GIUDED WAWES EXPERIENCE FOR MONITORING DISTRICT HEATING PLANT FOR CORROSION EVALUATION TEST

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1 INTRODUCTION

District heating plants are characterized by a very complex network of pipe of different diameter and with an overall length which can be in the order of hundred of kilometers. Pipe corrosion can produce loss of hot water which in turn represents a loss of the heat which can be sold with a temporary stop in heat delivering to final users with relevant regrettable troubles. The pipe network is composed by buried coated pipe and the thermal coating can produce high attenuation of the guided wave. Thus the objective of present work is to test guided wave performance when applied to this plant type and, in particular, to determine maximum inspection length on pipes of different diameter and defect detection sensitivity.
The experiences on coated pipe has been preceded by some test on uncoated pipe of same type in order to have same reference result unaffected by coat attenuation. Thus, different defect typologies has been designed in order to check axial (or longitudinal) resolution and system sensitivity and, further, to verify the possibility of making corrosion-like defects by simple grinding procedure. Thus we have manufactured: slit like defects, series of defects produced by means of hemispherical grinding and uniformly distributed around the pipe, and, finally, corrosion like defects produced by random grinding over a given area; all the defects were characterized in term of *reduced area*.

2 SAMPLE DESCRIPTION AND MEASURMENT RESULTS

The following table shows mechanical characteristics of manufactured sample used in the present research work

ID	coating type	out diameter [mm]	thickness [mm]	overall length [mm]	number of welded pieces	number of defects	defect type	main purpose
sample 1	uncoated	110	4.1	6,000	2	1	full penetration slit	axial resolution test
sample 2	uncoated	88	5	12,750	6	4	series of hemispherical shaped defects	sensitivity test
sample 3	uncoated	88	3.5 ï 4.1	14,160	7	2	corrosion like	corrosion like defect manufacturing test
sample 4	coated	88	4.6	10,000	3	1	corrosion like	inspection length test
sample 5	coated	220	4.6	9,000	2	2	corrosion like	inspection length test

Table 1: sample data

More detailed sample description is given in the following subsection together with the results of inspection carried out with TELETEST (Plant Integrity ltd) instrumentation.

2.1 Sample 1

This simple sample was designed for a fast check of instrument performance with particular reference to the axial or longitudinal resolution power. In fact, the big and sharp defect is placed in the middle of a short pipe piece, only 1 m long, welded to another pipe piece 4 m long.

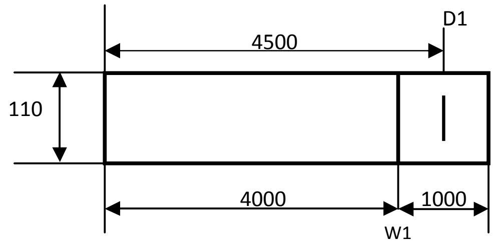

Figure 1: sample 1 sketch

defect D1 is an artificial full penetration slit defect with circumferential orientation and a width of 84 mm with a reduced area of 26%. Inspection has been carried out with a 16 transducer per ring collar probe placed at 1 m from the beginning working only in T(0,1) torsional mode at frequencies of 28 kHz, 36 kHz, 44 kHz, 64 kHz.

