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Advantages of the Total Focusing Method

Zalety metody pełnego ogniskowania TFM

ABSTRACT

Total Focusing Method has been recently made available in portable Phased-Array Ultrasonic Instrument. Portable industrial equipment with full-parallel capabilities allows handling of matrix-array probes, 3D imaging and advanced techniques for optimal focusing. Total Focusing Method, a reconstruction based technique, is discussed: it allows better sizing of the defects during inspections, a clear detection of small defects and defect characterization. Moreover, real-time adaptive inspection associated to Total Focusing Method has been implemented to take into account the variability of the examination surface.

Keywords: *Total Focusing Method, ultrasound testing, nondestructive testing*

STRESZCZENIE

Metoda pełnego ogniskowania TFM (ang. Total Focusing Method) została niedawno udostępniona w przenośnym urządzeniu ultradźwiękowym z technologią phased-array. Przenośne urządzenia przemysłowe stwarzają możliwość nadzorowania równoległego pracy przetworników macierzowych, obrazowania 3D i zaawansowanych technik optymalnego ogniskowania. W pracy omówiono metodę TFM bazującą na technice rekonstrukcji. Pozwala ona na lepsze określenie rozmiarów wad podczas inspekcji, wyraźne wykrycie drobnych wad i ich charakterystykę. Ponadto przedstawiono wdrożenie kontroli adaptacyjnej w czasie rzeczywistym związanej z metodą TFM, uwzględniającej zmienność badanej powierzchni.

Słowa kluczowe: *metoda pełnego ogniskowania TFM, badania ultradźwiękowe, badania nieniszczące*

1. Introduction

Phased-array technology has been accepted for many years and used in many NDE applications thanks to its flexibility and the major improvement in productivity. Instead of the typical amplitude vs time signal, phased-array systems can display ultrasonic data as sectorial or linear images (Sscan or Escan) allowing an inspector to see instantly a complete zone of the component and thus interpret data more easily. These images are obtained by applying time delays to each element of an array probe. Increasingly, more advanced operating modes involving the post-processing of elementary signals are exploited in NDT. A posteriori synthetic focusing of signals, called TFM (Total Focusing Method) is one of the most natural ways of such processing and has been proven to be an efficient way of imaging inspected parts [1]. This method might be applied, at least in theory, to any set of signals, its performances depending obviously of the acquired data. The algorithm has been implemented and extended in the CIVA software to complex geometries and various modes of reconstruction [2]. While this technique presents great benefits, one of the main disadvantages is that, up to now, it has been mainly used as a post-processing method making it difficult to apply on the field. M2M, now Eddyfi, was the first to propose a portable phased-array system, the Gekko, with full-parallel phased-array capabilities that allows real-time TFM reconstruction. The system has been accepted by the industry and is used for many applications. Since, Eddyfi has extended its range of system with TFM to its tabletop system, Panther, and to the smaller portable unit, Mantis.

Since July 2019, ASME section V has added various sections that describes TFM making the technique code compliant.

2. The Total Focusing Method

2.1 Principle of TFM

The TFM imaging technique can be applied to any acquired data as long as elementary ascans are recorded for each channel. At the time of publication, the TFM in the Gekko is applied to a dataset recorded from a FMC (Full Matric Capture) acquisition to produce an image in a region of the component. Later this year, the Gekko will upgraded to incorporate other modes of TFM reconstruction. The FMC presents the advantage of maximizing the information available from a given array composed of N elements by sending ultrasonic energy everywhere in the component; this way potential defects can be seen from multiple directions. The FMC acquisition consists in firing each element of the array in turn and recording the information reflected/diffracted in the component on all the elements. The result of the FMC is a NxN dataset composed of every emitter-receiver pair combination of elements in the array. The TFM algorithm consists in coherently summing all the signals $s_{ij}(t)$ from the dataset to focus at every points of a Region Of Interest (ROI) in a specimen. Mathematically this can be expressed as:

$$I(P) = \sum_{i,j=1}^{N} s_{ij}\left[t_{ij}(P)\right]$$

where $t_{ij}(P)$ denotes the theoretical time-of-flight corresponding to the propagation time between the i-th transmitter and the j-th receiver, through point P.

2.2 Comparison of sectorial scanning and TFM

Figure 1 shows a comparison between sectorial scanning and TFM for an ASTM E2491 standard mockup. We use a 64-element 5-MHz linear array probe. This calibration mockup has an array of side-drilled holes (SDH) along a 1" radius and another along a 2" radius. For the sectorial scanning we perform a -50-+50° scan with a 0.5° step focusing

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the energy at 25 mm (1"). For TFM we define a 70 x 50-mm ROI underneath the surface.

