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A Breakthrough in Sputtering Target Inspections: Ultra-High Speed Phased Array Scanning with Volume Focusing

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ABSTRACT:

In the manufacturing industry, more and more plate parts are inspected to detect tiny defects. As the rate of manufacturing increases, new and innovative inspection methods are required. This paper presents the method and results for inspecting sputtering targets, which are typically used in LCD manufacturing. The flaws are either inclusions or disbonds, in the range of 0.5mm in diameter, or thin slits in the range of 5µm by 5mm long. Over the years, the technique progressed from using single element probes with high speed mechanical scanners to conventional phased array with electronic scanning. This improvement resulted in productivity increases by a factor of more than 4. However, Volume Focusing offers a new breakthrough in phased array technology, exceeding conventional phased array scanning speeds by a factor of 4.

KEY WORDS:

Phased Array; Ultrasonic; Inspection; ultra-fast; target inspection;

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.

Volume Focusing was developed to remedy this problem by using 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.

CONDITIONS OF THE EXPERIMENT:

For the experiment, a 10MHz, 128 element, 0.5mm pitch and line-focused IMASONIC probe was used. The mechanical scanner that was used to move the probe along the part was set so that the water path was 40mm.

The parts used during experimentation were mainly aluminum blocks or plates with EDM notches or holes. The parts that were inspected were generally around 30mm thick and never exceeding 100mm.

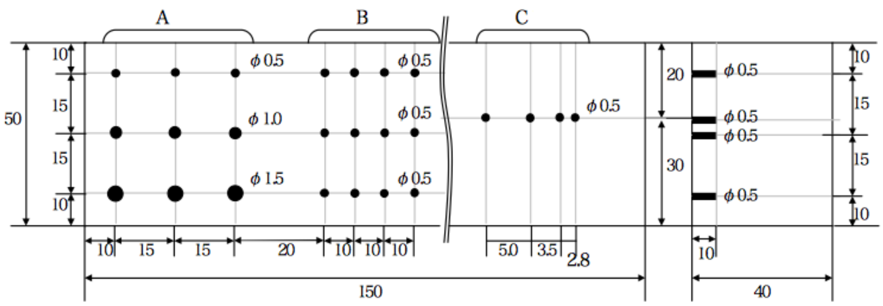

Figure 1: Typical Block drawing that was used for some experiments (front and side view)

The phased array system used for the experiments was the same as a typical unit delivered to customers (FlashFocus In-Line version: VF128).

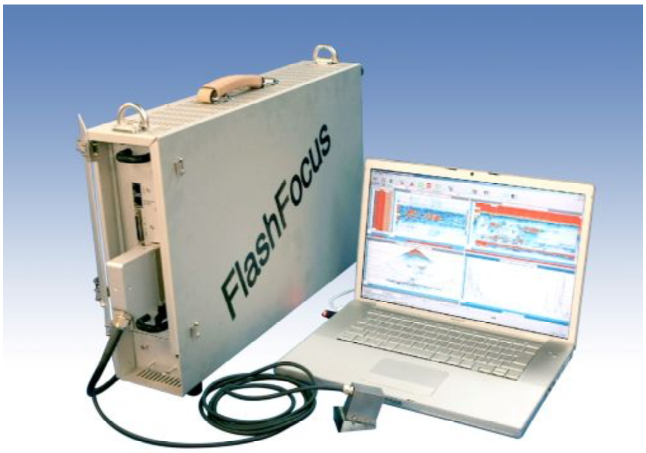

Figure 2: FlashFocus: It can also be integrated for In-Line inspection systems (VF128).

EXPLAINATION OF THE TRANSMITTED PULSE WAVE:

The so called near field distance (also called Fresnel distance) of the probe when all the elements are used at once is approximately calculated in our case by the formula:

$$N = a.\left(D^2 / 4.\lambda \right) \xrightarrow{With} a = 1$$

This formula is valid in the case of large discrepancies between the length and the width of the probe. When we apply the right values, it gives a near field distance of 6.8m in the water and 1.6m in the aluminum.

The beam is then used in the very near field close to the probe in a short distance. In this short distance after the probe, the field does not diffract, producing a flat and plane wave.

Here is a view of the field simulated in the first 100mm from the probe. The probe is not shown but is located in the lower corner in the left and is firing in the right and upper corner. The amplitude is represented by a vertical elevation.

