IMPROVEMENT TO DEFECT DETECTION

BY ULTRASONIC DATA PROCESSING: THE DTVG METHOD

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INTRODUCTION

In the case of coarse grained austenitic stainless steel, an important diminution in the defect detection possibilities is noted. The wave amplitude is attenuated and can also be deviated, according to the importance of anisotropy and/or heterogeneity.

Consequently, using the ultrasonic amplitude as a discriminant criterion of defect detection proves to be of some difficulty. The ultrasonic signal is easy to digitise, the solutions can be found in a certain number of processes. Generally these processes only take into account mono-dimensional signals

The research into characteristic data for testing , from bi-dimensional signals, that is from one image, is a most original step. There are digital processes, often used in order to improve image quality [1]. Few processes are used to help us extract information from the ultrasonic image thus formed [2]. In most cases, the image is used as a mode of information final representation, and not as the data initial basis.

We show an image processing method which is entirely automatic aimed at improving the defect detection in the ultrasonic testing of welded or not welded austenitic or austeno-ferritic stainless steel. The obtained ultrasonic image (BScan) is analyzed from criteria different from the analysis of the sole amplitude, which allows processing even in case of a low signal to noise ratio.

We first recall the principle of the method, developed in the case of rather thin parts that are controlled in immersion and under normal incidence [3-4]. Both DT and VG criteria are established. Optimization as well as the analysis complete automation are presented.

We secondly present the modifications that must be made because of a BScan image that is obtained on thick parts controlled under oblique incidence. The angle of events in the image is found first and the final result shows that defect detection appears unambiguously in a complete automatic way.

PRINCIPLE OF THE DTVG METHOD: APPLICATION TO CONTROL UNDER NORMAL INCIDENCE

The basic principle (figure 1) of the method consists in segmenting the image into two classes thanks to a specific data processing as is naturally done by the visual perception system.

First Criterion: VG

In case of B or DScan images (i.e "space-time"), the visual perception of the imperfection first bears on the notion of stability, in an image zone, of constant grey level. The first criterion (VG) studies the spatial stability of the maximum temporal gradient for each signal of the ultrasonic image: a defect zone has a higher stability than a noise zone.

Let S(i,j) be the original ultrasonic image formed by a set of N numerical signals $s_i(t_j)$ juxtaposed vertically. The image can be written under the following matrix form, in which M equals the number of the image lines:

$$S(i,j) = \bigcup_{i=1}^{N} s_i(t_j) \qquad \text{for } j = 1 \text{ à } M \qquad (1)$$

By a discrete convolution of S(i,j) with a vertical gradient, the derived image S'(i,j) is obtained. It can also be expressed, with $s'_i(t_j)=s_i(t_{j+1})-s_i(t_{j-1})$

$$S'(i,j) = \bigcup_{i=1}^{N} s'_i(t_j) \qquad \text{for } j=2 \text{ to } M-1 \qquad (2)$$

Next the maxima and minima of the image S'(i,j) are searched for, column after column. Let G(i) be the maximum of amplitude of column i and g(i) its minimum of amplitude, and G_i and g_i their vertical positions. Thus we get, for j = 2 to M-1:

