HOW BSS CAN BE USED ON EDDY CURRENT SENSOR BASED ON INDUCTION BALANCE PRINCIPLE

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Abstract

In this paper, we describe how the Blind Source Separation (BSS) techniques can be applied to an eddy current sensor based on the induction balance principle. The aim of this work is to restore a representative response of a metallic tag buried in the ground when the signal is completely perturbed by the external environment (metallic perturbation near the tag). To apply BSS methods we need to fulfil several conditions. We show here that most of them are respected theoretically and experimentally. For the others, we describe the modifications we had to bring to the sensor. These modifications allow to apply BSS methods to separate the tag signal from a perturbation one. The very good results obtained with the modified sensor are presented. They show the improvements and the reliability of the new designed system. The industrial project involved in this paper is the recognition, without drillings, of buried pipes by a smart eddy current sensor.

1. Introduction

Blind Source Separation is now intensively studied and applied in many domains [1] [2] [3] [4]. It provides an excellent response, under some conditions, to problems of multiple perturbations.

The application we have developed consists in creating an eddy current sensor able to identify buried metallic tags characteristic of different pipe contents.

The main problem we met is the great influence of the external environment during the signal acquisitions, especially when metallic objects are buried near the tags or when the tags are too close from each other.

As there is no signal processing methods able to completely remove these negative effects [5], we have chosen to apply BSS techniques in order to solve this particular problem.

In this paper, we test the possibility of BSS applications to our sensor according to the theoretical requirements they need. From this analysis, we study the feasibility of such a new system in an industrial context.

In the first part of this article, we check if the different conditions that require BSS are fulfilled and how they are. We also show how we have to modify the sensor working to obtain the wanted result.

After this work, we present the capacity and the performances of the developed device to solve very awkward real cases met in test sessions.

Finally, we conclude by the great improvements (robustness, reliability) that can bring the BSS technique implantation on the eddy current we have developed.

2. BSS Requirements

The BSS techniques [6] consist in separating several statistically independent signals named sources from several sensor signals.

According the nature of the physical phenomenon, which governs the operation of our eddy current sensor, one can be consider that the propagation velocity of information is done at the speed of electromagnetic waves. This leads within the meaning of the BSS that one will have to consider only instantaneous mixing.

Three conditions are required to apply the BSS techniques.

The first one is the number of sensors that must be superior or equal to that of the sources.

The second one is that it exists several statically independent sources.

Finally, it must exist a linear mixing matrix between the source and the sensor signals.

A limitation of this technique is the restoration of the sources through a permutation matrix and a multiplicative coefficient.

Before verifying the respect of these conditions, we will now shortly describe our eddy current sensor and present its sensibility response.

We show how to exploit the experimental system to answer to the BSS conditions.

2.1. Principle of the eddy current sensor

To obtain the best performance with a minimal cost, we have developed our sensor from the induction balance principle. In the original configuration we used [7], two flat coils carved on an epoxy support are working, an emitting one which generates an electromagnetic field and a receiving one which measures any modifications of this field due to the presence of a metallic target in its proximity. This receiving coil must be located in the shadow area of the emitting one.

The electromagnetic field modification is visible on the receiving coil, it creates an impedance variation and so a phase variation (figure 1).

To transform these changes into a signal characterising the metallic target, a digital synchronous filter is applied between the image of the signal generated and the received one.

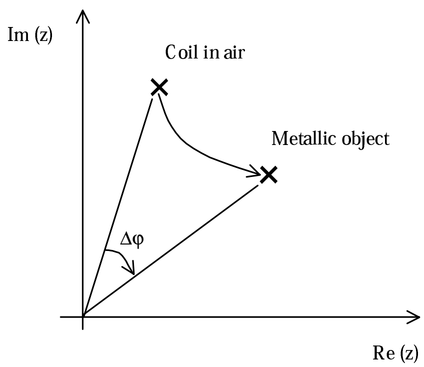

Figure 1: Impedance variation

The metallic targets in our case are different tags characteristic of the pipes to be identified.

