# Corrosion Monitoring and Thickness Measurement

## - What are we doing wrong ?

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ASNT Level III - JM1191

## INTRODUCTION

During the last three years my interest in the use of ultrasonics for the detection of corrosion and the measurement of remaining wall thickness has been re-awakened. The method has been extensively used to verify and quantify Magnetic Flux Leakage (MFL) results. Discrepancies between ultrasonic and MFL results have usually been put down to "Another MFL false - call." However, having watched many ultrasonic tests being carried out, I have come to believe that the boot is often on the other foot and that we place too much faith in the ultrasonic method for corrosion monitoring. The techniques used by many practitioners give rise to serious shortcomings in both probability of detection, and accuracy of remaining wall assessment. These shortcomings are not confined to corrosion monitoring of flat plate, but apply equally to pipe and vessel inspection. This paper looks at the root causes of poor performance with ultrasonics and suggests some methods to improve the situation.

## REFLECTIVITY

As with any proposed ultrasonic procedure, we first need to consider the nature of the target reflecting surface since this will affect signal amplitude and thus the probability of detection. Reflectivity and other factors to be discussed later can also have a significant influence on the accuracy of remaining wall thickness measurement. The amplitude of an echo from a target reflector depends on the following factors [10] :-

AREA of the reflecting surface

ORIENTATION of the target

SHAPE of the target

SURFACE ROUGHNESS of the target

BEAMPATH RANGE to the target

ATTENUATION of the test material

In the context of erosion/corrosion monitoring we need to look at how these factors vary with typical targets. We can probably ignore attenuation and far field beampath range since we are usually dealing with rolled, drawn or forged materials with a maximum thickness not greater than 30mm or so.

The ideal reflector would be flat, smooth, parallel to the scanning surface and larger in area than the beam cross section at that range. Unfortunately corrosion and erosion are not ideal reflectors. Purely for illustrative purposes I shall describe three basic categories of target reflector we might encounter in "corrosion monitoring" and look at their inherent reflectivity.

**1. EROSION**

Fig. 1 illustrates erosion at a pipe bend, the sort of problem which was amongst the first to be solved by ultrasonics. As a reflector it is quite reasonable, the gradient is gradual over most of the length of the eroded area - so it is nearly parallel, the surface is relatively smooth, and the overall area is much larger than the beam cross section. Even at the top of the bend, where the erosion gradient is steeper, we can expect a reasonable signal. An ultrasonic probe placed anywhere in the eroded region is therefore likely to give a reasonable echo amplitude, and, with care, a reasonable measurement accuracy.

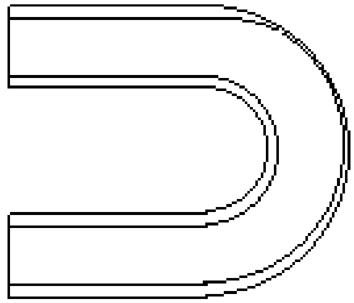



Figure 1

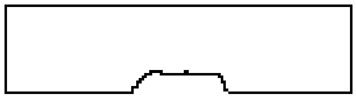



Figure 2

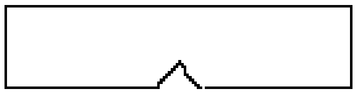



Figure 3

**2. LAKE TYPE PITTING**

This type of pitting is illustrated in Fig.2. The major part of the reflecting target is relatively parallel to the scanning surface, not quite as smooth as the erosion shown in Fig1, and it is much more localised than the erosion. In fact the area of the flat part of the lake could be smaller than the beam diameter. Though probably not such a good reflector as the erosion, it will nevertheless give an adequate echo amplitude - provided that the ultrasonic probe is placed over the "flat" region.

**3. CONE TYPE PITTING**

This type of corrosion pitting, illustrated in Fig.3, is very common and is the most difficult to detect. The major reflecting surfaces are not favourably orientated, the surfaces are rough and often ridged, and the target area is often small in relation to the beam cross section. The latter is true particularly of the tip of the pit, which may not be the most reflective facet of a ridged pit. This type of corrosion has the lowest probability of detection and the greatest inherent inaccuracy in its measurement.

