\Delta t}. \tag{1}$$

ECV of the R-L series circuit is given by Eq. (2).

$$\lambda = -\frac{1}{\Delta t}\ln\left[\frac{i_{n\Delta t} - i_{(n+1)\Delta t}}{i_{(n-1)\Delta t} - i_{(n+1)\Delta t}}\right]. \tag{2}$$

Apply Eq. (2) to the current in Fig. 2 gives the ECV shown in Fig. 3. Obviously, real part of ECV corresponds to the characteristic value of the R-L series electric circuit.

2.2.2. Averaged sum ECV

ECV is computed precisely from the response current to the DC voltage input. But, local noise occurs as shown in the Fig. 5 whose input signal is a response current to a sunusoidally time varying voltage shown in Fig. 4.

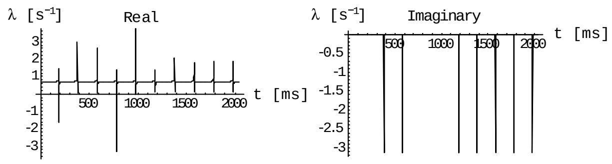

Fig. 5. ECV values evaluated from the AC response current in Fig. 4, Left: real and Right: imaginary parts.

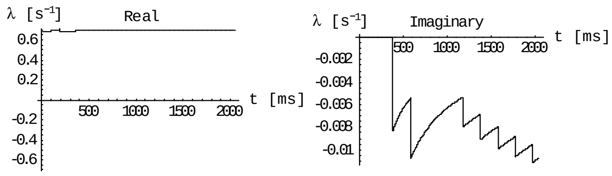

Fig. 6. Averaged sum ECV values evaluated from the AC response current in Fig. 5, left: real and Right:imaginary parts.

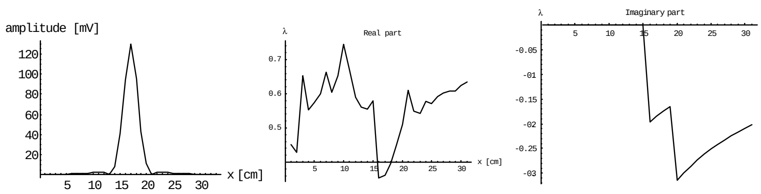

Fig. 7. Space domain signal(left), the real (center) and imaginary (right) parts of ECV.

To reduce the spiky noise in Fig. 5, an additional averaged sum deals with ECV as shown in the Fig. 6. As understood from Fig. 6, ECV of the real part is settled in ECV of the value in Fig. 4. The other side, an imaginary part settles it in ECV, which copes with it to the angular frequency of input voltage.

Figure 7 shows one of the measured space domain magnetic sensor output signals, and averaged sum ECV of this signal.

2.3. Cognition of the magnetic sensor signals

Our purpose is to distinguish every target by a sensor signal analysis. To achieve this, it is essential to build up an enormous database. In the present paper, we try to recognize a datum from the entire signal database.

2.3.1. EigenPattern

We propose the eigen pattern, which is a three-dimensional complex locus constructed by the real and imaginary parts of ECV, to represent the essential characteristics of the distinct target.

Eigen pattern makes an modified Lissajous diagram in the real and imaginary parts of ECV. This modified Lissajous diagram is different from conventional Lissajous diagram and does addition in the same position is taken in like a histogram. Therefore, it is called an eigen pattern. Figure 8 shows an example of eigen pattern.

2.3.2. System of equations

Each of the eigen patterns shown in Fig. 8 consists of the 32×32 elements. Those are rearranged into one-dimensional eigen pattern vectors. By using number of n^{th} eigen pattern vectors $\mathbf{c}_i, i = 1, 2, \ldots, n$,

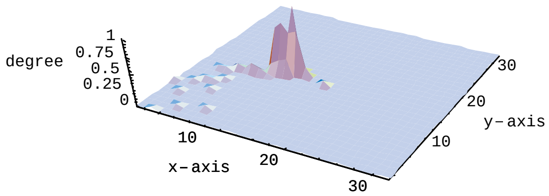

Fig. 8. Eigen pattern.

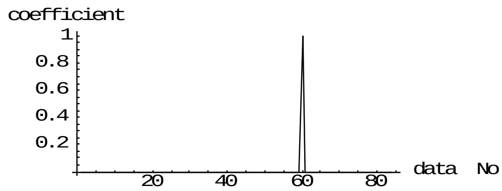

Fig. 9. Elements of a solution vector X,where the No. 60 target signal was recognized.

it is possible to obtain a system matrix C with n^{th} rows and $32 \times 32^{\mathrm{th}}$ columns as

$$C = [\mathbf{c}_1, \mathbf{c}_2, \ldots \mathbf{c}_n]. \tag{3}$$

Denoting an input vector $\mathbf{Y}$ obtained in a similar way to $\mathbf{c}_i, i = 1, 2, \ldots, n,$, we have a linear system of equations:

$$\mathbf{Y} = C\mathbf{X}, \tag{4}$$

where the biggest value in the elements of the solution vector $\mathbf{X}$ reveals a recognized signal.

2.3.3. Least square solution

If a number of the elements in vector $\mathbf{X}$ is smaller than those of equation, i.e., $n < 64 \times 64$, then a least squares solution, which minimizes a error norm

$$\varepsilon = ||\mathbf{Y} - C\mathbf{X}|| \tag{5}$$

to Eq. (4) is formally given by

$$\mathbf{X} = (C^T C)^{-1} C^T \mathbf{Y}. \tag{6}$$

To build up the database, we have measured the $n = 84^{\mathrm{th}}$ sensor signals changing the materials and position of target, after that we have evaluated their eigen patterns.When we set the original signals as an input vectors, all of the signals were completely recognized. Figure 9 shows an example of solution vector.

3. Conclusions

In this paper, we have proposed a simple magnetic sensor detecting the metallic materials embedded into the ground and concrete walls. To recognize the distinct target, the equivalent characteristic values as well as eigen pattern have been proposed. Least squares solution along with the eigen patterns has exactly recognized a datum from the signal database.

Thus, we have succeeded in establishing one of the deterministic methodologies for magnetic sensor signal analysis.

References

[1] Y. Shigeta, S. Hayano and Y. Saito, *A method of signal processing by wavelets transform*, VSJ, 2000.
[2] Y. Shigeta, S. Hayano and Y. Saito, *Magnetic sensor signal analysis – Concept and an example*, Mag-00-116, 2000.
[3] Y. Shigeta, S. Hayano and Y. Saito, *A Study of magnetic sensor signal analysis*, Mag-00-273, 2000.