The principle used to define the tags is very simple. Two very thin metallic parts separated by empty spaces constitute an elementary pattern. The size variations of these elements permit to obtain different tags.

The data acquisitions are obtained by moving the sensor above the buried tag. The sensor response permits to identify the tag and after that the pipe characteristics.

It can be seen that a metal disturbance (bolt, screw, can, ...) in the close vicinity of the tag can constitute a problem for the data acquisition and can alter the sensor response.

A complete study of the system we have developed can be found in [7].

After this brief description of the sensor, we present now its sensibility curve.

As we used our sensor to detect metallic buried objects, we have defined as reference an orthogonal axis system Oxyz (figure 2a).

The Ox axis corresponds to the moving direction. The Oy axis is perpendicular to Ox and parallel to the ground. Moreover, the Oz axis is perpendicular to the ground and represents the burial depth.

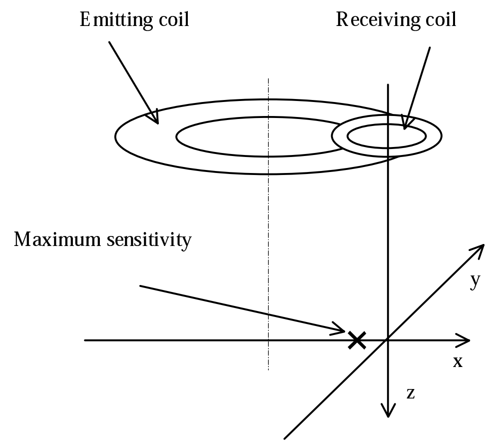

Figure 2a: Coil position and axis definition

To simplify, the metal object used as a reference is regarded as a point. This approximation is valid because of the values of various distances intervening in the calculations. This reference is a square metal sheet the side of which is equal to 10 cm.

Figure 2b shows the sensibility curve when we move the sensor above this reference metallic object in the plan xOy. The centre of the receiving coil is chosen as origin. We can notice that the maximum of this curve is located between the two coil centres and that it corresponds to the point (-4,0). The curves of constant sensibility are circles centred at this particular point. The different sample curves are identical for different depth conditions, only the signal amplitude decreases when the distance becomes deeper.

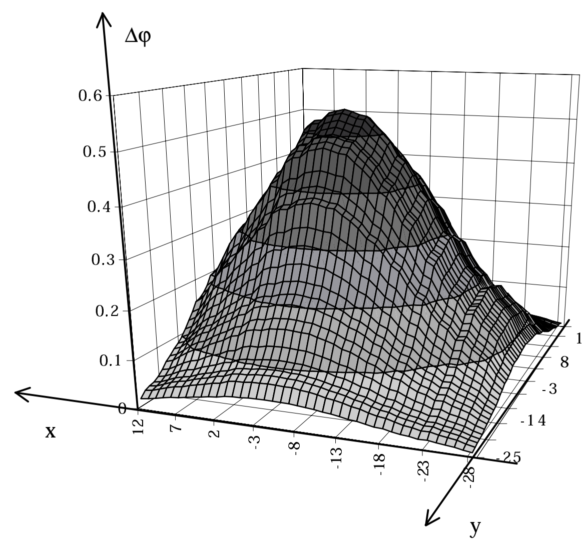

Figure 2b: Sensibility curve of the sensor

We have now a good knowledge of the sensor response to metallic object presence. Nevertheless, in this sensor definition we can only obtain a unique response representative to all the metallic elements placed near the detector even if they are not constituent of the tag to be identified.

So to be able to separate the different elements, we need to have multiple signals. That is why we have developed a unique sensor constituted with several receiving coils placed on the emitting one.

This will be one of the first steps allowing to consider the application of the BSS techniques.

2.2. Multiple sensors

The surface representative of the detector sensibility is dependent of the receiving coil position.

So several receiving coils placed at different location (figure 3a) on the emitting one will give identical sensibility curves simply shifted one compared to another.

