Why you should not use a focussed beam for general weld inspections

NDT.net forum discussion topic
Aug. 2015/Ed Ginzel

To Focus or Not to Focus, That is the question;
Whether 'tis better in the mind to suffer
The Slings and Arrow of outrageous TCGs
Or to take natural divergence against a Sea of defects.

Not exactly the contemplation of life and death as Shakespeare wrote it for Hamlet, but perhaps it is a worthwhile consideration in PAUT weld inspection.

It has been drawn to my attention that there are still NDT training facilities where instructors are telling students of phased-array ultrasonic testing of welds, to focus the beam as part of the inspection setup. This topic has been broached before on the NDT.net forum; (http://www.ndt.net/forum/thread.php?admin=&forenID=0&msgID=56991&rootID=56972#56991) where in January of 2015 a formula was indicated to be used to set "focal depth".

I suspect that a part of this problem has been the way in which some manufacturers of PAUT sets have configured their software's User Interface. Handy input boxes are generally provided in the User Interface. The user is expected to enter information about the probe and test piece and the desired scanning technique. Typically the user is asked to enter parameters like the number of elements to use in the active aperture, the start element, and the step size (number of elements for E-scans or angle increment for S-scans).

In addition to these parameters, most software asks for a focal distance of some sort. Because it is a User Entry parameter, the user is expected to provide a value. But it seems that not only do the users not understand the concepts, neither do some of the instructors.

By now, even most instructors should be aware that the beam focus is limited by the near field distance. A beam cannot be "focussed" at any distance greater than the near field distance. Identifying the actual near field becomes a challenge when we add a wedge and the beam is refracted. The shortening of the near field distance has been estimated by a variety of empirical formulae and it is incorporated into some of the manufacturers' software. Details of this problem were discussed in our paper in 2014 (http://www.ndt.net/article/ndtnet/2014/4_Ginzel.pdf).

To add to the concerns of focussing inside the near zone, there is the issue of plane of focus. It is possible to focus all the beams in an E-scan at a specific depth. This requires changes to each delay-law to compensate for wedge-path differences on an angled wedge. Or, if using an S-scan, perhaps the user plans to focus at a soundpath (half-path distance) or at the fusion line of a weld so the focal plane will be at some angle and a specific distance from the active aperture.

But not all manufacturers have software to allow for the beam to be focussed at any plane. And at least one manufacturer does not even indicate which plane is being used when the User Interface requires the user to enter a focal distance. So what does the user enter??

Focussing would typically be used to improve resolution of small thickness changes when performing corrosion assessments; or perhaps when trying to increase the response from nonfusion or inclusions at a specific plane in a weld. But this is done at the expense of reduced resolution to indications at greater or lesser soundpaths. Another reason to focus is to attempt to reduce the signal amplitude of geometries in close proximity to the point at which the beam is focussed.

For a general weld inspection there should be no focusing applied when using PAUT. It is possible that an instructor will rationalise that the use of a TCG will compensate the reduced sensitivity before and after the focal distance...but the application of TCG does not improve the resolution; which is usually the primary "raison d' être" for focussing!

At the focal point, the beam has its smallest dimensions and therefore the lowest sensitivity to off-axis features. But a general weld inspection is not only looking for indications at a specific soundpath. It is looking for flaws throughout the entire volume of the weld and heat affected zone. Dynamic Focussing can be applied to overcome the beam divergence, but this uses an unfocused transmitted pulse and only the receiving delay laws are focused.

In normal pulse-echo operation, the use of focussing increases the sound pressure at the focal region, but at the expense of reducing pressure at a faster rate after that point. To illustrate the effect, Civa modelling is very helpful.

To illustrate the effects we have used the Civa beam modelling to provide pressure plots for a commonly used probe and aperture. The linear array probe is a 5L64 with a pitch of 0.6mm and a passive aperture of 10mm. It is placed on a 36.5° refracting wedge of cross-linked polystyrene and elements 1-16 are used to make a 45°, 60° and 70° beam that is unfocussed. The delay laws were then adjusted to provide the same angled steering but focussing at a depth of 10mm below the test surface. The beams were modelled for the transverse mode in a steel block 100mm thick.

At 45° refracted angle we see the beam has a near zone 37mm along the soundpath from the entry point into the steel. This is equivalent to a depth of focus of 26mm below the test surface.