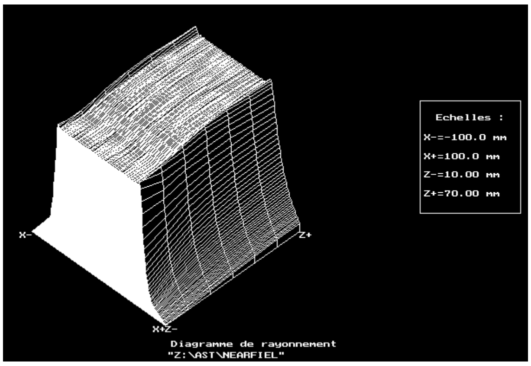

Figure 3: 2 Typical Plane wave issued from the transmit pulse in Volume Focusing

A FEW RESULTS WITH SIMPLE TEST PIECES:

Experiments with a typical SDH (Side Drilled Hole) block:

The following experimental results show that the lateral resolution is excellent and has the ability to detect flaws at different depths along the same axis.

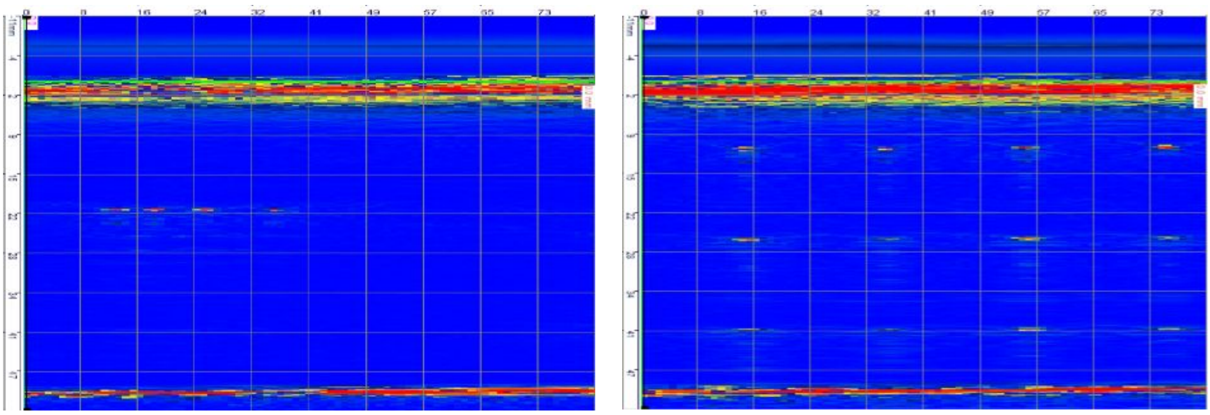

Figure 4: Lateral resolution (Left), Depth of field (Right).

On the left: The lateral resolution allows us 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).

On the right: 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.

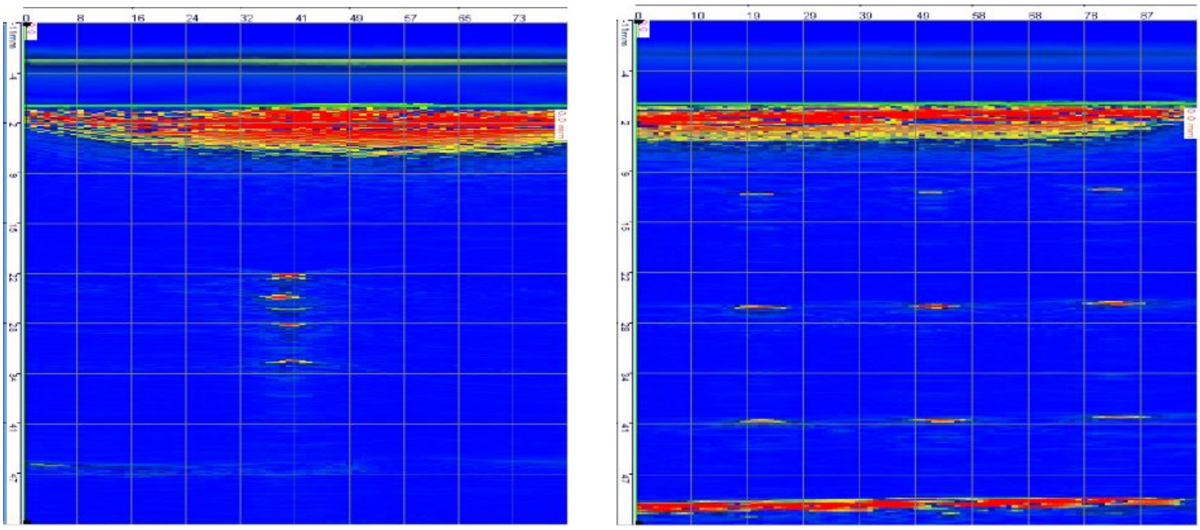

Figure 5: Axial resolution (Left), Depth of field (Right).