**PROBABILITY OF DETECTION**

I think it wise to consider probability of detection first. The highest degree of measurement accuracy on detected pits is of little consolation if the deepest pit has not been detected. Based on the three reflector types described above, I consider that the probability of detection depends on the following three topics:

Scanning technique

Calibration technique

Probe and Flaw detector characteristics

## 1. SCANNING TECHNIQUE

Two quite different approaches are in common use, spot readings on a defined grid pattern, and area scanning on an overlapping raster pattern. Clearly the grid pattern technique is suitable for erosion monitoring if a suitable grid spacing is chosen. From the reflectivity of erosion we can suppose that both Digital Thickness Meters (DTM's), and 'A'-scan ultrasonic flaw detectors (UFD's) would be suitable for this application. The DTM is simpler to use and may have some advantages in the hands of less experienced operators. However the grid pattern technique is just as clearly <u>not</u> suitable for isolated pitting of either lake or cone type. Hoping that any corrosion pit will coincide with one of the grid points is like a game of Russian Roulette, or playing the National Lottery. So if we want to detect pitting type corrosion, we <u>must</u> use an area scanning technique. Nevertheless, I still see operators taking 12 random readings on a plate 10 metres by 2 metres !

An area scan using an overlapping raster can be a slow process and most operators, believing that they are taking the greatest care, make it painstakingly slow. In fact they are decreasing the probability of detection because almost certainly when they encounter a corrosion pit, the first indication is a loss of backwall echo. This they assume is due to loss of couplant, so they lift the probe, apply more couplant and replace the probe - but not exactly where they left off! A movement of as little as 1.5mm can make the difference between no signal and a normal backwall echo. If, by chance, this is what happens, the scan continues and the defect is missed! What we should do is to use a <u>rapid</u> <u>scan</u> because the natural reflex action of the eye and our brain is to react to a sudden change in visual image. The rapid change in pattern when scanning at speed across a corrosion pit, particularly the cone type, is very characteristic and quite distinct from couplant loss. The initial scan of a 250 x 250 mm square should take no more than 30 seconds. I will describe the complete set-up later in this paper and you can try it for yourselves, this is one case where seeing is believing.

## 2. CALIBRATION TECHNIQUE

There are two main aspects of calibration, gain and timebase range. Most operators treat both in the way they were taught during training, as a precise thickness measurement exercise on finished product with ideal parallel machined surfaces. In order to extract maximum accuracy the fastest possible timebase range for the wall thickness is used, and the gain is adjusted to a value which puts the first backwall echo at some value below full screen height ( see Fig. 4 ). Following their training to the letter, this gain setting is rigidly maintained throughout the scan.

But, as we have seen, the reflectivity of corrosion pitting is poorer than the reflectivity of either the calibration block or the normal plate or pipe backwall. The gain really needs either constant adjustment, or setting at a much higher level than for finished product inspection. I prefer to adjust the timebase so that three backwall echoes from the plate or pipe are displayed, and set these at 3, 6, & 9 along the timebase. The gain is adjusted so that the third backwall echo is at 80% full screen height ( see Fig. 5 ). Even at these settings the gain is adjusted during the inspection when circumstances demand. So the first method might be suitable for erosion, but for pitting, the second approach is better.

