Inspection of Thick Parts with Phased Array Volume Focusing

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ABSTRACT: VOLUME FOCUSING IS A NEW TECHNIQUE BASED ON PHASED ARRAY UTILIZATION.

Some of its advantages are to inspect faster, to be able to make multi-mode inspections at once, and to increase the depth of field of the UT beam to inspect thick parts with only one probe. This document does not demonstrate or explain concepts, but provides an experimental point of view. This document confirms advantages, by showing that the lateral resolution as well as the ability to detect flaws on the same axis isexcellent. Finally, typical application work for Power Generation part inspection or service inspection field and square bar On Line inspection is also described to illustrate two real cases.

KEY WORDS:

Phased Array; Ultrasonic; Inspection; Thick part; Volume Focusing; Ultra-fast;

INTRODUCTION:

Conventional phased array inspection techniques consist of creating virtual probes along the phased array, by programming the aperture, a group of elements firing or receiving together, with a delay pattern to provide the same effect as a focusing lens. The electronics are usually fast enough to scan different settings at each transmitted pulse. This time between each pulse can be referred to as either a cycle or time slot, and the rate of the transmitted pulse can be defined as the PRF (Pulse Repetition Frequency). Electronic scanning can be thought of as running the inspection with virtual probes scanned one after the other. The advantage over single element probes is obvious where scanning can be performed without any mechanical movement. On the other hand, a disadvantage is that each virtual probe requires one transmitted pulse, causing the maximum inspection speed to plateau at the maximum PRF. This is due to a real-world physical ultrasound limitation where the PRF can only be driven so high before resulting in adverse effects or ghost echoes. There is currently no solution with conventional phased array when the maximum PRF is reached.

The Zone Focusing technique is taken as a reference in this experiment due to its excellent sensitivity and lateral resolution. Zone Focusing consists of transmitting pulses and receiving, while focused on each

zone that we define in the depth. The optimized sensitivity and lateral resolution comes from the fact both transmit pulse and receiving are both focused at the depth of interest.
Volume Focusing uses a completely different approach. Using all the elements, the transmitted pulse is generated along the probe at once with a delay pattern that keeps the generated wave consistent. This removes any chances of diffraction, and captures the entire volume that has to be inspected, section by section. A massive parallel and powerful calculation in the electronics makes the spatiotemporal de-correlation of the signal. The imaging of the flaw pattern then becomes available for more data processing, usually oriented for evaluation. This technology, as a particular case of tomography processing, not only lends itself to a more simple method, but provides an answer to overcome several limitations of conventional phased array inspection techniques. Multi-mode inspections consist only of doing more calculations with the electronics. The PRF does not have to be high to get a very high speed inspection because 1 pulse is enough to provide the results of 1 section of the material (in front of the probe). Then, the problem of ghost echoes disappears. The whole concept is based on the fact that a consistent transmitted wave is used to inspect an entire section of a part.

The Volume Focusing technique uses consistent waves, resulting from all elements of the probe, such as plane waves, cylindrical waves, spherical waves or others. Therefore, a relevant question is whether the wave is broken when it encounters a flaw or is it still possible to detect another flaw along the same axis? Another relevant question consists in wondering whether the lateral resolution is preserved or not? It is possible to consider this problem with a theoretical approach, for example by using a finite element wave propagating simulation. Herein, the emphasis is put on the experimentation.

EXPERIMENTAL COMPARISON BETWEEN VOLUME FOCUSING AND CONVENTIONAL ZONE FOCUSING :

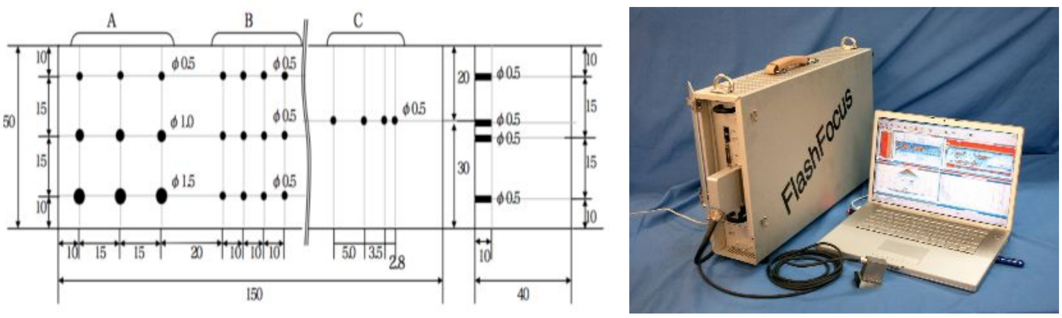

Figure 1: 2 Block drawing beside a FlashFocus

In the middle of the figure. To do the experimentation, we used an aluminum block. Aluminum has the advantage of low structural noise and low attenuation, so that the experimentation is not affected by such parameters. ***The electronic equipment, FlashFocus (on the right)***. FlashFocus, from KJTD inc., is a massive parallel 128/128ch acquisition system, capable of Conventional Focusing as well as Volume Focusing.