We can notice an excellent axial resolution and depth of field. Each flaw can be clearly identified despite the fact that they are very close to each other. Although the transmitted wave is a plane wave, the image of the flaws can be displayed perfectly.

Experiments with a typical FBH (Flat Bottom Hole) block:

Artificial flaws that are the closest to real flaws are typically FBH. This is the reason why much attention has been spent on experiments with FBH specimens.

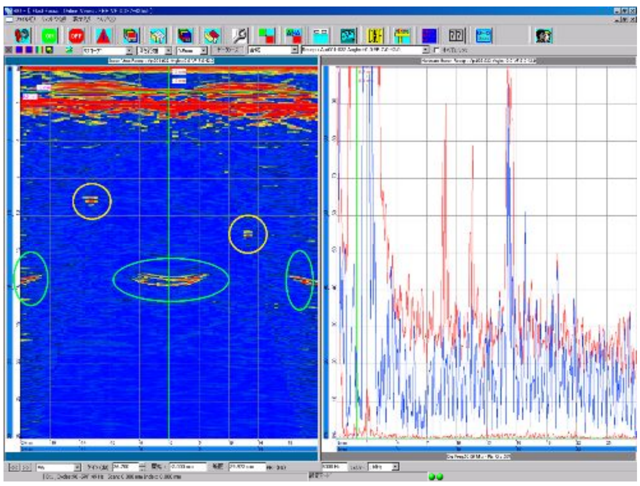

Figure 6: Results on 0.7mm FBH at depths of 7 and 10mm.

The signals surrounded with yellow circles are from FBH. The signals surrounded with green circles are expected echoes due to the geometrical construction of the block. These other echoes resulted from slits that mark out the surface of the part. One slit marks the presence of an FBH in its center. These slits are quite big which explains the high level of noise, as well as the large amount of extra echoes.

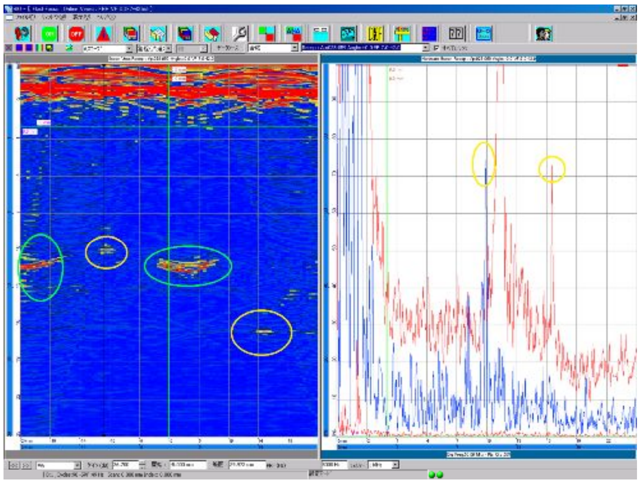

Figure 7: Results for 0.7mm FBH at a depth of 12 and 20mm.

The sensitivity along the depth is not decreasing much, because Volume Focusing is compatible with DDF (Dynamic Depth focusing). DDF allows you to change the depth of the focusing within the same inspection. Applied to Volume Focusing, it allows you to get images with excellent lateral resolution and sensitivity throughout the specimen.

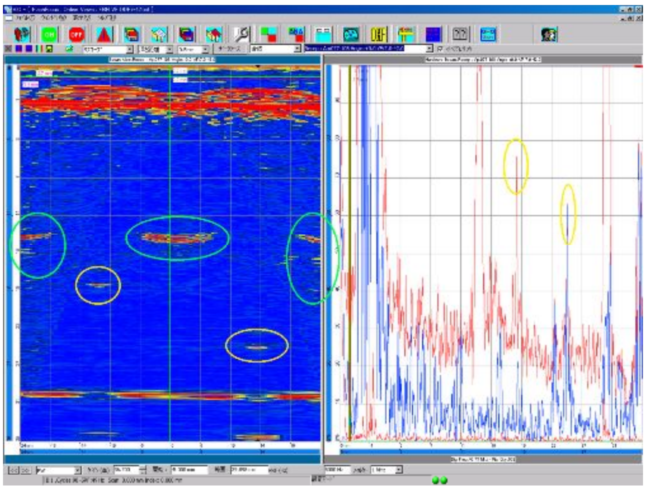

Figure 8: Results for 0.7mm FBHs at depths of 20 and 28mm.