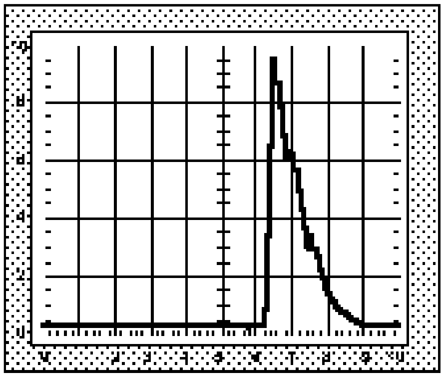


Figure 4

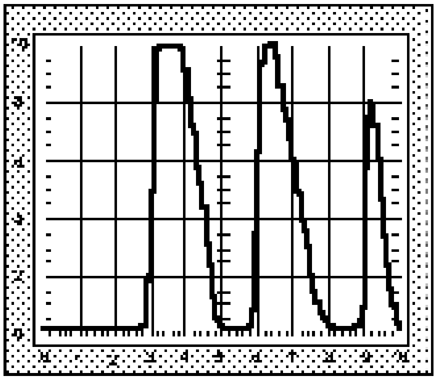


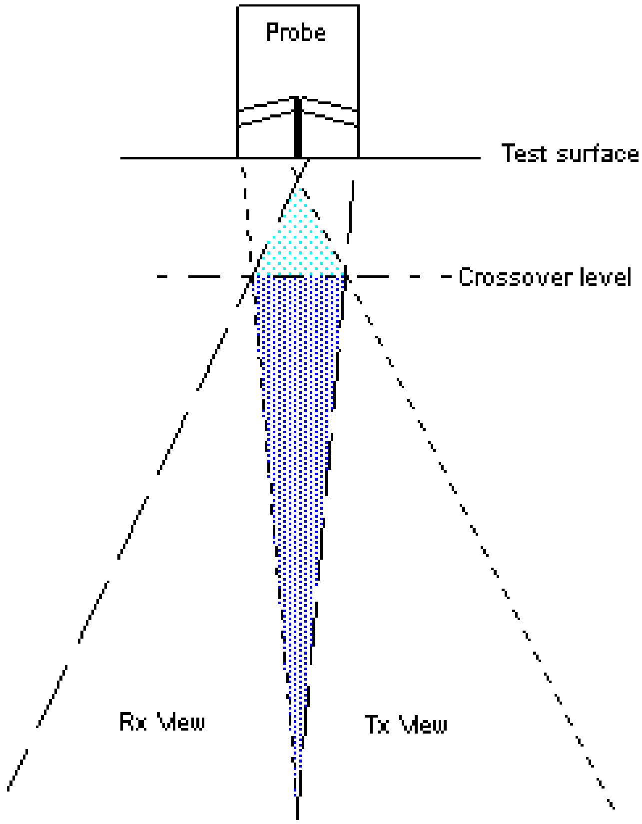
Figure 5

## 3 OTHER FACTORS

The choice of instrument, or more particularly, the display mode, and the probe characteristics also have a significant impact on probability of detection. We have seen that the simple DTM is suitable for detecting erosion, but for pitting, an A-scan display is essential to allow the operator to judge whether a particular signal, or lack of signal, is significant. Even with an A-scan display, unless the characteristics of the twin crystal ultrasonic probe are taken into consideration, there is a serious risk that the deepest pits may be missed

Fig. 6 illustrates a typical twin crystal compression wave probe showing the field of view of the transmitter and that of the receiver. Only in the shaded region, where the two fields of view coincide, can echoes be obtained. Outside this region, either the transmitter doesn't interrogate the spot, or the receiver doesn't catch the echo. Within the shaded area the significant zone is the triangular portion from the test surface to the beampath range at which the transmitter beam completely crosses the receiver viewing angle. Close to the scanning surface ( the apex of that triangle ) not much of the transmitter beam reflecting from that range is seen by the receiver. The proportions increase until they maximise at the crossover range. In this triangle even very large reflectors will only give small echo amplitudes, the closer to the scanning surface ( ie the thinner the wall ) the smaller the echo. If the operator suspects that the reflector is within this region, he needs to adjust the gain.

The best way to appreciate this problem is to look at multiple echoes in, say, 10mm of steel and 3mm of steel with a standard twin crystal probe. Fig. 7 illustrates the multiple echo decay pattern for the 10mm plate, and Fig. 8 shows the pattern for the 3mm plate. There are no surprises in Fig. 7, the first backwall echo is the largest, and subsequent echoes follow the expected decay pattern. But in Fig. 8 it is the third backwall echo which is the largest, and normal decay comes with subsequent echoes. The first two echoes climb up to the third in a sort of reverse decay. These are the echoes which are at a range which is inside the shaded triangle. Too little gain and a touch of suppression and another pit has been missed!