From this point, we will consider the different receiving coils, as "sensors" and the complete sensor will be called detector to avoid confusion.

The object perception will be different and dependent from the respective sensor position as shown in figure 3b.

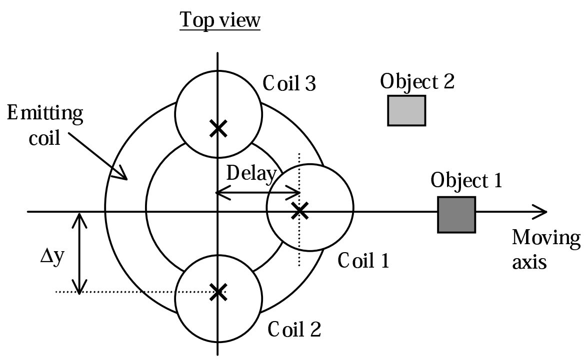

Figure 3a: Relative position of the receiving coils

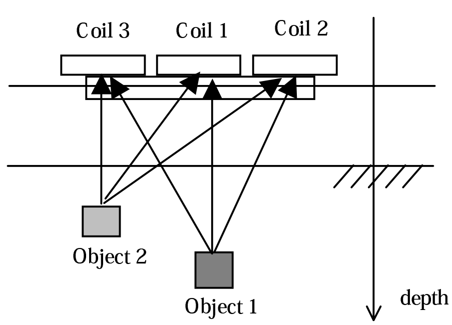

Figure 3b: Perception of different metallic objects

After these modifications on the detector have been done, we can use a device composed of three sensors. Therefore, it will be able to separate a maximum of three sources.

It is now necessary to define the different sources, which can be separated.

2.3. Source and independence notions

An important point in the BSS theory is that the different sources must be statically independent.

In our particular case, a source is constituted by the signal given by a sensor (one of the receiving coils) when the detector is moving along the Ox axis and above a metallic object located at a depth z_0 and a lateral distance y_0.

Another metallic object placed further (along the same axis) and which has the same values (z_0 and y_0) belongs to the same source. However, any other object that has different values (z_1 or y_1) defines another source.

By this way of definition, the sources are representative of concrete elements. If these elements have different locations, the relative sources will be compulsorily independent. This assures the notion of independence, which is need in BSS.

At this point of the study, we have checked the respect of the two first conditions that requires the application of BSS techniques; we will now verify the last one. This verification will be deduced from the sensibility curve presented on figure 2b.

2.4. Mixing matrix

The existence of the mixing matrix is due to the multiple sensors and to the presence of several objects.

Firstly, the gap Δy, shown on figure 3, between the sensibility curves explains that a source gives different sensor signals.

Secondly, the distance, according the axis Oy or Oz, between the positions of different objects involves the existence of several sources.

These two points explain the presence of the mixing matrix.

The last requirement we have to check is the linearity of this mixing matrix. To prove the linearity the mixing matrix must satisfy the homogeneity and additivity conditions.

2.4.1. Homogeneity

The homogeneity property can be verified on the figure 4 by using the successive responses of a receiving coil when moving above an object located at different values of y.

The different responses of a receiving coil are represented on the top of the figure 4 (above) for y values varying from 0 to ± 16 cm.

On the lower part of the figure 4 we present these same responses normalised by the maximum value of the curve at y = 0. We notice that they are quiet well superposed, which means that the system is homogenate.

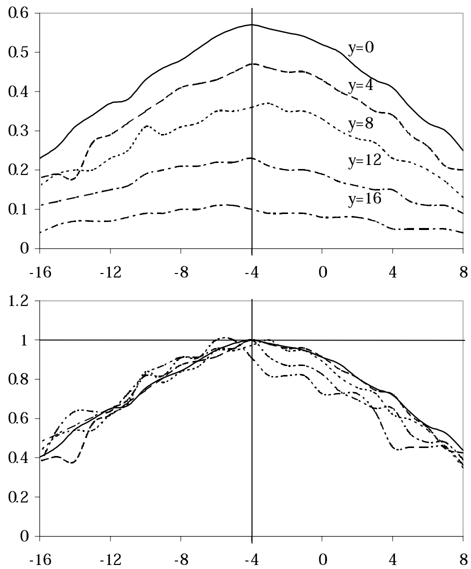

Figure 4: Homogeneity check

The dispersion measure comes mainly from the acquisitions done for important value of y (± 16 cm).