VOLUME FOCUSING VERSUS CONVENTIONAL PHASED ARRAY:

With single element probes, the mechanical motion is the bottleneck of the total inspection speed. For example: The maximum PRF possible without problems of repetition ghost echoes was in the range of 8KHz for this application. A pitch of 0.5mm would require a mechanical speed of 4m/s which is not realistic because of hydraulic limitations. Usually, 0.5m/s is used as a max speed of inspection. A 0.5mm pitch in both X and Y, corresponds to a PRF of 1KHz, a 25m^2 (5m by 5 m) surface of material is inspected in approximately 6 hours. If the mechanical pitch is increased to 1mm, corresponding to a PRF of 500Hz, the inspection speed is unchanged, and a 25m^2 (5m by 5 m) surface of material is still inspected in approximately 6 hours.

With conventional phased array, the PRF is the bottle neck of the speed inspection. If the PRF is too high ghost echoes will appear. For this application, 8KHz is the maximum. Let us consider that the probe inspects a band of 50mm per sequence and with an electronic pitch of 0.5mm, meaning that 1 sequence can be performed at 80 Hz. If we consider a Y pitch of inspection of 0.5mm, the mechanical motion along the Y axis is about 40mm/s. Then, a 25m^2 (5m by 5 m) surface of material is inspected in approximately 3 and half hours. If the mechanical pitch is increased to 1mm, the inspection speed is doubled, and a 25m^2 (5m by 5 m) surface of material is inspected in approximately 2 hours and 45 minutes.

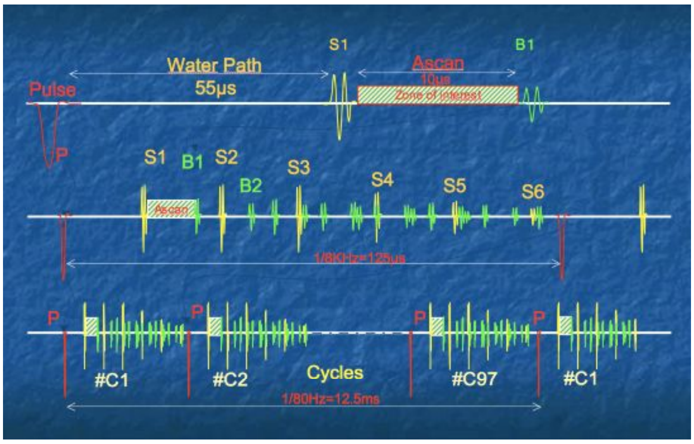

Figure 9: Inspection sequence with conventional phased array.

With Volume Focusing, the PRF is equal to the SRF (Sequence Repetition Frequency). The sequence is composed of the acquisition cycle and calculation of the Bscan and resulting gate values. In the present acquisition, the acquisition cycle consumes only 55µs (~40mm of water path) and 10µs (30mm of steel path), which is roughly less than 70µs in total. The actual calculation time of the Bscan and gate values for 1 section is 2,910µs. The complete sequence consumes approximately 3ms (333Hz). With a pitch of 0.5mm, it allows a mechanical motion of 166mm/s. In such conditions, a 25m^2 (5m by 5 m) surface of material is inspected in approximately 50 minutes. If the mechanical pitch is increased to 1mm, the inspection speed is doubled at 333mm/s, and 25m^2 (5m by 5 m) surface of material is inspected in approximately 25 minutes.

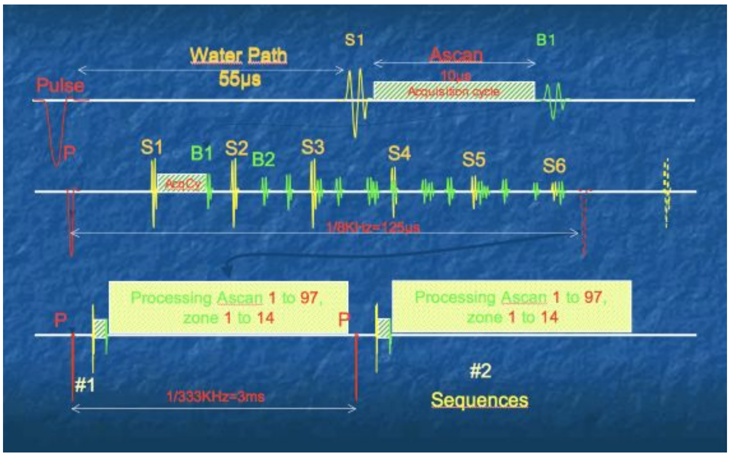

Figure 10: Inspection sequence with Volume Focusing phased array.