Probe definition. All the first part of experimentations have been done with 32 elements apertures, scanned with a 1 element pitch along the 128 elements of the probe. The probe definition is 10Mhz, 0.5mm pitch per element, 12 mm elevation (IMASONIC). The water path is in both cases the same: 20mm.

All experiments with conventional phased array are done with Zone focusing (3 zones). The PRF is set to 2Khz to avoid reverberation phantom echoes (ghost) from the water path, and the SRF (Sequence Repetition Frequency corresponding to the acquisition speed of 1 Bscan) is close to 7 Hz. In all experimentations with Volume Focusing, the setting of PRF is equal to the SRF (Sequence Repetition Frequency) and is 438 Hz.

Lateral resolution experimentations:

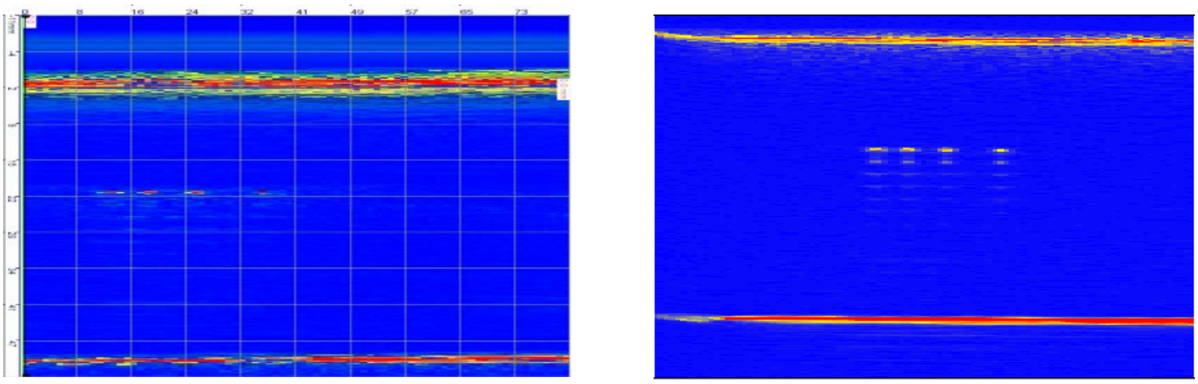

Figure 2. Lateral resolution 1. Volume Focusing (Left), Zone Focusing (Right).

This experimentation shows a comparison between both techniques concerning the lateral resolution. For that we consider zone C of the test piece. In both cases, the lateral resolution allows you to distinguish all 0.5mm diameter side-drilled holes (SDH) (in the range of 1 wavelength), from 5 mm, 3.5mm and 2.8mm (center to center).

The small lateral resolution loss from Volume Focusing can be compensated by increasing the aperture size. Experimentation with an aperture of 48 elements proved this fact.

Same axis flaw experimentation:

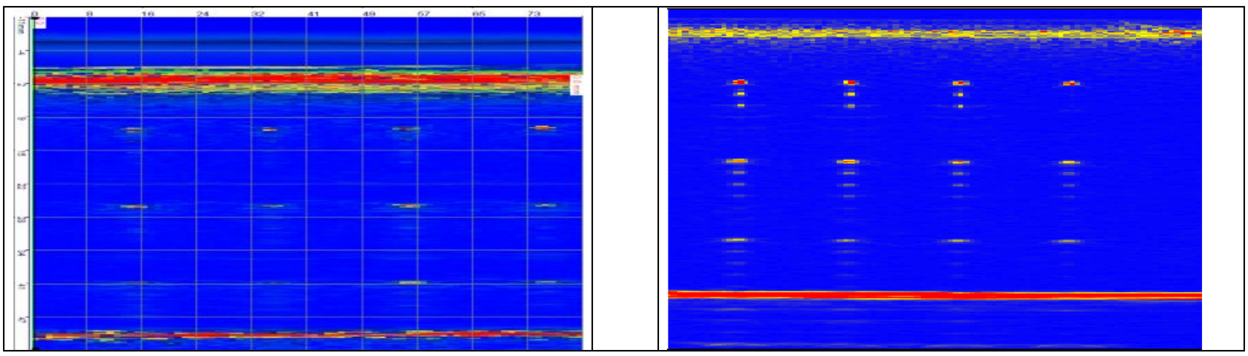

Figure 3. Flaws on the same axis 1. Volume Focusing (Left), Zone Focusing (Right).