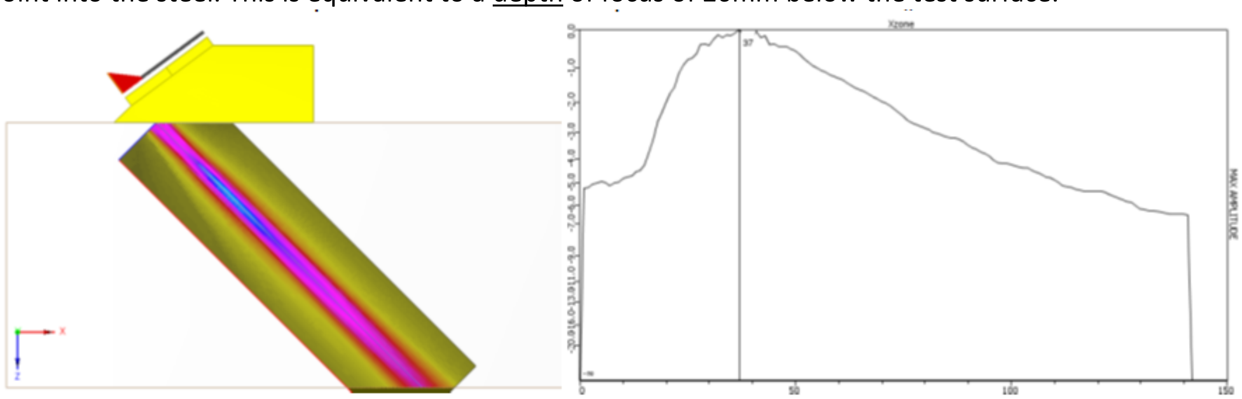

Figure 1 **45° unfocused beam**

The same aperture steered at 60° is seen to have a near field of 31mm along the beam axis in the steel, equivalent to a depth of 15.5mm.

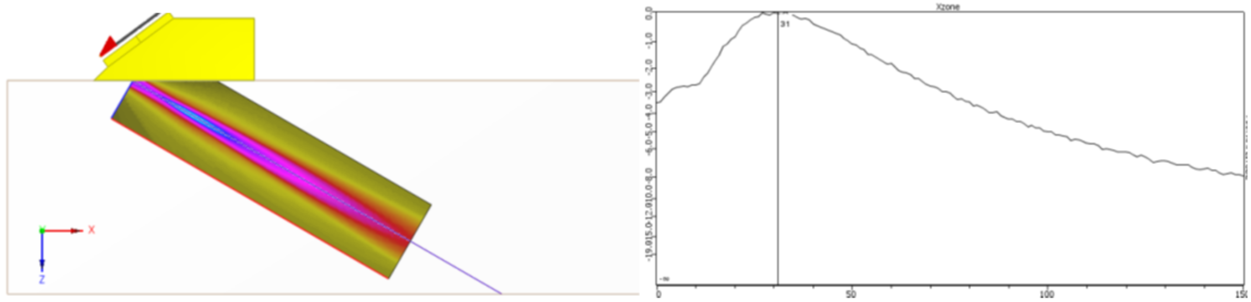

Figure 2 60° unfocused beam

The same aperture steered at 70° is seen to have a near field of 27mm equivalent to a depth of 9mm.

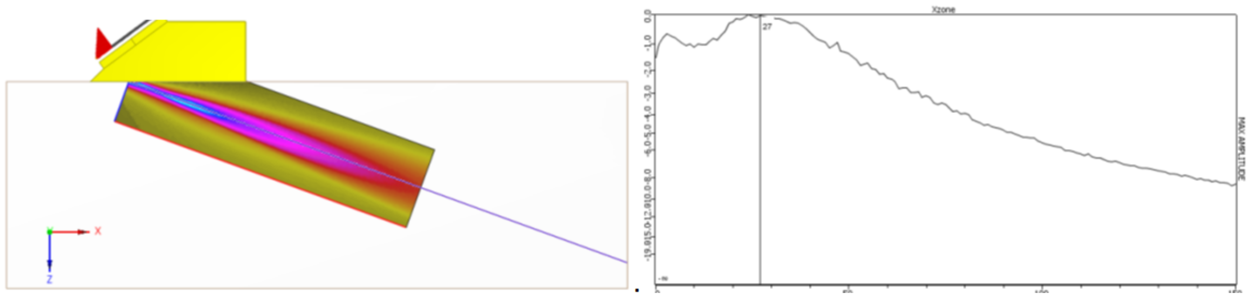

Figure 3 70° unfocused beam

By overlaying the amplitude plots, we can compare the relative pressures along the centre of beam axes for the three unfocused delay law conditions. In addition to the shift of the near zone to shorter (and shallower) paths, we also note that there is a relative reduction in amplitude as angle is increased.