Twin crystal probe - effective beam

Figure 6

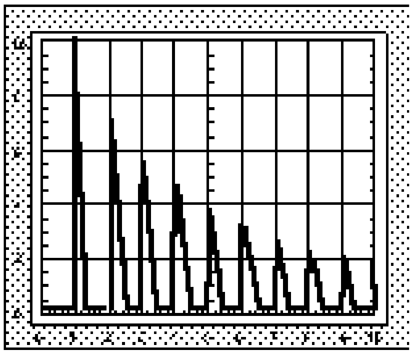


Figure 7

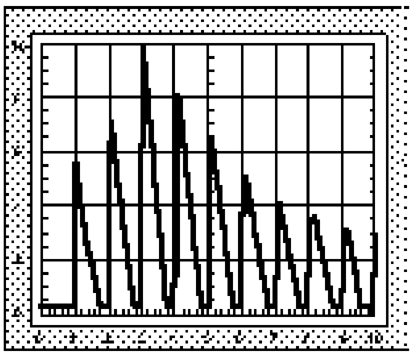


Figure 8

## IMPROVING PROBABILITY OF DETECTION

We can use the pointers raised above to devise a technique which should improve the probability of detection of corrosion pitting, particularly the cone type. We need to use plenty of gain, especially if the remaining wall thickness is likely to come within the crossover range of our twin crystal probe, and the calibration shown in Fig. 5 forces us to get the first backwall echo well into saturation. Using multiple echoes placed at 3, 6, &9 on the timebase irrespective of wall thickness ensures that we have a standard signal pattern to which the eye becomes accustomed quite quickly. Finally we need to carry out a raster scan using a rapid probe movement and sufficient overlap to ensure coverage. How does one define "rapid" in an article such as this ? The nearest I can get is to say that I use a raster to cover about 250mm (10 inches) width at about the cycle frequency of my windscreen wipers on "Fast wipe".

## INTERPRETATION

As you scan over sound plate or pipe at this speed, the three signals will "shimmer" that is to say that there will be small rapid changes in amplitude due to surface roughness, couplant, and probe pressure. If you scan over a region in which there is no couplant, or where scale or dirt is obstructing coupling efficiency, the entire three signal pattern will "flick" off with no sideways movement. On the other hand, if you scan over a pit, the signal pattern will move left and down in a characteristic way which is better seen than described ( see Fig. 9 ) - I can only suggest you try it for yourselves! There is a difference which, with practice, you can spot when you traverse a lamination. In this case the signal pattern jumps left rather than slides left, and often the amplitude change is less severe than for a cone shaped pit. There can still be a problem in the interpretation of laminations because large lake type pits can give a similar effect. If in doubt, try using a shear wave bottom corner reflector technique to confirm your interpretation - you won't get a bottom corner reflector from a lamination.