$$G(i) = S'(i,G_i) \qquad \text{and} \qquad g(i) = S'(i,g_i) \qquad (3)$$

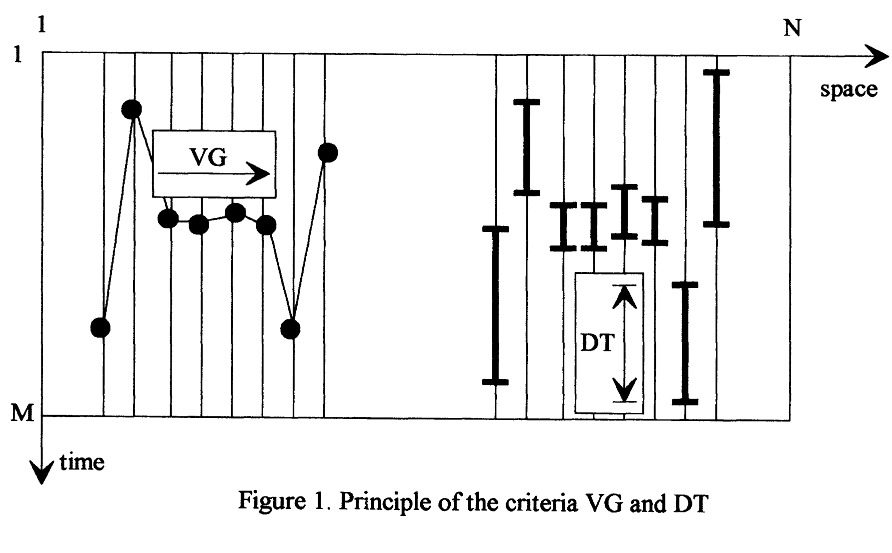


Figure 1. Principle of the criteria VG and DT

A binary image S"(i,j) is then obtained, in which only the positions of the maxima and minima are considered. We have shown that the physical nature of the ultrasonic image processed is such that the structure noise can be considered as pseudo- aleatory, and the position of a gradient maximum or minimum in each column, i.e. signal after signal, will be located anywhere in the signal. But the presence of a defect in the weld necessarily induces an echo on several consecutive signals of the image, hence the position of the gradient maximum, or that of the minimum, should remain more or less constant from one column of the image to the other, on the whole dimension of the defect.

Consequently a sound stability of the gradient maxima (or minima) will reveal the presence of a defect in the sample under control. The measurement of this stability of position is performed by means of a sliding variance calculation on the binary image S"(i,j). The calculation window W, within which the variance is calculated, is F=2f+1 wide and as high as the size of image S"(i,j), i.e. M-1. It is centered on column i_c. The nature (positive or negative) of the highest gradient, in absolute value, of all gradients maxima or minima contained in the window, determines the following calculation:

$$VG_{f,i_c} = 1/(2f+1) \sum_{i=i_c-f}^{i_c+f} ((G_i \text{ or } g_i) - G_{moy})^2 \qquad (4)$$

in which G_{moy} is the mean position of the gradient maxima calculated on the (2f+1) signals belonging to window W. The width F is therefore a significant parameter in the defect detection algorithm, and the value of " f " must above all be optimized.

Optimization of Window W.

In an image Sb(i,j) representative only of a structure noise zone, the influence of " f " on the gradient stability is as follows:
a) if " f " is too small, the variance of the position of the gradients is unstable. There is a possibility to have a stable event born of the structure (due to the weld structure) which gives a low value of the variance, as would a possible defect. It means this could lead to a false call.
b) if " f " is too large, the variance of the position of the gradients is high but stable. The stability provided by a possible defect cannot be detected but under the condition that the defect "size-width f" ratio be high enough. The detection of small defects is thus impossible.

This size must be found automatically, thus reliable. The chosen method consists in being sure that a defect will disturb the analysis, whatever the size of the defect and especially whatever the defect location in the noise. The basic idea is the following:
a) as long as the window is not large enough (F<F0), the variance of the gradients "witnesses" the presence of stable events. The curve VG sometimes reaches null values, with:

$$VG = \bigcup_{ic=f+1}^{N-f} VG_{f,ic} \qquad (5)$$

b) as soon as the size of the calculation window becomes larger (F>F0), VG increases to approach relatively constant values (but not null). It is the variance of this variance (constant) that becomes null.

If the size of the window that shows the passage from a) to b) for the first time is noted (F=F0, figure 2), that is the size of the window from which no variance is no longer null, a solution to the problem is found: if a defect was present, it would inevitably decrease VG, whatever its location as $VG_{f,ic}$ is calculated on the whole image.

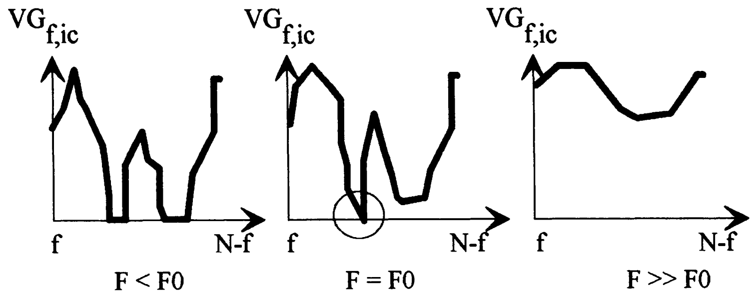


Figure 2. Optimization of the size F of the window W

For a window of a size F0+1, one is able to distinguish any defect whose spatial width equals F0, whatever its location in the image, and without a pseudo-defect being detected (figure 3). A window size that is not "optimum" is thus found but it is found in an automatic and reliable way. Thus the operator no longer has to make a choice

