

A FEEDTHROUGH EDDY-CURRENT TRANSDUCER WITH ROTATING MAGNETIC FIELD

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INTRODUCTION

Encircling eddy-current transducers with rotating magnetic field have many applications with regard to the testing of cylindrical products. Indeed, contrarily to standard encircling differential transducers, they are sensitive to any kind of flaws, including long ones, and can determine their angular positions. In addition, the rotation speed of the magnetic field can easily reach values much larger than those possible with rotating probes devices. As a consequence, they make possible the inspection of the whole surface of products moving at very high speed (up to 80 meters per second for hot wire being rolled). Finally, the mechanical simplicity of these transducers enables the insertion of cooling circuits and, therefore, the testing of hot products.

In the past, eddy-current transducers with rotating transverse magnetic field were designed and patented in the USSR [1]. One of these transducers is being used in a Romanian plant to control wire quality [2].

This paper describes our first studies to design a new kind of rotating field eddy-current transducer. The main feature of our transducer lies in the direction of the magnetic field that we have chosen axial. Indeed, the eddy-current induced by an axial field being perpendicular to long flaws, this transducer should be particularly sensitive to this kind of flaws.

DESCRIPTION OF THE TRANSDUCER

Figures 1 and 2 show respectively schematic views of the transducer and of the excitation currents waveforms. The transducer is fully static and encircles the cylindrical produce [1]. It consists of 3 excitation windings [3,4], [5,6], [7,8] and of a measuring coil [2]. Each excitation winding is made of 2 eccentric elliptical coils located inside the same plane [9], symmetrical with regard to the axis of the product [1], and fed by the same current in opposite directions. The 3 excitation windings are identical, arranged at $2\pi/3$ rd intervals, and fed by the 3 following modulated currents:

$$I_1(t) = I_0 \cos(\Omega t) \cos(\omega t)$$

$$I_2(t) = I_0 \cos(\Omega t + 2\pi/3) \cos(\omega t)$$

$$I_3(t) = I_0 \cos(\Omega t + 4\pi/3) \cos(\omega t) \quad \Omega \ll \omega$$

We can notice that, because of the flat geometry of the excitation windings, the magnetic field is axial only inside the plane [9]. Outside this plane, the field lines diverge very fast. That is why the flux coil [2] should be theoretically located inside the plane [9] and, in practice, was chosen very short. Because of the symmetries, the flux measured by the coil [2] is equal to zero when the product is both perfect and located in the center of the transducer. Eccentricities, ovalizations and flaws disrupt the symmetry of eddy currents and, therefore, induce a non-zero flux inside the measuring coil.

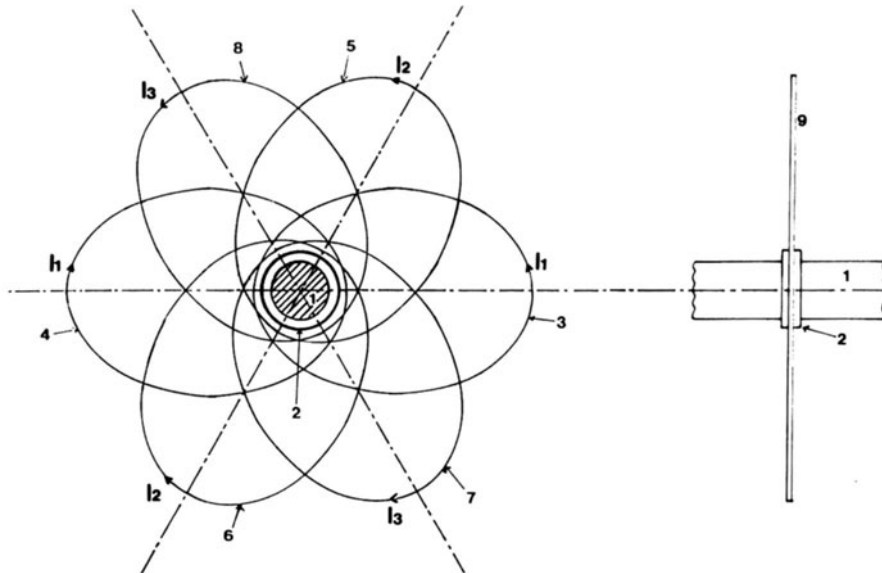


Figure 1 Front and side views of the axial rotating field transducer.