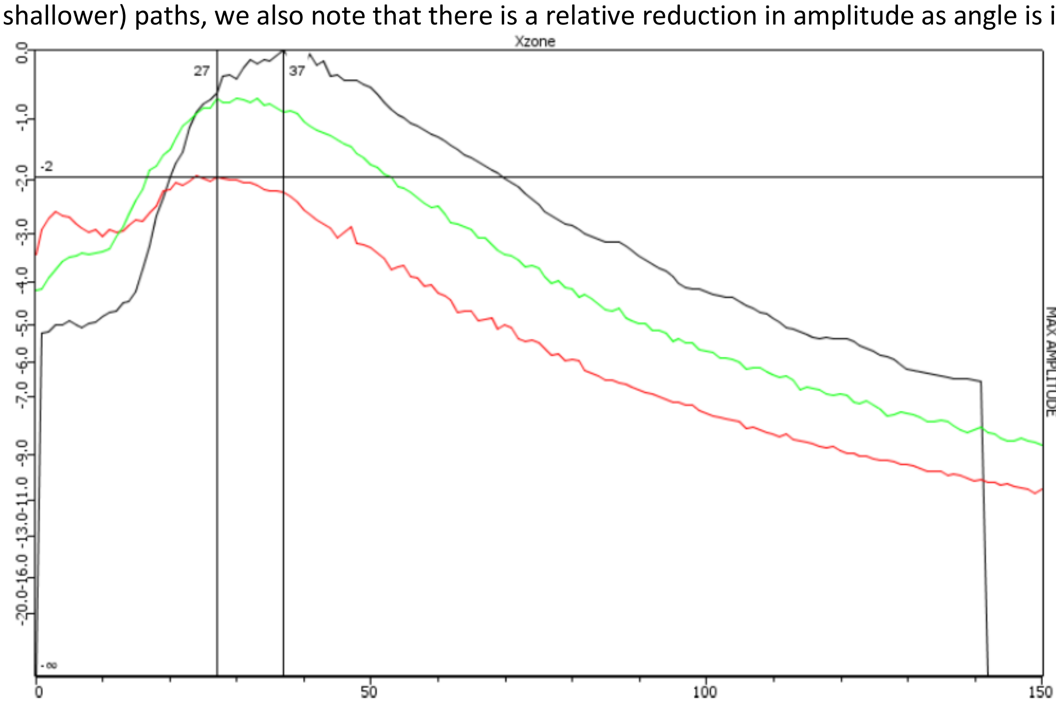

Figure 4 Relative beam pressures along centre of unfocussed beam axis (45° Black, 60° green, 70° red)

This difference is typically compensated when the user constructs a TCG.

When imaged on a simple V-bevel weld in a plate 25mm thick, we can see that, when the beam is plotted for equal time of travel, the 70° beam is approaching the area of interest in the root as the 45° beam has reached the cap after a skip off the far surface. In the 25mm thickness example, this occurs at the soundpath equal to about 70mm. The amplitude difference between the 45° and 70° beams at that point is 3dB.