Second Criterion: DT

The second stage consists in getting interested in the vertical of the grey levels: a defect is expected as a determinist and short temporal event, corresponding to a sharp reflection on an interface. A structure noise signal, that cannot however be fully considered as a stochastic process, as is an electronic noise signal, has a representation under the form of rather long temporal events. The second criterion (DT) takes into account the time difference between the minimum and maximum amplitudes of each signal. The calculation method is as follows:

a) the amplitude maxima A(i) and minima a(i) for each column i of the original image S(i,j) are calculated, and only the positions A_i and a_i column after column of these extremes are considered:

$$A(i) = S(i,A_i) \quad \text{and} \quad a(i) = S(i,a_i) \tag{6}$$

Then, for each column i, the distance d_i between the positions of these two values is calculated. Let it be noticed that d_i physically corresponds to a time interval.

b) because of the very low signal-noise ratio of that type of signal, an optimization of this distance d_i is necessary, in order to make this criterion more performing:

1) the position of the first extremum detected is unchanged;

2) the position of the second extremum is altered; the new position corresponds to the position of the most distant point from the first extremum belonging to column i, and the amplitude of which equals that of the second extremum as detected previously, reduced by x decibels.

If the first extremum is a maximum, the second point taken into account will be a minimum localized at position $a_{i,x}$. In the other case, it will be a maximum localized at position $A_{i,x}$. The distance between the positions of these new extrema, according to the cases, will be:

$$d_{i,x} = a_{i,x} - A_i \quad \text{or} \quad d_{i,x} = A_{i,x} - a_i \tag{7}$$

The mean value of the time intervals $d_{i,x}$, called d_{ic}, is calculated on the averaging and sliding window of a three column size. The domain of variation of D_{ic} can be expressed in a different way, if we take into account the measurable lower limit d_{Ri} related to the impulse answer of the transducer, under normal incidence. Thus we have:

$$DT_{3,i_c} = \frac{1}{3}\sum_{i=ic-1}^{ic+1} (d_i - d_{Ri}) \quad \text{and} \quad DT = \bigcup_{ic=1}^{N-1} DT_{3,i_c} \qquad (8)$$

In the presence of a defect, the optimized temporal distance is relatively small, whereas it grows important in the presence of a noise (figure 3). Thus this optimization, that proved very efficient, has confirmed the choice for the DT criterion. Studying this criterion then consists in searching for a certain determinism in the temporal and spatial (due to the average calculation) evolution of the signals in the presence of a defect.

Total Criterion DTVG

The calculation of DTVG is now a binary one (figure 3): $DTVG_{f,ic}$ is equal to 1000 (arbitrary value) if $VG_{f,ic}$ and $DT_{3,ic}$ are null, which means that a defect is likely to be present. Otherwise, $DTVG_{f,ic}$ is null, and:

$$DTVG = \bigcup_{ic=f}^{N-f} DTVG_{f,ic} \qquad (9)$$

The first results showed that $VG_{f,ic}$ and $DT_{3,ic}$ being null was very constraining and that the sole large defects were detected. We then introduced two thresholds, called TV for the variance and TD for the temporal distance, and now:

if $VG_{f,ic} < TV$ AND if $DT_{3,ic} < TD$, then $DTVG_{f,ic} = 1000$, otherwise $DTVG_{f,ic} = 0$ (10)

Automatic search for TV and TD.

Curves VG and DT are calculated for the image of structure noise. The binary value $DTVG_{f,ic}$ is therefore null, otherwise the case is that of a pseudo-defect. The problem is now to know up to what couples of values ($VG_{f,ic}$ - TV) and ($DT_{3,ic}$ - TD), it is still possible to have the binary value $DTVG_{f,ic}$ null.

To do so, we can calculate the sum ($VG_{f,ic} + DT_{3,ic}$) for each column. The minimum of this curve indicates column ic that is the first to give the couple of values ($VG_{f,ic}$ - TV) and ($DT_{3,ic}$ - TD) which cancels the binary value $DTVG_{f,ic}$.