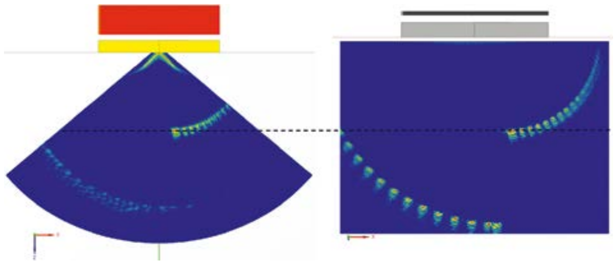

Fig. 1. Sscan (left) and TFM (right).
Rys. 1. S-scan (po lewej) i TFM (po prawej).

The SDH located around 25 mm (horizontal dotted line) ae clearly detected for both the Sscan and TFM. However, for the Sscan we can see that the echoes clearly show an out-of-focus effect for the SDH located along the 2" radius. The echoes are elongated and weaker (-17 dB compared to the maximum). For TFM all the SDH are detected at all depths with similar energy (6 dB variation). The advantage is that the operator doesn't need to specify a depth of focalisation; the TFM offers optimum focusing at every point in the ROI.

2.3 TFM for manual inspection

This ability to focus everywhere is demonstrated on a manual inspection of an electron beam welded component made of a titanium alloy. The material is composed of large grains ~0.5-1.5 mm and porosities can occur during the welding process. The weld is inspected manually which can be an issue and can lead to variations in sensitivity. To evaluate the sensitivity of the NDT technique several hemispherical bottomed holes (HBH) were machined from the side of the sample to finish in the middle of the weld at several depths.

We inspected the component with a 64-element 7.5-MHz linear array with a 75-mm focusing in the passive plane. We compare sectorial scanning using longitudinal waves focused along the weld (top row) with TFM (bottom row) in Figure 2. For both the Sscan and TFM images we see the echoes obtained at the root of the weld.

In the top left image, we can see the echo obtained at the tip of the HBH; it is detected with a 20 dB Signal-To-Noise (SNR) ratio. To represent an error of positioning during the inspection we moved the probe away from the weld by 4mm. On the right Sscan, we can see that the echo from the HBH becomes much weaker (5 dB SNR). Because of the structure of the titanium alloy and the size of the HBH (ø = 0.8mm) the ultrasonic beam needs to be focused on the defect otherwise the SNR is too small. We see that the sensitivity decreases dramatically when the defect is not the in depth-of-field of the probe.

For TFM, we see that the HBH is detected with a 17 dB SNR for both positions. Because it focuses everywhere in the ROI, TFM is not as sensitive to positioning as sectorial scanning. This can be very important when looking for low-amplitude signal such as porosities or tip diffraction. We see however that the SNR is a little bit smaller compared to the sectorial scan properly focused at the defect. This is due to the fact that data acquired to perform the TFM were obtained using a FMC meaning that element were fired one by one. This could lead for some cases to lower amplitude signals, particularly when the elements are small.

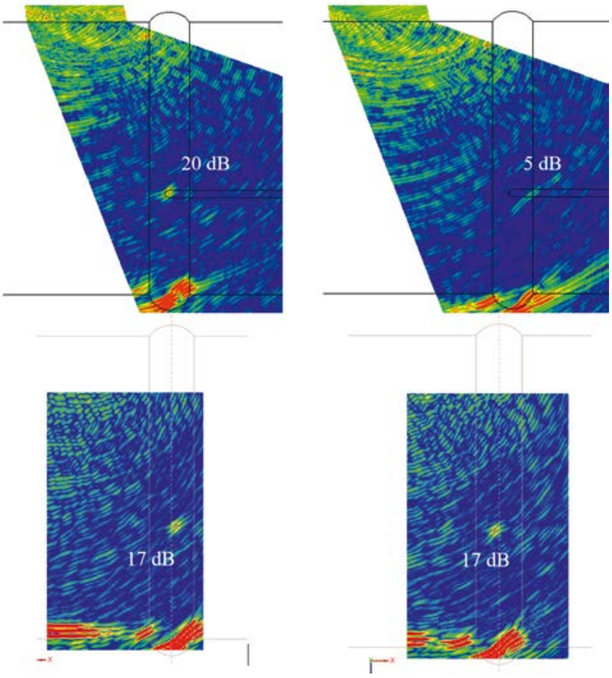

Fig. 2. Sscans (top) and TFM (bottom) obtained for a HBH in the middle of a laser weld. The right column was obtained after moving the probe 4 mm away from the weld.
Rys. 2. S-scan (u góry) i TFM (u dołu) uzyskane dla HBH w środku spoiny laserowej. Prawa kolumna została uzyskana po odsunięciu sondy na odległość 4 mm od spoiny.

By focusing everywhere within the ROI the TFM offers an ease of use for operators/experts; they don't have to worry about the depth of focalization.