After checking the first part of the linearity with the homogeneity, we will now study the additivity.

2.4.2. Additivity

This notion is much more complex to verify. In the impedance plan, the phase additivity is represented by a moving of the working point according to a circle arc centred on the origin as shown on figure 5.

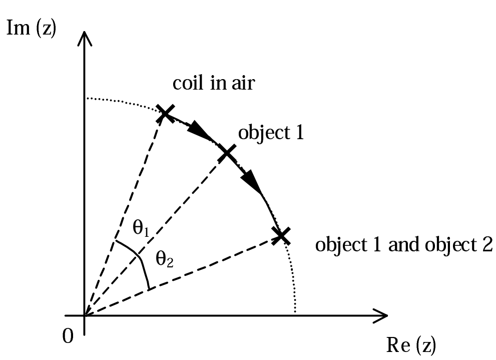

Figure 5: Phase additivity

In the literature [8], for most of the materials, the displacement in the impedance plan can be considered as a circle arc.

We have checked experimentally this concept for two identical objects placed in the xOy plan and for several different positions randomly taken in the space XYZ.

We have verified the notions of homogeneity and additivity, which proves that our experiment fulfils the linearity condition of the mixing matrix.

3. BSS Application

This previous study has permitted to verify that the requirements of BSS application are totally fulfilled, by the modifications brought to the detector, in the system set we have developed.

3.1. Experimental context

Practically the lateral receiving coils are shifted according the Ox axis. This is due to the necessity to locate them in the shadow area of the emitting coil.

This shift is compensated by software during the signal-processing step.

We use here classical algorithms of BSS like JADE [9] or SOBI [10].

All the realised experiments have been done in the laboratory with a primary prototype.

Let us see now the results obtained for two very difficult cases that could not be resolved with our old system built with only one receiving coil [11].

3.2. Results

The first experiment we are speaking about corresponds to the most general problem we met during real acquisition. It is the presence of unwanted metallic objects (defects) buried near the tag to be identified. These defects alter the sensor response significantly when their burying depth is inferior to the half of the sensor/tag distance. With these kinds of perturbations, it becomes very difficult to obtain a further good recognition of the buried tag. In the worst cases, a tag can be considered to be another one if the metal defect is particularly positioned. That situation could be very dangerous in our kind of project.

In the first example shown on figure 6, the defect (a metallic can) gives a sensor response that is identical to a part of the tags. Therefore, the obtained mixing is representative of another tag. Here it is impossible to detect the presence of a defect altering the signal, by conventional methods of data analysis.

After using the BSS algorithms, the estimated (restored) sources are the same that the real sources.

Moreover, the analysis of the mixing matrix can give some information on the exact positions of the tag and that of the defect(s).

We show here that we are able to restore the true shape of the tag to be identified and so to obtain its good recognition in the worst configuration of acquisition.