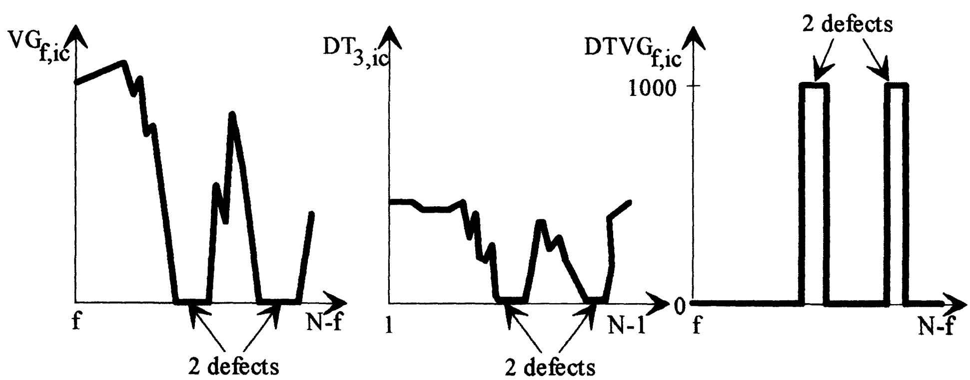


Figure 3. Curves VG, DT, and DTVG, for 2 defects.

The values of TV and TD are thus determined automatically, and the detection sensitivity has thus been improved.

Displaying Results

The operator is shown the initial image and a binary image with a white background whose black events correspond to $DTVG_{f,ic}$ =1000. The dimensions of the events are width (number of columns for which DTVG = 1000), location (a_i or A_i), and height (a_i-A_i or A_i-a_i).

ADAPTING THE METHOD TO CONTROL UNDER OBLIQUE INCIDENCE

In case of acquisition under oblique incidence, the echoes formed by the reflection of ultrasounds on a defect give an inclined event, in the image, of an angle which depends on the incidence angle and on possible deviations due to material (anisotropy, heterogeneity). The representation of the angle in the image also depends on the chosen format (step, sampling,..).

The two parameters VG and DT, taking into account horizontal stabilities of grey levels, and of vertical distances, can no longer be directly used. The analysis should take into account the real angle of events on the image, whether the angle corresponds to the theoretical assumption in homogeneous isotropic environment (Snell law) or not.

If the material is thought to be sufficiently homogeneous so that the wave front is always perpendicular to the direction of wave propagation, the value of $DT_{3,ic}$ can still be deduced from the measures on the image columns. Adapting the measure is more complex for VG than DT because :

a) VG is normally calculated in an optimum window that is itself determined after taking into account a noise zone on the image. A noise image is therefore necessary for calibration.

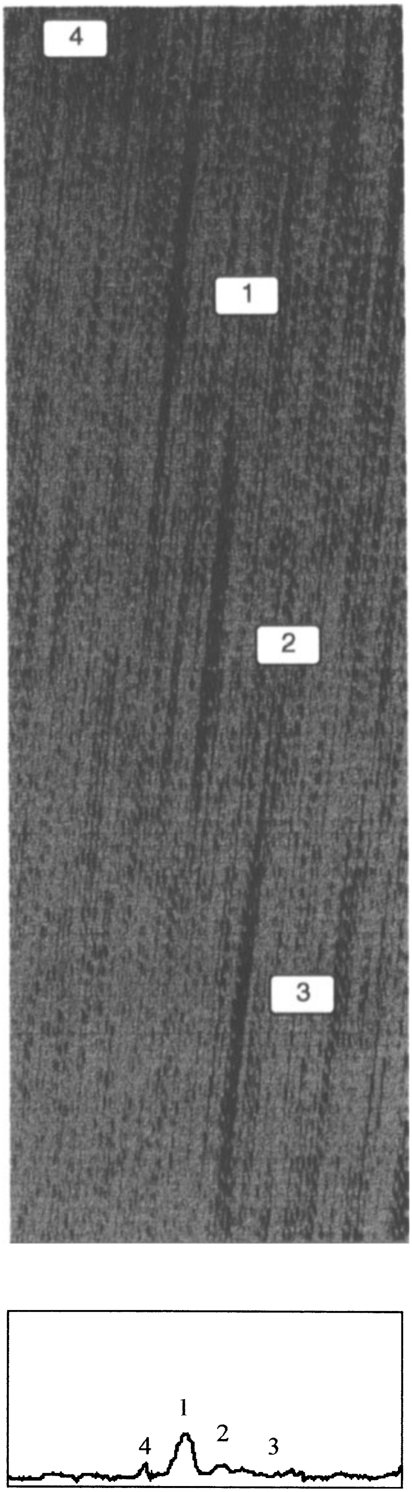
b) VG will be optimum, within control under oblique incidence only if the angle of ultrasonic events on the picture is taken into account; the variance cannot be calculated from the usual mean value (i.e horizontal). In fact, knowing the real angle of events on the image can only be deduced from working on an image with a defect, as noise has no spatial coherence. A defect image is also necessary (e.g standard defect). If impossible, the theoretical angle deduced from the acquisition conditions can be used.

