On Line Analysis and Interpretation of Ultrasonic Images to Improve the Selectivity of the Control Installations for Steel Pipes

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Abstract

The ultrasound non destructive testing methods are based on the comparison of the amplitude of the signal of response compared to the amplitude of calibration standard flaws. They therefore presuppose a high correlation between the depth of a detected flaw and the amplitude of the signal, which is generally false. The idea described in this paper consists in the use of the capacities of acquisition in production lines of the ultrasonic raw data and the reconstruction of "ultrasonic images" of pipes. Thereafter, a system automatically analyzes these images using image-processing techniques and expert systems. The system described can then evaluate on line the gravity of the acquired ultrasonic indications much more reliably than with a single threshold.

Keywords: Ultrasound, Imagery, Flaw detection, Tubes

1. Introduction

Non-destructive tests play an important role in many industrial sectors. Their purpose is to detect flaws inside a given part without damaging it. Examples of non-destructive examinations used are ultrasonics, Eddy Currents, radiography, magnetic particle inspection and thermography. The choice of technique depends mainly on the application and required degree of precision. At present, the high technicality of manufacturing processes and new requirements of customers and standards dictate that these non-destructive tests constantly need to develop.

Our work focuses mainly on ultrasonic non-destructive testing and is applicable to a wide range of industrial sectors, essentially in the field of metallurgy, owing to the simplicity of the principle, its implementation and its relatively low cost. A great many techniques are involved in perfecting the test, particularly with regard to signal and image processing methods which have improved considerably in recent years. The present study concerns the use of image processing technologies and expert systems in order to locate and estimate the type and depth of the flaws. This paper proposes a new concept for the ultrasonic testing of steel pipes and is the subject of a patent published in January 2007.

At present, non-destructive techniques are based on the comparison of the amplitude of the signal from an inspected pipe and the amplitude of the signal from a calibration standard flaw. Studies of the correlation between the amplitude of the flaw response and the depth of the flaw have shown that the correlation is very low. On the basis of this finding, we are seeking to improve our estimation of the criticality of a flaw by using all the parameters available from the ultrasonic image rather than simply its amplitude. In order to arrive at this interpretation, it is necessary to follow three steps:
• Acquisition and reconstruction of the image
• Extraction of potential flaws using filtering and image processing tools
• Interpreting and characterizing the flaws (type, depth) by means of neural networks.

2. Description of the Work Performed

2.1 Conventional ultrasonic testing of steel pipes

Among the various ultrasonic testing techniques, it is the immersion technique that is the most suitable for pipes. It consists in immersing part of the pipe inside a tank containing the probes. This technique is extensively used industrially as it enables the entire pipe to be inspected automatically.

The imperfections encountered in pipe manufacture include longitudinal and transverse flaws of varying obliquities and at various angles, and imperfections in the wall thickness, as illustrated in figure 1. The aim of our study is to improve our knowledge of these imperfections.

![Figure 1 - Types of flaws](image)

Conventionally, the inspection tank contains two probes for detecting longitudinal and sometimes oblique flaws, and two probes for inspecting transverse flaws, as well as a probe for wall thickness measurement and for inspecting imperfections in the wall thickness.

All the probes for longitudinal and transverse inspection are arranged diagonally opposite to each other in order to inspect the pipe in two directions of deflection so that any flaws positioned at an angle can be detected.

The interpretation involves comparing the signals received from the inspected pipe with those from a calibration standard containing reference flaws. This reference pipe serves to establish the positions of the time selectors on the A-scan for detecting internal and external flaws. The position of these selectors involves setting limits for the time base and signal amplitude according to the response obtained from the reference flaws in the internal and external surfaces, as shown in figure 2. If the amplitude of a particular echo exceeds one of the selectors, the pipe will be classed as suspect and will be either repaired or scrapped.
The gravity of the imperfections is estimated on the assumption that the amplitude of their echo will be proportional to their depth. When we plot the following distribution:

$$K = \frac{\text{Amplitude}}{\text{Amplitude de réf.}} = f(\text{profondeur})$$

we obtain a very poor correlation (around 0.3 to 0.4). This is why we are exploring image processing and shape recognition techniques in order to achieve more reliable and more precise interpretation of flaws.

### 2.2 General Description of the proposed method

Figure 3 illustrates the system according to the following steps:

- **Image acquisition and reconstruction**
- **Extraction of potential flaws**
- **Interpretation and characterization of the flaws**
  - Neural network: type of flaw
  - Neural network: Depth estimation

The first step is the acquisition of ultrasonic signals for image reconstruction. The next step combines signal processing and image processing techniques for recognizing the zones of imperfections. The third step includes the interpretation of the imperfection zones using two neural networks to estimate the type and depth of the flaw. Each of these steps will be described in more detail below.

### 2.3 Acquisition and reconstruction of the image

Based on the same principle as a conventional inspection, the idea we propose is to recover and process the signals received by the probes in order to interpret and assess the criticality of the imperfections.

The inspection tank used is the same as for the conventional inspection, containing two sets of probes for longitudinal inspection, two sets for transverse inspection and one set of probes for wall thickness measurement and inspecting imperfections in the wall thickness. In
the same way as for the conventional inspection, the longitudinal and transverse probes are arranged with opposing deflection directions in order to be able to detect tilting flaws.