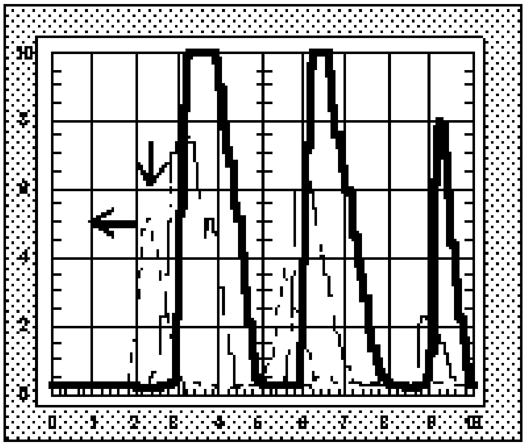


Figure 9

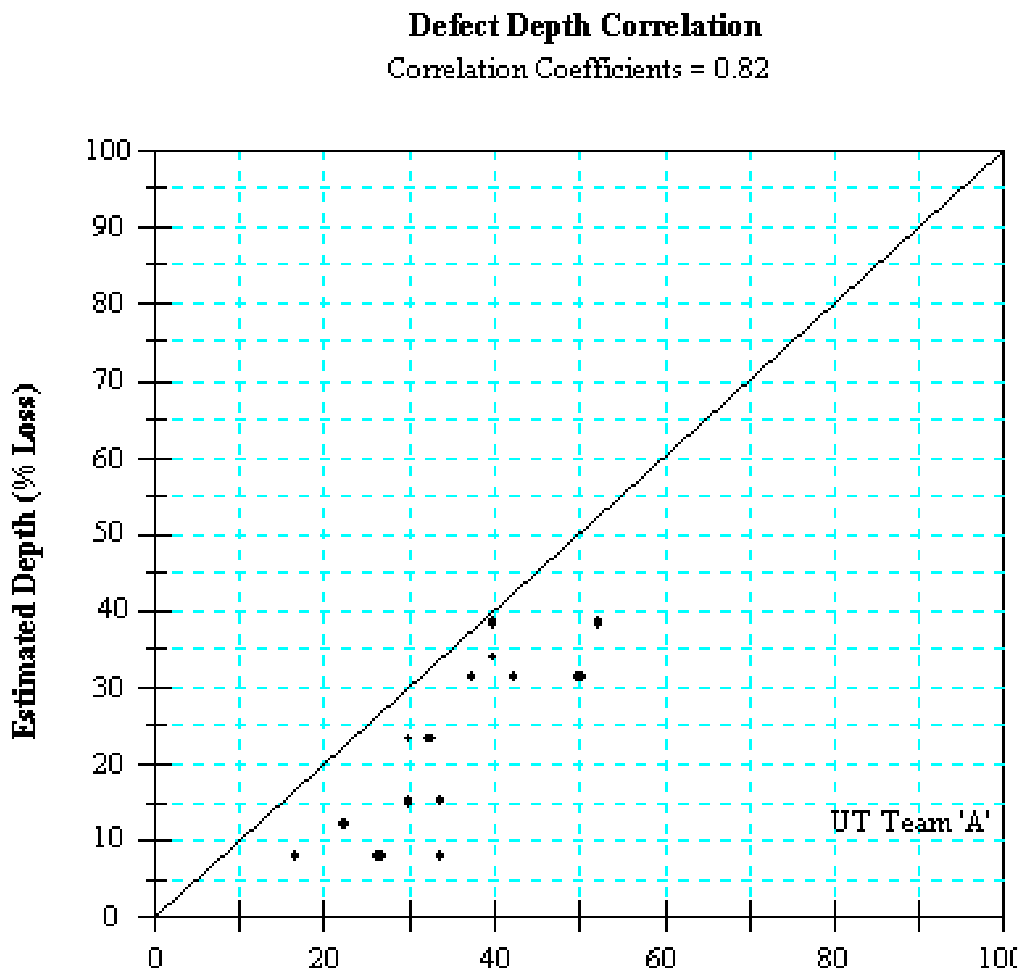
When I use this technique, I usually complete the entire scan in one go, rather than stopping at each indication, but I do make a mental note of the suspect regions. On completion of the full scan, I go back to the suspect regions in turn, re - identify each pit, reduce scan extent and slow scan speed until I "hone in" on the individual pit. When I am sure that my probe is right over the pit, I mark it's location for remaining wall measurement. Measurement can be carried out using any good thickness technique which the operator favours, I'm lazy and don't like constant re-calibration so I use my 3, 6, &9 calibration. The way I go about this is to start off by doing a normal thickness check in several spots on sound plate or pipe before doing the corrosion survey. I take the average of these readings and note this as "average wall thickness for that section of plate or pipe. Then when I have identified the pit using my scanning calibration, I adjust the gain to ensure I am displaying the thinnest reading and carefully read this from the timebase - of course it will always be less than 3. I take this thinnest reading (n), divide the value by 3, and multiply by the "average wall thickness" (T) - the result is remaining wall thickness (R**)**. Expressed another way:-

$$R = \frac{n}{3} x T$$

## ACCURACY

We hear a lot about the inherent accuracy of modern ultrasonic equipment, and many DTM's show two significant decimal places - (0 . 01mm). Such claims are fine when measuring between perfect parallel surfaces, but that sort of accuracy is not for the likes of us! Remember that the most reflective facet of a rough corrosion pit is not necessarily the tip, and remember also that as the remaining wall thickness gets very thin (below 2 - 3mm) our twin crystal probes perform poorly on such surfaces. In my experience, the very best that can be reliably achieved in the field on corrosion measurement, is about 0.5mm and that will be an <u>over estimate</u> of remaining wall thickness. In other words, ultrasonics will consistently under estimate the depth of a corrosion pit. Others share my views on the accuracy of ultrasonics in corrosion measurement. [2][3]

Dr. Peter Charlton [3] illustrated typical accuracy when two teams were asked to measure the depth of 14 natural pits in 6mm plate using ultrasonics. The results are shown in Figs. 10, & 11, note that two of the pits were not detected by Team UT B. Just to show that we all have our problems, I've also included MFL results for the same 14 natural pits ( Fig. 12 ), as can be seen these show that MFL consistently over estimates pit depth.