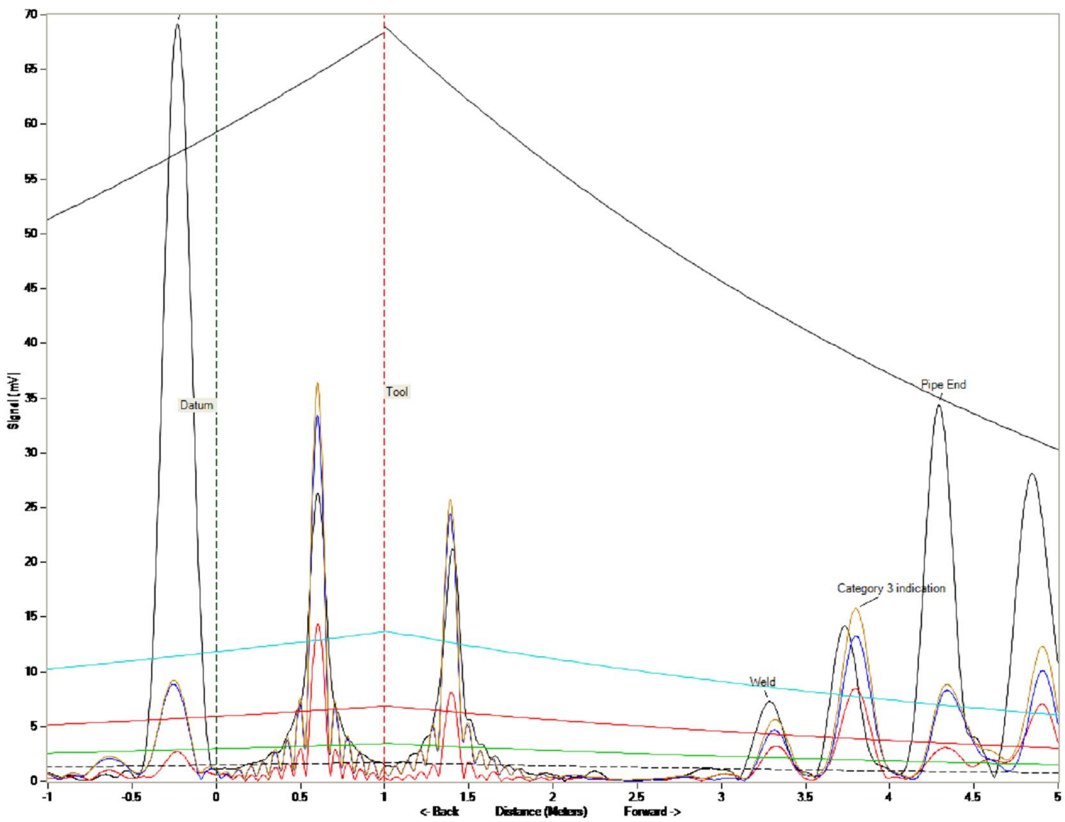

Figure 2: echo signal A-scan @ 44 KHz on sample 1

Figure 2 shows the best A-scan obtained at 44 kHz. The high flexural components are present in the A-scan confirming the non axial symmetric nature of the defect; further, echo amplitude is in good agreement with the defect reduced area. With a frequency of 28 kHz, axial resolution is at its limit, that is 0.5 m, while at 44 kHz axial resolution is quite good and can be estimated in 0.25 m.

2.2 Sample 2

This sample was designed to check system sensitivity against a series, four, of calibrated and axial symmetric defect with calibrated reduced area of 2.5% (D1), 5% (D2), 7.5 (D3), 10 % (D4).

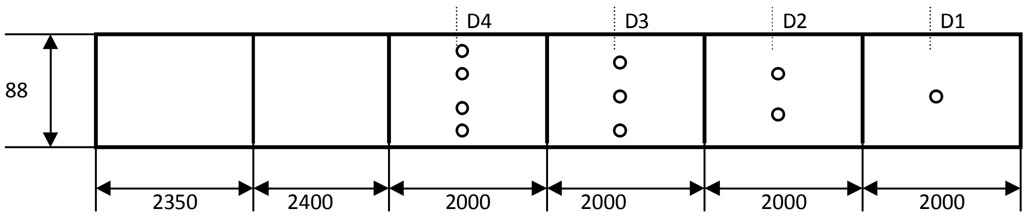

Figure 3: sample 2 sketch

Each series of defects is composed by a number of artificial defects equally spaced around the pipe circumference. Each defect is obtained with a spherical grinding tool in order to have a very smoothed discontinuity; in this way it is possible to check the influence of low axial gradient of discontinuity on the overall system sensitivity. The reduced area of each hemispherical defect is about 0.625 %; the different reduced are of the four series is obtained with a different number of hemispherical defects.
Inspection has been carried out with a 16 transducer per ring collar probe placed at 1 m from the W1 weld, thus at about 3.4 m from the sample beginning, in T(0,1) torsional mode. The best results are obtained at 36 kHz, figure 5, and 44 kHz, figure 6. At 36 kHz all the defects are well detected with higher amplitudes than expected, especially the smallest ones which, as shown in the figure, seems to be of same category of the second one. This is probably due to the axisymmetric nature of such defect type. At 44 kHz the defects, as shown in figure 6, are still detected with higher amplitudes than expected even if the amplitude trend seems monotonically decreasing except for the smallest defect which is highly disturbed by unwanted component at the pipe end.