The images processed in our approach are complementary Cscan pairs. A point on the Cscan x axis corresponds to a position on the length of the pipe and a point on the y axis corresponds to a position on the circumference of the pipe (see figure 4). Each point of the Cscan show the maximum amplitude of an ultrasonic wave using shaded colours.

The position of the probe in relation to the pipe needs to be known, either by means of an angle coder or laser system.

Figure 4 illustrates the reconstruction of the Cscan images acquired by the probes for the longitudinal inspection corresponding to each deflection direction named “direction 1 and direction 2” respectively.

2.4 Extraction of potential flaws

The aim of this step is to determine the zones of imperfections in the Cscan images so that they can then be analysed by the neural networks.

The zones of imperfections are extracted by means of a threshold that adapts to the current noise level of the image. The method is based on the theory of signal detection in white noise, which can rest on two assumptions:
Assumption H0: measurement = white noise with average (m_b) and standard-deviation (std_b)

Assumption H1: measurement = signal + white noise

Statistical tests were conducted to determine whether it is assumption H0 or H1 that applies. These statistical calculations are made in real time on all the points of the image.

According to this method (known as the “Gaussian additive noise” method) we can use Neyman-Pearson’s criteria to determine a detection threshold according to the probability of false alarms (pfa) given by the formula (1).

\[
\text{pf} = \int_{-\infty}^{\infty} \frac{1}{\sqrt{2\pi} \cdot \text{std}_b} e^{-\frac{(x-m_b)^2}{2 \cdot \text{std}_b^2}} \, dx = Q\left(\frac{\text{seuil} - m_b}{\text{std}_b}\right)
\]  

(1)

A cumulative Gaussian function was used, generally named Q. By inverting this function, the threshold can be obtained using formula (2).

\[
\text{seuil} = \text{std}_b \cdot Q^{-1}(\text{pf}) + m_b
\]  

(2)

Use of a variable threshold avoids the false alarms which occur with a fixed threshold. The false alarms are due to background noise from various sources: water inside the pipe, electric buzzing, phenomena due to the material structure of the product inspected.

The zones of imperfection are defined by positioning the points above the threshold identified on the image. These zones are processed using contour (Robert gradient), expansion and erosion detection algorithms in order to locate the imperfection and be able to efficiently apply the algorithms for calculating the angle of obliquity and length of the imperfection. The coordinates of the corresponding image zone are thus obtained for each imperfection and used for the subsequent neural network analysis.

2.5 Interpreting and characterizing the flaws

An imperfection in a pipe may be defined by its position, type and depth. In the interpretation proposed, the type and depth of a flaw are determined separately using three neural processes with the same general structure.

We have classed our flaws into four types, being those most often encountered in our production processes. These flaws are illustrated in figure 6:

- Type 1: Straight flaw
- Type 2: Slightly tilted flaw
- Type 3: Highly tilted flaw
- Type 4: Miscellaneous flaws

![Figure 1 – Types of flaws considered in this study](image)
In general, the neural networks used are the classifying type with probabilities of belonging to each class. As shown in figure 4, the first network allows the gravity of the flaw to be estimated by classifying the flaws into three groups according to their depths:

- Green: the indication is definitely an imperfection of no importance,
- Orange: suspect zone to be further investigated using the second model,
- Red: the indication is definitely a serious flaw.

This same neural network also serves to classify the flaw detected into one of the four types defined above (Type 1 to Type 4).

![Figure 2 – How the neural networks operate](image)

In general, the input parameters of the neural networks are characteristics of the two Cscan images. They are made up of the ratio of the maximum amplitude to the amplitude obtained from the reference pipe, the width of the echo, the position of the echo representative of obliquity and the length of the flaw among others. These two images are taken from the zones of imperfections previously detected. Other parameters are also taken into account, such as the probe characteristics, pipe dimensions, etc.

The learning process for the models was based on response data from around 2500 simulations, 150 artificial flaws and 100 natural flaws. The simulations were obtained using the CIVA software program developed and sold by the CEA.

Semi-industrial validation of the neural networks was conducted on 90 samples of natural imperfections from a UT test bench. The validation was conducted on the basis of a comparison between the estimation given by the neural networks and the result given by the conventional method with a threshold and micrographic cross-sections taken of each imperfection.

3. Results

The system validation trials correctly estimated the depth and type of flaw of 81% of the 90 natural flaws previously detected in the factory.

The estimation given by the proposed system is still closer to that given by the conventional method, with a correlation of $r^2 = 0.75$ obtained with the above samples. The following characteristic examples show why the system offers better results:
• Characterization of tilted flaws: by knowing the type of flaw, we can correct the evaluation accordingly,
• Characterization of straight flaws: When all the parameters are taken into account, we can refine our statistical prediction, but the improvement is less marked than in the previous example.

4. Perspectives of the Method

We have already envisaged some changes to the method. These changes concern three-dimensional ultrasonic image processing techniques which will offer better knowledge of the imperfections. Work on the three-dimensional reconstruction of ultrasonic images has already begun and the following figure shows an example of a prototype. The aim is to obtain three-dimensional micrographic images of the flaws.

![Prototype of the proposed change to the system](image)

**Figure 3 - Prototype of the proposed change to the system**

5. Discussion and Conclusion

This research offers a new concept in the ultrasonic testing of steel pipes. By estimating the depth and type of flaw, it gives us a better understanding of our flaws.

The tool has been validated industrially and is used parallel to the conventional inspection to allow better process control.