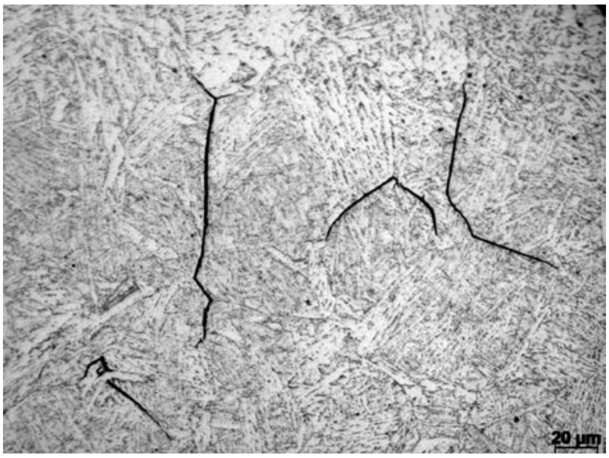

Fig. 3. Macrography of a sample containing HTHA damage.
Rys. 3. Makrografia próbki zawierającej uszkodzenie HTHA.

2.4 TFM for High Temperature Hydrogen Attacks

High temperature hydrogen attack is a form of damage commonly observed in steels exposed to high pressure hydrogen at elevated temperatures. The damage occurs as hydrogen atoms diffuse into steels, react with carbon, form methane gas internally in the material, which results in decarburization and fissuring (micro-cracking). As the defects are quite small (micro) it is quite difficult to detect them with conventional UT method; an analysis of the backscattered energy is usually performed. HTHA starts by methane bubbles being formed in solid state steel along the grain boundaries.

Micro fissures can grow and coalesce into large macro fissures Macro fissures ultimately grow connecting to form larger more serious cracks. Precise NDE essential to calculating Fitness For Service (FFS). TFM has been recently introduced by Oil & Gas companies and training centers as a mean to detect HTHA damage.

Fig. 4 show different TFM images obtained for two samples (45 and 100 mm thick) at different stages of the HTHA process.

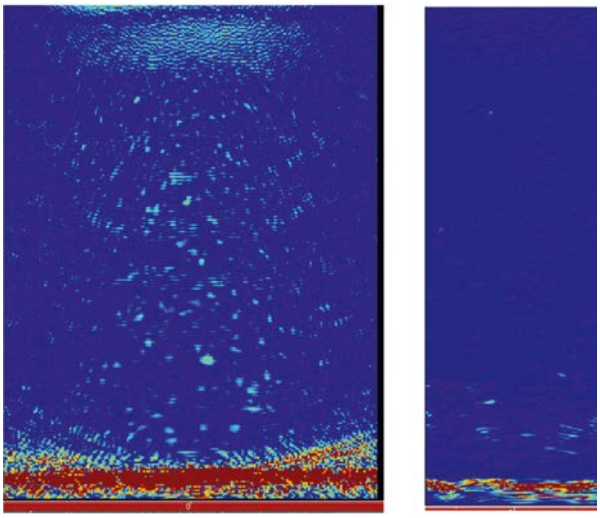

Fig. 4. TFM images of samples (45 mm and 100 mm thick) containing HTHA damage.
Rys. 4. Obrazy TFM próbek (o grubości 45 mm i 100 mm) zawierających uszkodzenie HTHA.

TFM is not being taught by some training schools as one of the methods to be used in the detection and characterization of HTHA damage.

3. Adaptive TFM

The reconstructions presented above were performed for components with flat surfaces. For complex geometries with an irregular entry surface, such as a corroded surface, the ultrasonic field can be distorted making the detection of potential defects impossible. Phased-array technology offers the ability to perform inspection under complex surfaces by adjusting delay laws to take into account the variations of the entry surface. However, the geometry of the surface needs to be perfectly known, which is not always the case.

M2M/Eddyfi has developed and implemented in the Gekko a real-time adaptive process, called ATFM (Adaptive TFM), that measures first the entry surface then performs a TFM reconstruction underneath the complex surface [4].

We describe here the various steps of the ATFM process.

1) A ROI is defined at an approximate distance equivalent to the water path
2) A TFM reconstruction is performed in a semi-infinite medium using the velocity of water
3) The profile of the entry surface is extracted by detecting the maximum of the envelop in each column of the TFM image
4) A TFM inside the component can be calculated taking into account the measured profile to adjust the delays and focus at each point of a ROI inside the component.
5) The profile of the front surface and the TFM reconstruction are displayed by the Gekko in real time.

We used this technique with a local immersion probe composed of a standard linear phased-array probe attached to a flexible wedge filled with water. The mockup is a 30-mm thick aluminium block containing two pairs of 10-mm wide notches and one 2-mm SDH; an irregular surface was machined above one set of defects. Figure 5 shows a side view of the mockup and TFM reconstructions with the adaptive process disabled and enabled.