Figure 4: photo of defect shape

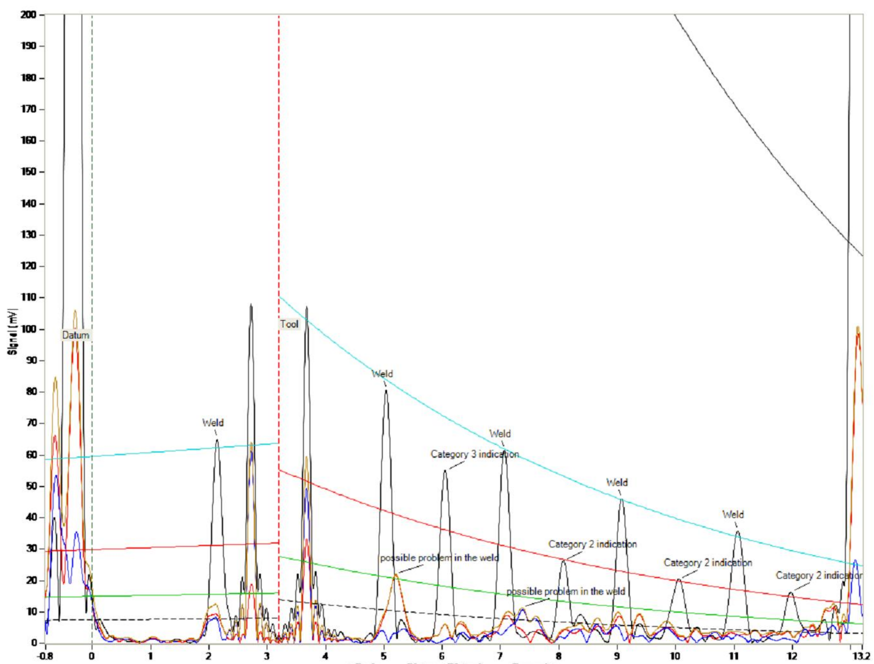

Figure 4: echo signal A-scan @ 36 KHz on sample 2

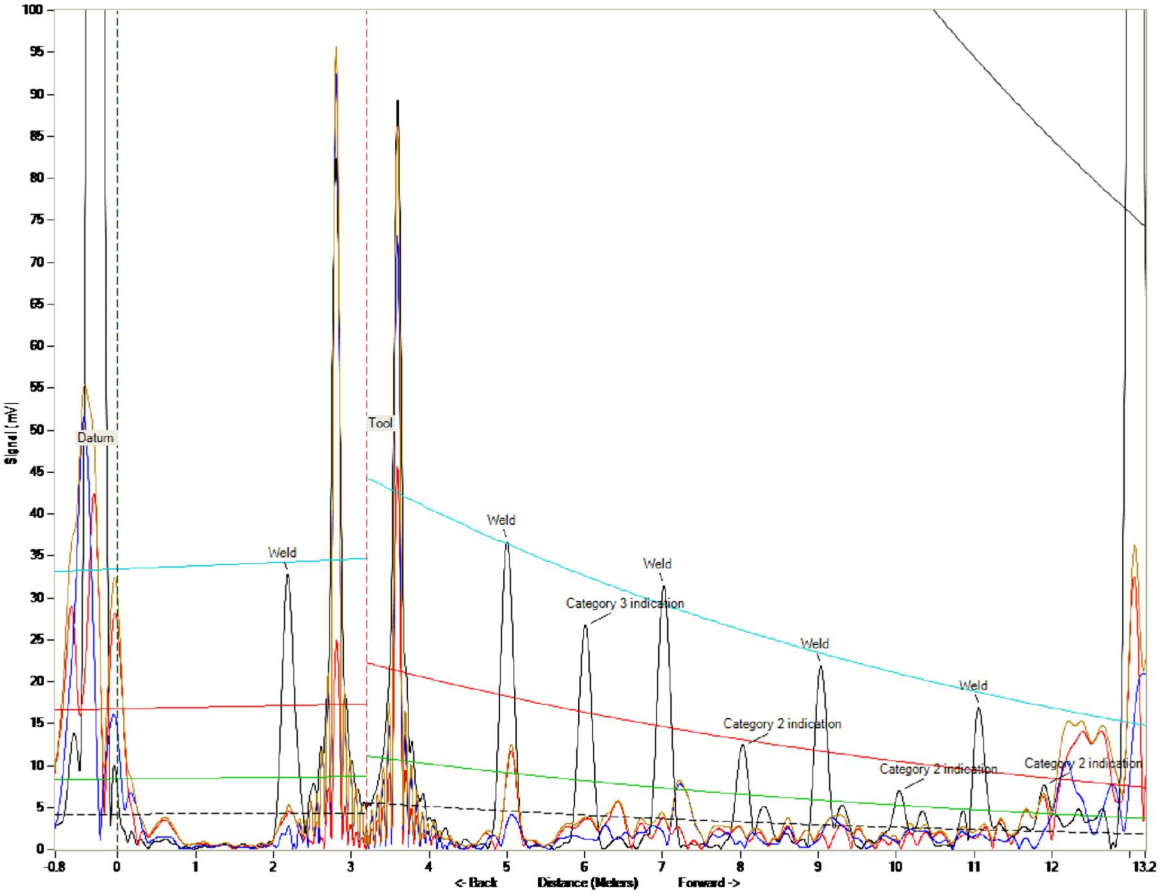

Figure 6: echo signal A-scan @ 44 KHz on sample 2

2.3 Sample 3

This sample was manufactured starting from an existing pipe string of similar outer diameter but with different thickness in the range 3.5 to 4.1 mm. This string was used to check the procedure to manufacture artificial corrosion-like defect similar to the real one.

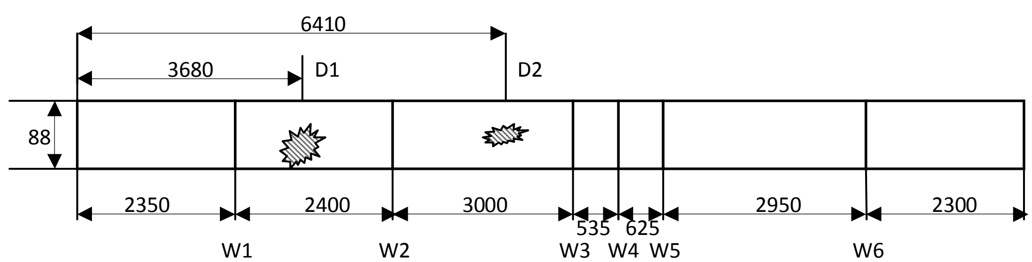

Figure 7: sample 3 sketch

This procedure consists in grinding a given area on the outer pipe surface in a random way in order to simulate the shape of corroded area. An accurate dimensional characterization of such random grinding gives the possibility to evaluate the effective reduced area. Two grinded artificial defect was produced, as shown in figure 7, with the following characteristics:

- D1: width = 123 mm; length = 55 mm; reduced area = 16,32 %;
- D2: width = 10 mm; length = 70 mm; reduced area = 7,76 %

Figure 8 shows photos of such defects.

Figure 8: random grinded defects on sample 3

Inspection was carried out with a12 transducer per ring collar working in T(0,1) torsional wave mode and the best frequency was found at 36 kHz. Reflections from welding are not monotonic due to the above mentioned non uniform thickness. As shown in figure 9, both defect D1 and D2 are clearly detected with a good correspondence of relevant echo amplitudes to the defects reduced area, while high amplitude flexural components are presents due to asymmetric nature artificial defects.