Automatic search for the angle of events on the image is achieved by working exclusively on the values of file BScan. The pixel "file" is considered as a square, that is to say that the acquisition step and displacement step are translated in an identical manner. In such conditions, the vertical displacement pixv (in pixel/column) of inclined events of the image can be expressed by the following formula :

$$pixv = \frac{2.p.\sin\theta.Fs}{C} \qquad (11)$$

with: Fs: sampling frequency; p: acquisition step; C: celerity of waves; θ: real angle.

The chosen method consists in searching the minimum of variance of maxima gradients (defined as they were for DTVG under normal incidence) calculated in a sliding



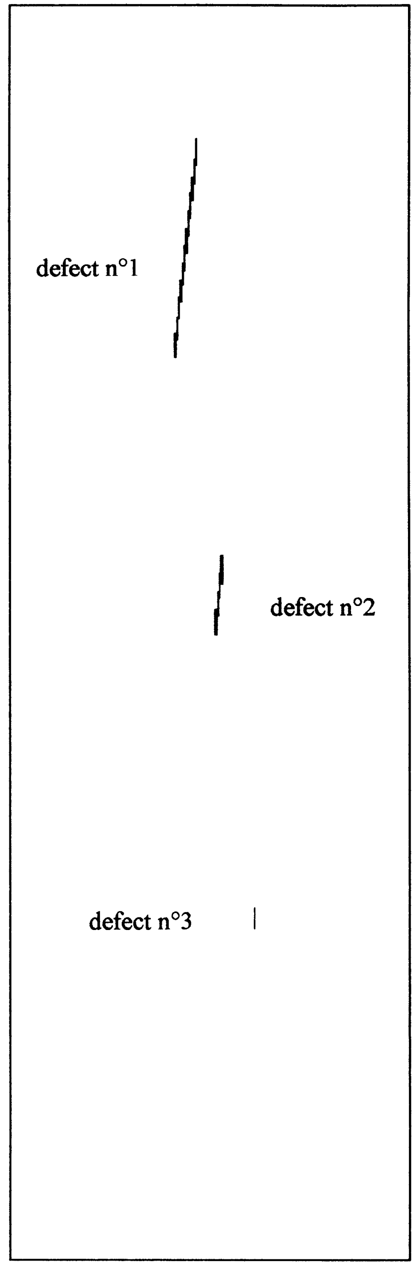


Figure 4. Results of the complete treatment for 3 defects (holes) in an austenoferritic steel sample of a 80 mm thickness. The initial BScan and the echodynamic curve show a very low signal-to-noise ratio. After DTVG, the structural noise is cancelled and defects appear unambiguously.

window and relatively to an inclined mean value. The window size depends only on the diameter of the focused beam as the search for the size F0 can only be made after the angle measure. By varying the inclined mean value according to pixv, the minimum minimorum of variances will be searched for.

The validation of this method was performed on images presenting inclined events on the image from 5 to 5 degrees (from 30 to 70) by moving an inclined transducer focused on a ball and from an image with an artifical defect re-created at the desired angles.

CONCLUSION

Originally the method DTVG was validated by numerous tests made on parts of small thickness, under normal incidence: no pseudo defect was detected and the smallest artificial defect found in a real weld (a hole of 0.4 mm in a 5 mm thickness) is totally undectectable by classical means.

In case of thick parts (100 mm), inspected under oblique incidence, the different analysed images have led to finding all the present artificial defects. All elements linked to reflection were found, and also all those linked to diffraction. Moreover, the complete automation of the method is appreciated. A simple binary image (fig. 4) is shown to the operator. It is very easy to locate the places where important probability of defect presence is calculated.

Many more tests are necessary to validate completely this adaptation of the method especially on real defects. Research is also under way to resolve the problem due to saturation of surface echo and so try to improve the detection of defects which are near the surface.

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