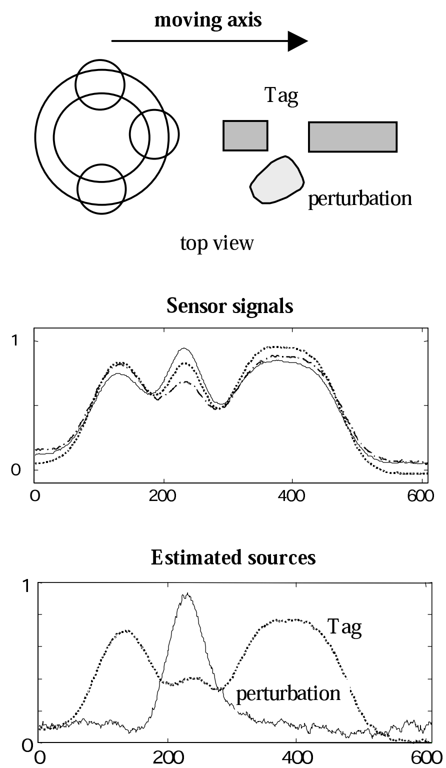

Figure 6: First example of separation

The second example corresponds to less frequent cases. When two pipes (tags) are buried very close from each other, the recognition by conventional processes is very difficult. Normally, the law imposes a distance of 20 cm between two pipes but in certain cases, it cannot be respected especially in town. It is nevertheless very important to be able to identify the exact pipe natures.

Figure 7 represents two different tags separated of only 10 cm for a burying depth of 60 cm. As like in the first example, it is impossible to detect a perturbation altering the signal. In this very particular case, we succeed in perfectly restoring the two tags and obtain their good recognition.

We have presented here these two characteristic examples to show the impressive results that could be obtained while applying BSS techniques. The improvements that they bring are not limited to these cases. We have tested many different configurations to evaluate the reliability of the new detector.

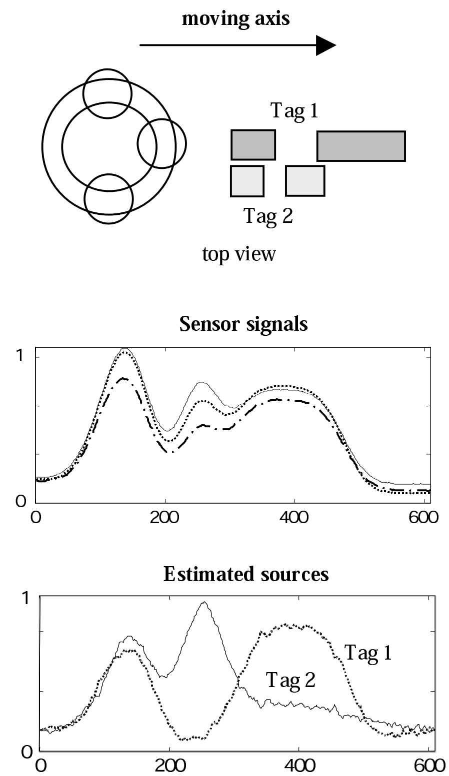

Figure 7: Second example of separation

3.3. Discussion

Two points have to be treated.

Firstly, it is not always necessary to use BSS techniques if there is no perturbation. It is possible to obtain information on the presence of perturbations, because if only the tag is present, the three receiving coils provide identical information to a multiplicative coefficient.

By operating a standardisation in amplitude and a subtraction of the signals resulting from two sensors, we obtain a signal representative of the sensor noise. If a perturbation is present, the signal resulting from the subtraction will be representative of the presence of the perturbation.

Secondly, the reasoning held in this article is based on point elements, particularly when they are in-depth and laterally shifted. If this assumption is not valid any more, in the case of a particularly significant metal element, various areas of the object will influence differently the sensors and we will have an artificial creation of sources. Their numbers will be equal to the number of present sensors. This problem can be partly solved by exploiting the matrix of mixture in order to determine the location of the various sources.

4. Conclusions

We have shown in this paper the possibility of BSS application on eddy current sensor based on induction balance principle.

We have presented the essential modifications of the sensor. With this new detector, we have been able to apply BSS algorithms to restore efficiently the estimated sources.

Whatever the kind of perturbations that alters the signal, the BSS techniques lead to a good recognition of the buried tag.

Therefore, this brings a great improvement to our system that becomes extremely reliable in any environmental conditions. The risk of misclassification is reduced near to zero.

This first study of the use of BSS on eddy current detector proves that impressive results can be obtained. Nevertheless, it still exists some limitations and problems linked to the use of BSS, especially in the case of very large defects.

After bringing some minor improvements, we hope to product soon this new kind of detection system.

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