This experimentation shows a comparison between both techniques concerning the inspection of parts with small flaws along the propagation axis, with big gaps between them. For that, we consider the Zone B of the test piece.

In both cases the 4 columns of 3 lines of 0.5mm SDH (in the range of 1 wavelength) are all visible despite that the 3 SDH are all along the same axis of the wave propagation.

In the case of the Conventional Phased array Zone Focusing technique, we can observe the repetition of the flaw echoes. After detailed verification with different test pieces and different hole diameters, it was determined that it corresponds to the propagation inside the SDH in the water. Zone Focusing is probably more sensitive, because the entire aperture is focused in emission as well as in reception, though Volume Focusing in this experimentation uses a plane wave for the transmit pulse.

In the case of Volume Focusing, we can notice a smaller decrease of the amplitude along the depth than with Conventional Zone Focusing. The same explanation as the previous note is given, Volume Focusing works in this case with a plane wave, though Zone Focusing focuses the beam in emission and in reception. The focusing degree then must be bigger in the near field focusing than far field focusing in the case of Zone Focusing, which explains the above-mentioned.

APPLICATION: SQUARE BAR INSPECTION

An interst in square bar inspection resides in the main part of the bar, but also with oriented flaws and sub-surface flaws. Targeted flaw inspections are not any more limited to defects with a long extension, but also to voids and inclusions. Artificial FBH (Flat Bottom Holes) or rounded bottom holes correspond to a good approximation of the real target. As the extension of flaws in length is limited, a very fast inspection concept that improves at the same time the detectibility is necessary. Volume Focusing provides the solution for this application.

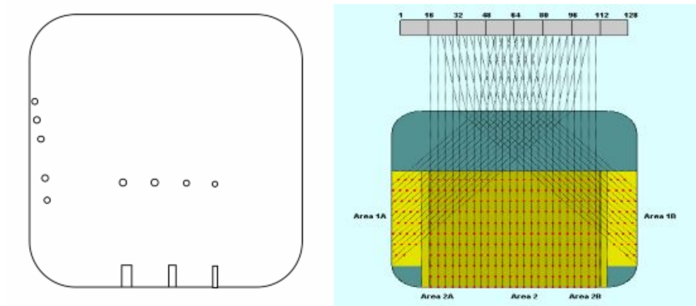

Figure 7: Square Bar drawing (left) and geometric view of sub-sequences (right).

The test piece has some flaws: 3mm and 2 mm SDH (Side Driled Holes) near by the middle of the test piece (at 2/3rd of the thickness); 1 mm SDH on the side of the test piece; 3 and 2 mm in the back (bottom) of the test piece. The inspection is done with 3 virtual electronic scanning using the Volume Focusing technique. The first sub-sequence concerns the left side, then the second sub-sequence concerns the middle of the part, and at last, the third sub-sequence concerns the right side of the part. Each sub-sequence contains 22 virtual Ascans, so that the complete section of the bar, where the whole sequence contains 66 virtual Ascans. The extension of the virtual Ascan in depth is limited to the 2 last 3rd of the thickness of the bar.

In the case of conventional electronic scanning, the PRF would be limited to 2Khz because of repetition ghost echoes in the water path as well as in the bar. So, the entire sequence would be 33ms (1/2000Hz x 66 configurations = 33ms). This speed of inspection is not enough. In the case of Volume Focusing, although the average ultrasonic path (including the water path) is longer than 150µs, the complete sequence is done within less than 2.7ms.

If we consider a linear line speed of 45m/min, that is to say 750mm/s, Volume Focusing allows a pulse density of 2mm, when conventional electronic scanning is limited to more than 24mm.

View of the different sub-sequence patterns of vitual scanning:

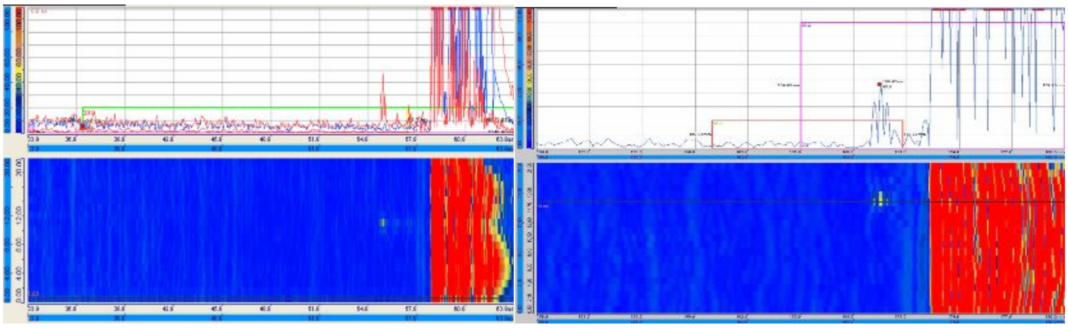

Figure 8: 2mm FBH 10mm form the bottom (left), 2mm FBH 3mm form the bottom (right),.