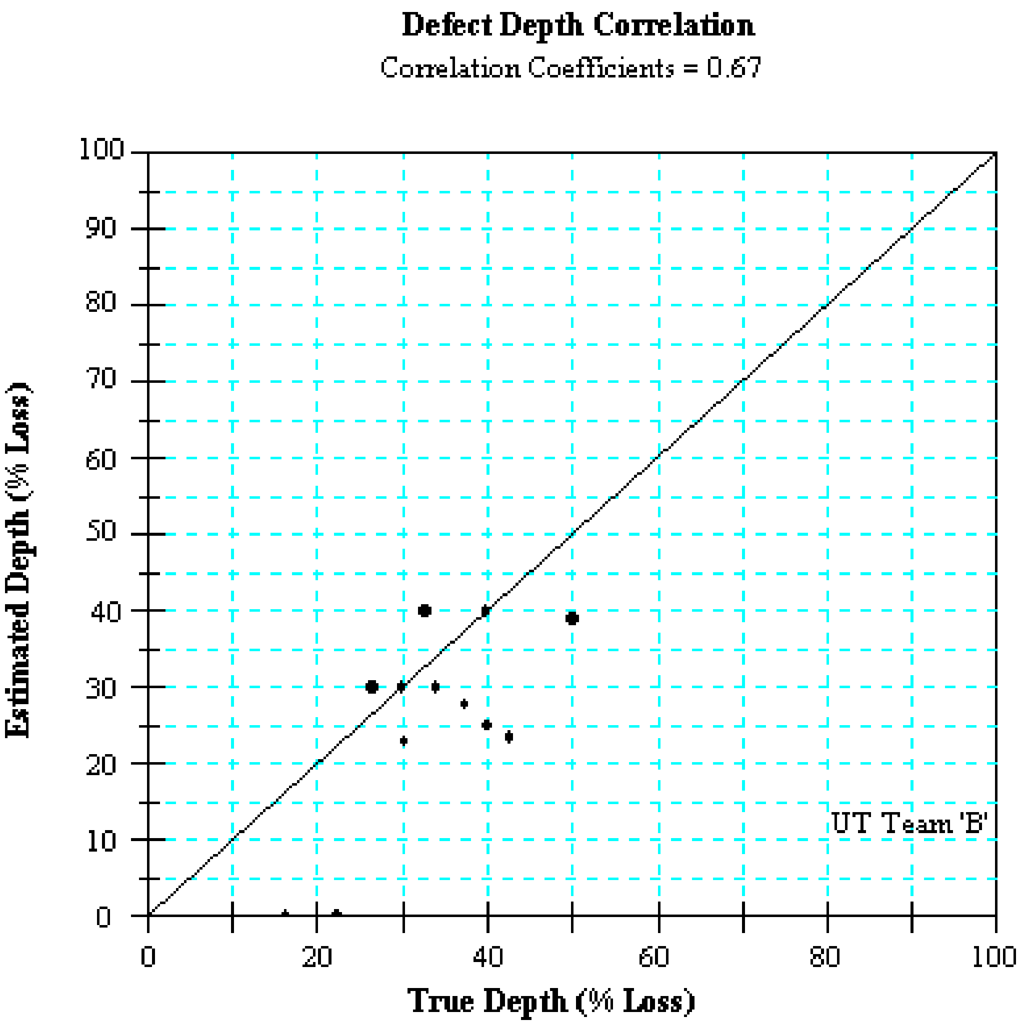

Defect Depth Correlation
Correlation Coefficients = 0.67
100
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
Estimated Depth (% Loss)
True Depth (% Loss)
UT Team 'B'