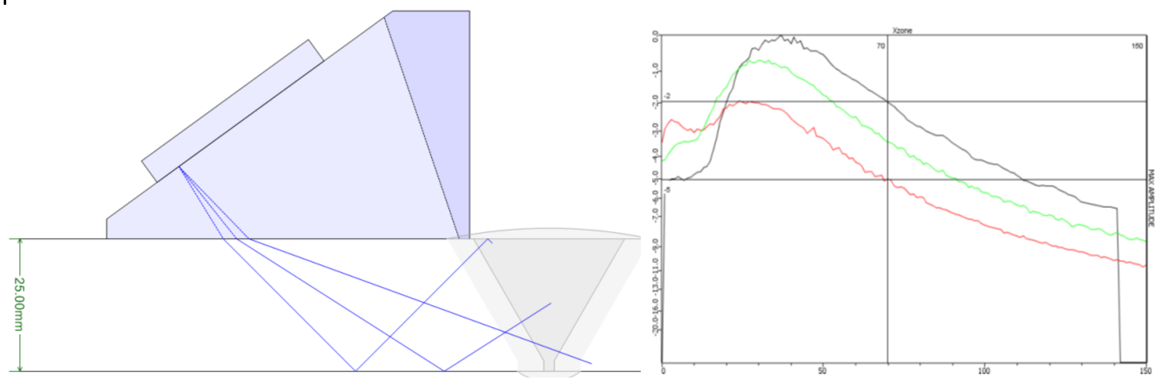

Figure 5 Relative amplitudes for unfocused beams at 70mm sound path

To illustrate the effect of focussing at a fixed depth, we plot the beam pressures for a 10mm depth of focus for the three beams using the same apertures.

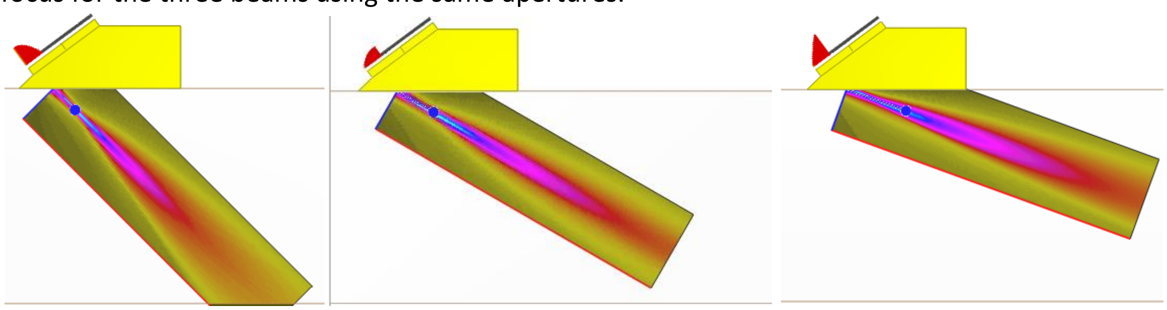

Figure 6 45°, 60° and 70° beams focussed at 10mm depth

When comparing the three angles focussed at 10mm depth, we see that the 45° beam has had a noticeable shift to about 16mm metal path (equivalent to about 11mm depth). However, the 60° and 70° beams both have their peak responses at 24mm sound path.

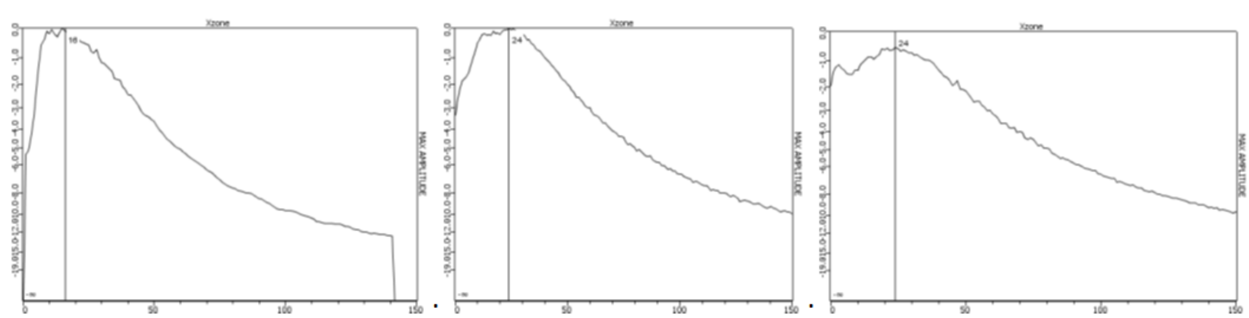

Figure 7 Relative focal distances for 45°, 60° and 70° beams focussed at 10mm depth

When compared one to the other and normalised to the 45° focussed beam, the focussed beams are seen to have a similar difference in sensitivity at the focal point as that which was obtained for the unfocussed beams; i.e. 3.2dB. However, we can see that the rate of decay of the beams is no longer following parallel curves. Instead, the 45° beam drops off much faster than the 60° and 70° focussed beams.