In the left picture, on the right part of the Bscan, below the Ascan, we can see clearly the 2mm FBH signal in the middle of the image. The red curve on the Ascan represents the peak hold of all the Bscan, the blue line represents the Ascan of the black cursor in the bottom of the Bscan. The right picture shows the detection of a 2mm FBH located at only 3mm form the back wall.

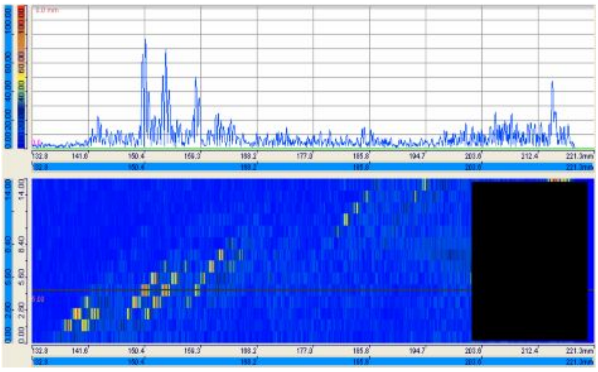

Figure 9: 1mm SBH 2mm from 1 to 5mm from the side of the part (right).

It is possible to see each of the 5 SDH with their reflection on the side of the wall of the part. They are located on the diagonal, with an absence of signal between the 3rd and the 4th SDH accordingly with the geometry of the test piece. The direct echo always comes in first, and the skip with the side of the part comes in second. Since the SDH is deep, as the test piece was designed, the SDH is farther from the side of the part, and then, logically, the skip echo occurs later.

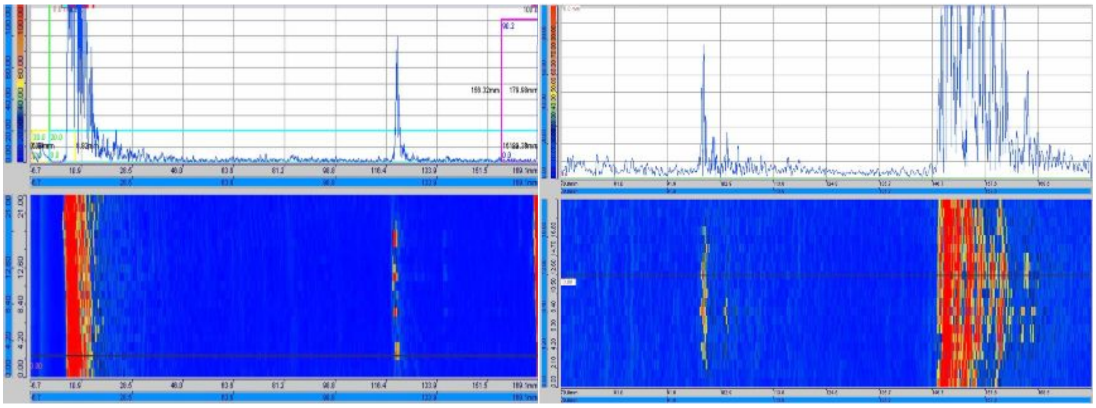

Figure 10: 4 SDH (2 of 2mm and 2 of 3mm) at 2/3rd of the depth of the part (left), 2mm SDH parallel to the section of the part (right).

The left picture shows the flaws located at 2/3rd of the thickness of the test piece. They are SDH of 3mm and 2mm, oriented parallel to the axis of the bar (perpendicular to the electronic plane of the probe). In the left side of the Bscan, we can see the surface echo, and in the extreme right side of the image, we can see the beginning of the backwall. We can distinguish very clearly the 4 SDH with a very high S/N ratio, better than 26dB in the worst case. The right picture shows also a SDH, but oriented along the electonic plane. Despite this orientation, which can be inadequate for a good detection, we can get a good detection all along the flaw.

CONCLUSION

Volume Focusing allows in all described cases an increase in inspection speed with a very high ratio, more than 10 in all cases, and typically 50. This increase in inspection speed is obtained without significant loss in lateral resolution, sensitivity and on the contrary with an increase of the depth of field.

Both in service inspections in power generation and OnLine inspections can benefit from this technique, as described in the experimetation for the reactor pressure vessel, and square bar inspections.

Besides the increase in lateral resolution, Volume Focusing does not shows significant drawbacks (The loss in lateral resolution when we compare the same number of elements in the aperture can be easily compensated by increasing the number of elements in the aperture), but a few advantages in the case of depth of field can be found.

This technique offers new possibilities for OnLine application as well as for field and maintenance purposes.

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