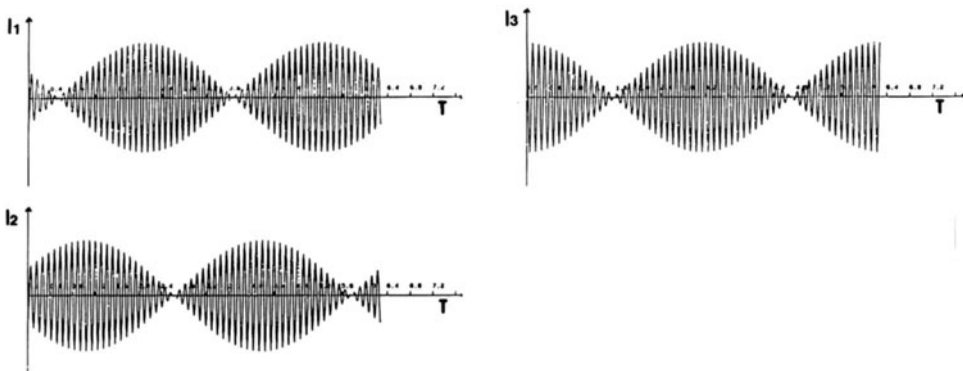


Figure 2 Excitation currents waveforms.

PRINCIPLE OF THE ROTATING FIELD GENERATION

Let C denote the circle intersection of the plane [9] and of the surface of the product [1]. Each excitation winding is designed in order to generate on the circle C an axial magnetic field varying as a cosine versus the angular position x . As a consequence, the fields, H_1, H_2, H_3 are generated on C by respectively [3,4], [5,6], [7,8] fed by the currents I_1, I_2, I_3 , are

$$H_1(x, t) = H_0 \cos(\omega t) \cos(\Omega t) \cos(x)$$

$$H_2(x, t) = H_0 \cos(\omega t) \cos(\Omega t + 2\pi/3) \cos(x + 2\pi/3)$$

$$H_3(x, t) = H_0 \cos(\omega t) \cos(\Omega t + 4\pi/3) \cos(x + 4\pi/3)$$

Therefore, the resulting field H can be written as

$$H(x, t) = H_1 + H_2 + H_3 = 3H_0/2 \cos(\omega t) \cos(x - \Omega t)$$

where $\Omega \ll \omega$.

This is the equation of an AC field of pulsation ω rotating on the circle C at a pulsation Ω . The adjustment of Ω depends on the translation speed of the product, whereas the one of ω is linked to a standard eddy-current considerations (skin depth, optimization of signal to noise ratio). In addition, we can notice that feeding the excitation windings with a standard three-phase current makes both pulsations ω and Ω become equal.

Finally, we could choose values different from 3 for the number of excitation windings. For instance, 2 excitation windings arranged at $\pi/2$ rd intervals and fed by 2 modulated currents, the modulation of which are phase shifted of $\pi/2$, also induce a rotating field. The more excitation windings we use, the more regular the rotating field is, but the more complex the transducer becomes. This explains our compromise.

DESIGN OF THE EXCITATION WINDINGS

We restricted our first study to products of diameter 35 mm. Therefore, the excitation windings had to be flat and to generate on the circle C of diameter 35 mm a magnetic field the amplitude of which varies as a cosine versus the angular position x .

The figure 3 presents the first geometry we studied. This excitation winding consists of 2 eccentric coils symmetrical with regard to the axis of the product and fed by the same current in opposite directions. Because of the symmetries, we deduce:

$$H(\pi/2) = H(3\pi/2) = 0$$

$$H(0) = -H(\pi) = H_0$$

We recognize here 4 points of a cosine, which explains our choice.