Figure 11

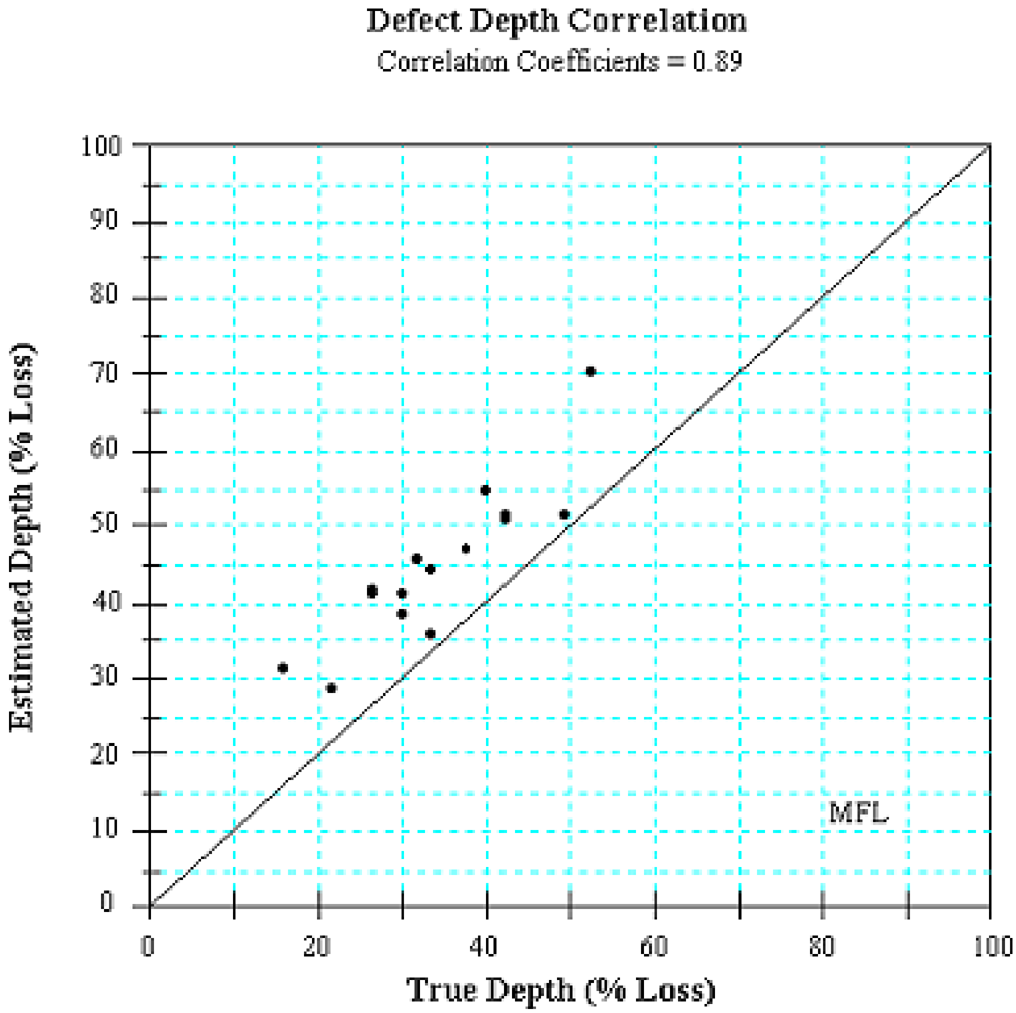



Figure 12

**CONCLUSIONS**

If we ignore the reflectivity characteristics of corrosion pitting, the performance characteristics of our probes and use an ultrasonic technique more suited to finished product thickness measurement, we are likely to reduce probability of pit detection and sacrifice measurement accuracy. Techniques which are suitable for detecting and measuring erosion are not suitable for pit detection, but are nevertheless in widespread use. The use of rapid scanning pattern recognition techniques can improve probability of detection, and careful consideration of the relevant defect and probe characteristics, particularly with reference to control of gain, can optimise measurement accuracy.

**REFERENCES**

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② Thickness Measurement of Hull Structures - R. Porter, Lloyds Register

(Paper presented at BINDT Seminar 13 March 1996)

③ Evaluating Current Options for NDT - Dr. P. C. Charlton

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