In addition, with the actual electronics, there is some room to increase the processing speed by a factor of 3, so that the inspection speed could increase again, this time, the mechanical motion speed would become the bottle neck, 25m^2 (5m by 5 m) surface of material would be inspected in approximately 16 minutes. If the mechanical pitch is increased to 1mm, the inspection speed is unchanged at 0.5m/s, and 25m^2 surface of material would be still inspected in approximately 16 minutes.

It is important to notice that for many industries such as target inspection, the inspection speed is the key factor, so that Volume Focusing is drawn to a successful future in the industry.

RESULTS WITH A TEST PIECE CONTAINING REAL FLAWS:

A test piece with a variety of real flaws was tested with both techniques, such as disbonds, inclusions, voids and cracks. In both techniques, the inspection speed was the maximum available. In the following picture, we can see small differences, but basically the results are similar. The difference mainly comes from the fact that calibration was not yet activated in the Volume Focusing technique experiment.

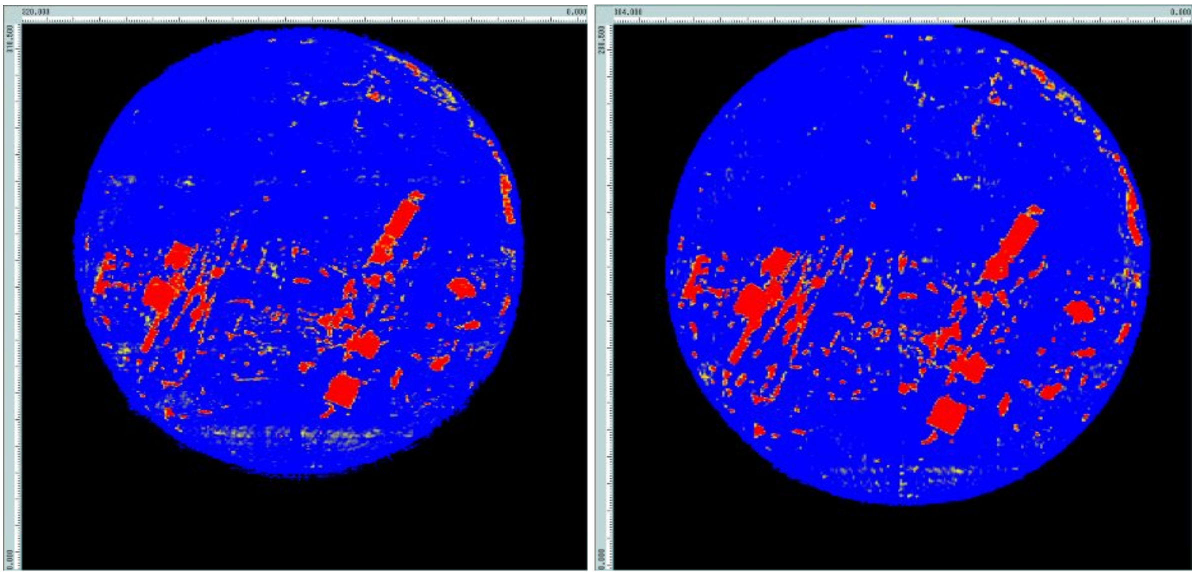

Figure 11: Result with Volume Focusing (Left) Result with conventional Phased Array (right)

CONCLUSION

Volume Focusing allows you in all the described cases an increase in inspection speed with a very high ratio of more than 4 in comparison with even the fastest conventional phased array technology for sputtering target inspections. This increase in inspection speed is obtained without significant loss in lateral resolution and sensitivity. With an increase in the depth of field a reduction of the ghosts is achieved, leaving the speed to be limited by the hydraulics that restricts movement to less than 0.5m/s.

Besides the increase in lateral resolution, Volume Focusing does not show significant drawbacks; rather it offers advantages to the depth of field. The loss in lateral resolution when we compare the same number of elements in the aperture can be easily compensated by increasing the element number in the aperture.

In the selected application for Target inspection, the inspection is done with a scanning speed of up to 0.5m/s with a band of 50mm width, so that the inspection speed is in the range of 1 m^2/min.

This technique offers new possibilities for In-Line applications as well as for field and maintenance purposes.

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