Then, we programmed the Biot and Savart formula and used it to compute the function H (x) corresponding to this geometry. The result shown in Figure 3 is much different from a cosine. In fact, the absolute value of the field decreases too fast round the points $x = 0$ and $x = \pi$. It means that round these 2 points, the active parts of the winding, i.e., the

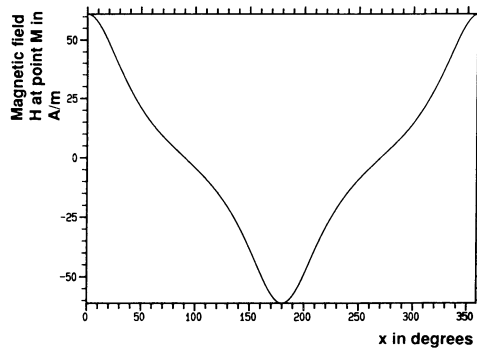
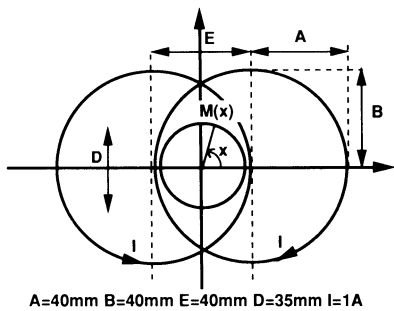


Figure 3 Circular excitation windings and corresponding function $H(x)$.

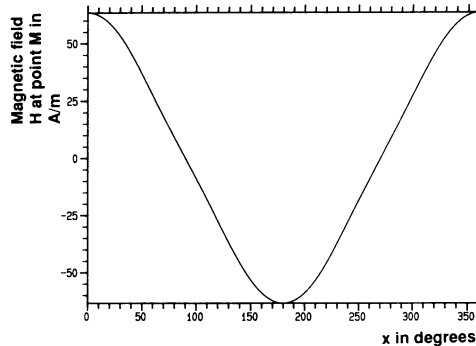
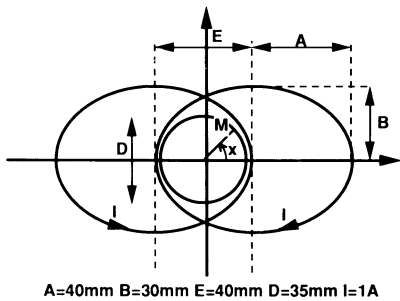


Figure 4 Elliptical excitation windings and corresponding function $H(x)$.

closest, do not follow closely the shape of the product. This is why, then, we replaced circular by elliptical windings and finally got the good result shown in Figure 4. Yet, the efficiency of this winding could be still improved. Indeed, the active part of the winding is restricted to both branches closest to the product, the purpose of the remaining part being only to close the circuit.

EXPERIMENTATIONS

The excitation windings were realized on a multilayer circuit, presented in Figure 5. This circuit including 6 layers, 2 for each excitation winding, has a total thickness of only 1.4 mm. As a consequence, we can consider that the 6 elliptical windings lie in the same plane. In addition, high intensity currents, up to 1 A, can be driven in such a circuit. The 3 excitation windings are powered by a purpose-built generator which is connected to a standard eddyscope (see Figure 6). The receiving flux signal is processed as an absolute signal by the eddyscope.

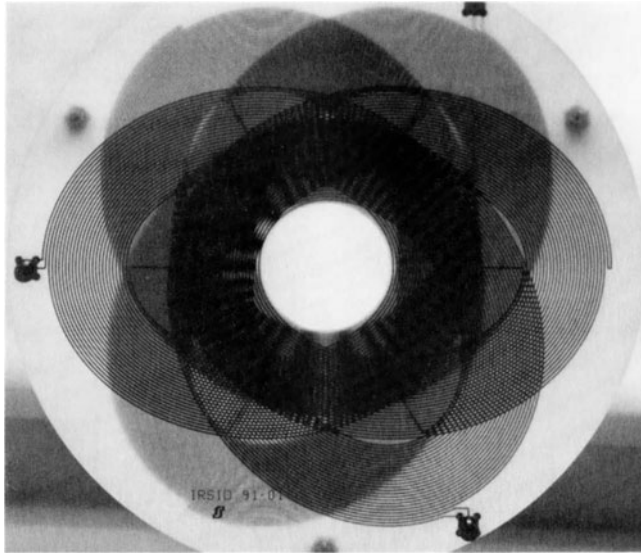


Figure 5 Photograph of the excitation multilayer circuit.