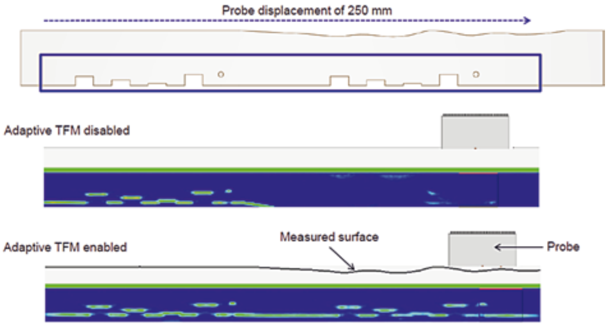

Fig. 5. Adaptive TFM on an aluminium mockup with irregular surface.
Rys. 5. Adaptacyjny TFM na aluminiowej makiecie o nieregularnej powierzchni.

One can see that when the adaptive process is disabled only the defects located underneath the flat surface can be detected. Even the backwall is not detected when located underneath the wavy surface. This is due to the fact that the times-of-flight are not properly calculated to take into account the variation of the front surface. When the process is enabled, the profile of the front surface is reconstructed correctly; one can compare the “measured surface” in the third image to the front surface of the mockup in the first image. Using the information from this “measured surface” the TFM algorithm is able to detect all the defects even those located underneath the irregular part of the entry surface in real time.

The adaptive process was then applied to the thickness measurement of a welded pipe. A 64-element, 5-MHz probe was used over a 21-mm thick pipe. The weld cap was slightly smoothened to remove the weld passes but the weld cap was still there. An image of the setup is displayed in figure 6. The probe uses the same conformable wedge and it is connected to a scanner to perform a scan across the weld with a 1-mm step.

The image shows a screen capture of the adaptive reconstruction using the Gekko. One can see the reconstructed profile of the weld cap and the TFM image of the backwall surface taking into account the front surface profile. The zoom shows the detection of a notch at the root of the weld. Without reconstruction of the front surface it would have been impossible to detect the notch.

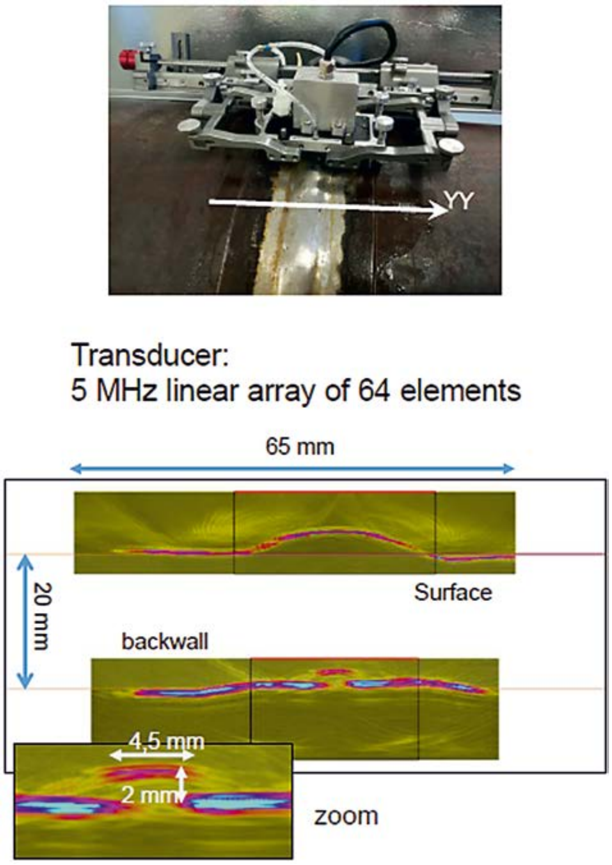

Fig. 6. ATFM on a weld cap
Rys. 6. Adaptacyjny TFM w spoinie

ATFM offers huge potential for the inspection of components that requires polishing the entry surface to remove a weld cap for example. This could lead to big time and cost savings.

4. Conclusions

Total Focusing Method is a technique that has been used for quite some time. However, it was limited to post-processing making it difficult to apply it in the field. Recently, portable phased-array systems, among which the Gekko, have been made available with TFM capabilities. In this paper, we showed some TFM results showed some of the advantages of TFM over sectorial scanning. Because of its ability to focus everywhere, TFM is less sensitive to positioning and easier to use. TFM allows characterization of small defects and complex defects where standard phased-array could not. Finally, we showed the potential of TFM to perform reconstruction below complex surfaces such as a weld. This opens the way for inspections for which the surface is not known (after hand machining for example) and inspection of welds from the weld crown.

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