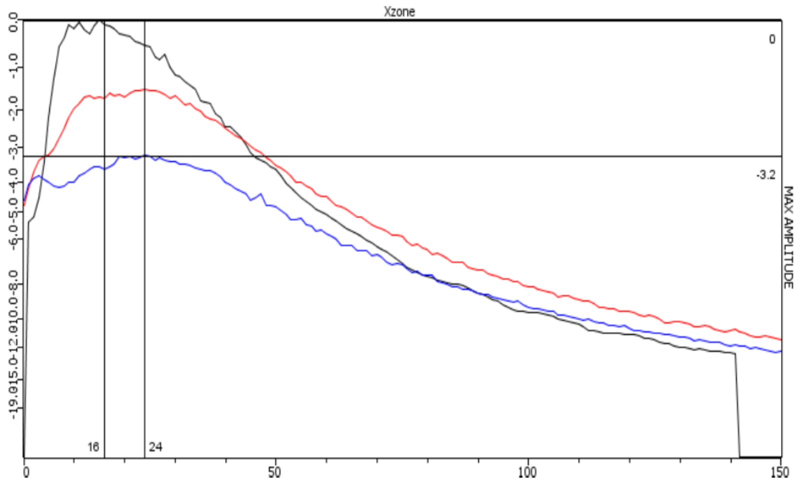

Figure 8 **Relative beam pressures along centre of focussed beam axis (45° Black, 60° red, 70° blue)**

More importantly for the purposes of weld inspection, we should compare the relative amplitude of the focussed and unfocussed beams.

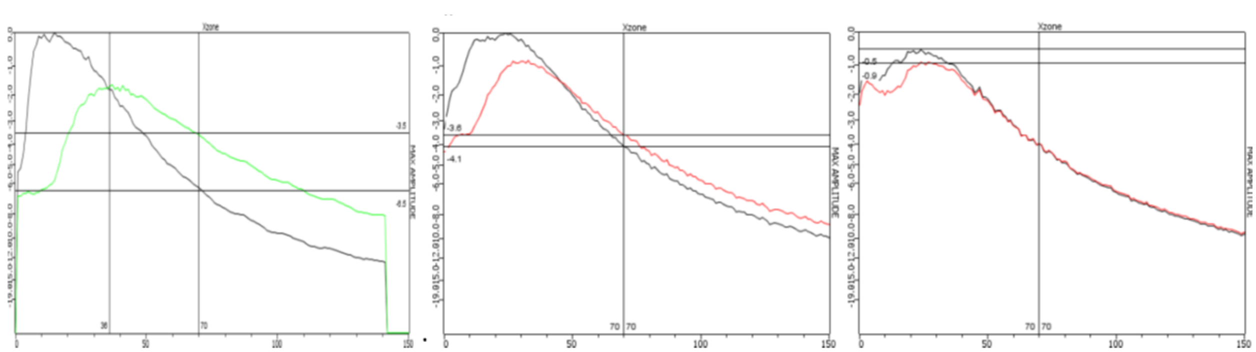

Figure 9 **Comparing relative beam pressures for focussed and unfocussed beams (45° left, 60° middle, 70° right)**

Figure 9 illustrates how the relative increase of sensitivity at the focal point decreases with increasing refracted angle when focussed at the same depth. I.e. the 45° focussed beam is about 2dB more sensitive at its peak compared to the unfocussed 45° while the 70° beam is only about 0.5dB more sensitive at its peak when focussed.

However, at a useful working range (e.g. 70mm in the example in Figure 5) focussing actually reduces the sensitivity for the 45° beam and requires significant (3dB) correction compared to the 60° and 70° beams which indicate very little benefit from focussing.

When we refer back to Figure 5, we see that the focussing increases sensitivity in a region 16-24mm from the entry point of the beam. However, this is in the plate well before the weld or heat affected zone! This increase of sensitivity was done at the expense f reducing sensitivity in the weld/HAZ zone, thereby requiring the operator to use more receiver gain in the TCG construction in the region of interest. As a result of the increased beam spread that occurs after the focal point there is reduced beam resolution. Therefore, closely spaced indications are more difficult to resolve.

In summary I would like to recommend that for general weld inspections using PAUT, no focussing is used. It would also be helpful if equipment manufacturers provided an option to configure delay laws or User Interfaces that provide beam steering without beam focussing.