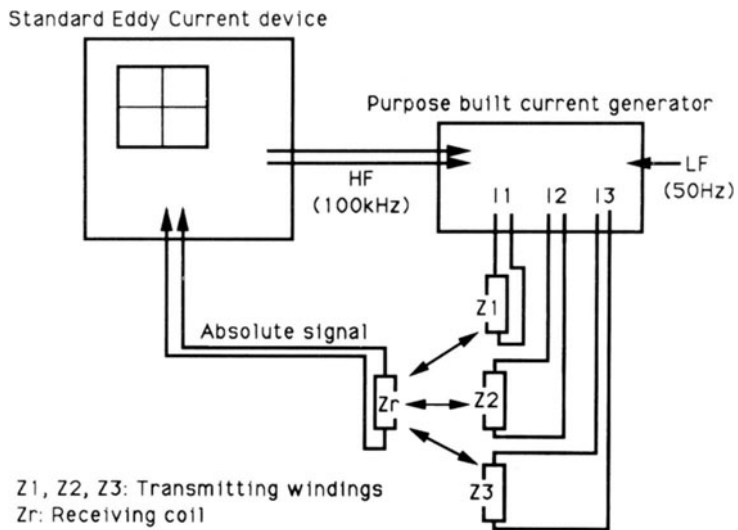


Figure 6 Schematic diagram of the experimental apparatus.

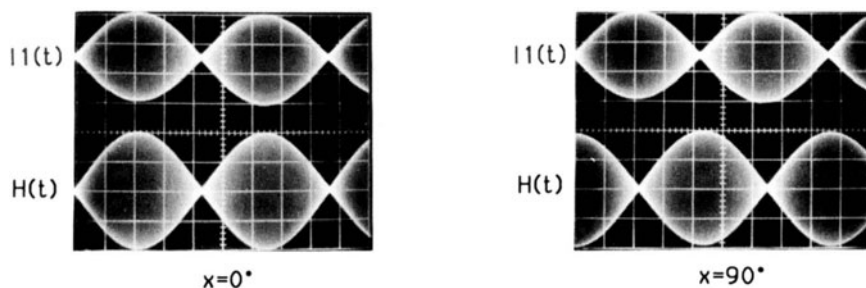


Figure 7 Measured field versus time at 2 different angular positions on the circle C.

In a first step, we used a small flux coil to measure the excitation field in the air, i.e. without the product. The field was displayed versus time at different angular positions on the circle C (see Figure 7). We first checked that the amplitude of the field modulation is independent of the angular position. Second, we verified that the phase shift between the I_1 modulation and the field modulation at any given point on the circle C, is equal to the angular difference between this point and the large axis of the excitation winding fed by I_1 . Therefore, the possibility of generating an axial rotating field in the air was experimentally demonstrated.

In a second step, we translated through the transducer a stainless steel bar of diameter 35 mm including machined flaws (depth varying between 0.1 and 0.5 mm), in order to analyze flaw signals. Unfortunately, this transducer being very sensitive to the eccentricities of the product, and our mechanical guiding device being not accurate enough, the flaw signals remained hidden by the important noise. Nevertheless, further experiments will be soon undertaken with a better mechanical guiding.

CONCLUSIONS

A new kind of rotating field transducer was designed. Experimentations demonstrated the possibility of generating an axial field rotating at the surface of the cylindrical product. Nevertheless, further work needs to be done, especially about the improvement of the excitation windings (new shapes more efficient, arrangements looking like Helmholtz coils to prevent the field lines from diverging too fast) and of the signal-to-noise ratio (differential arrangements, filters).

REFERENCES

1. V. K. Zhukov and P. A. Ovsyannikov, Defektoscopia, 4, 1983, pp. 30-35.
2. R. Grimberg, I. Olteanu, T. Cristea, M. Goia, D. Gradinariu, R. Plavanescu, T. Bacanu, A. Andreescu and D. Apavaloaie, NDT International, Volume 23, Number 4, August 1990, pp. 201-206.