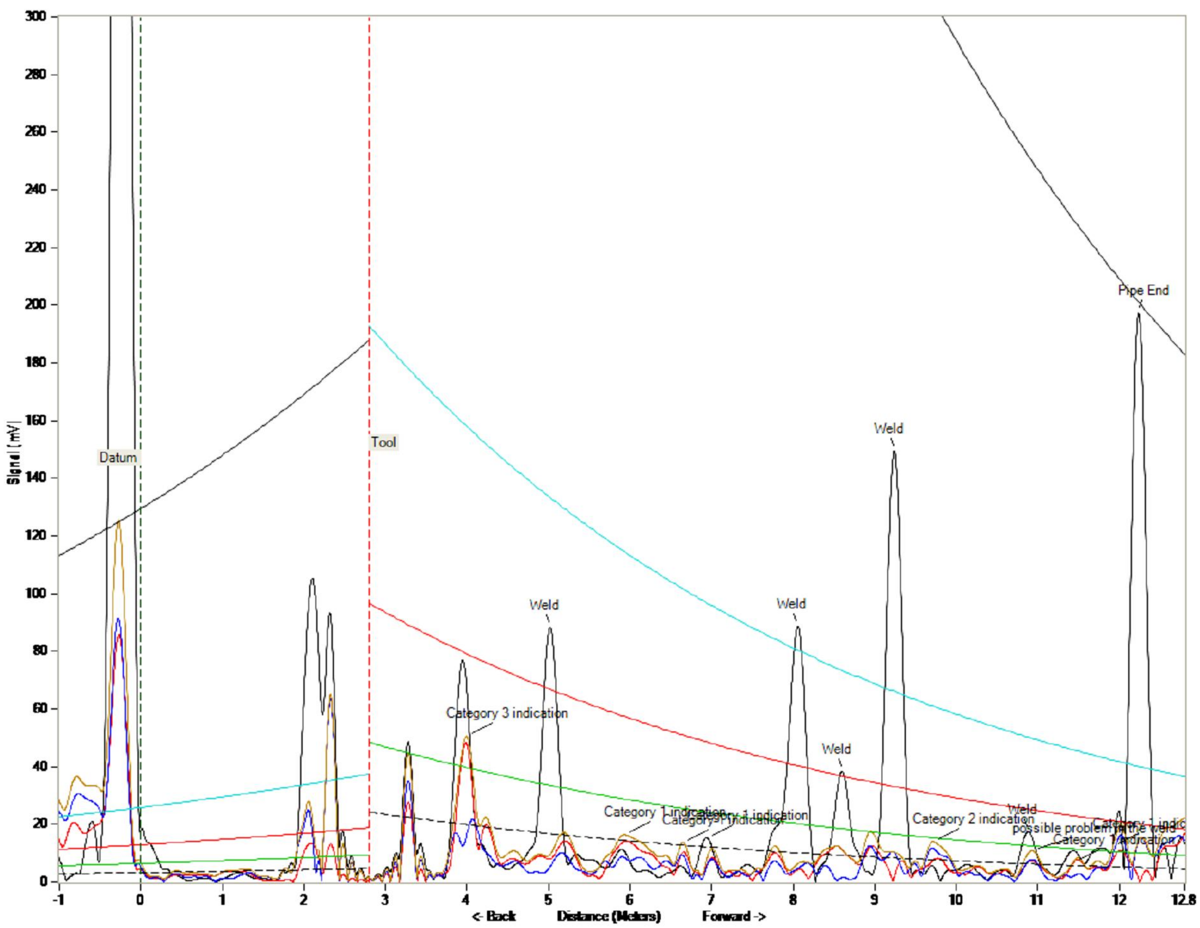

Figure 9: echo signal A-scan @ 36 KHz on sample 3

2.4 Sample 4

This is the first sample with coating and its outer diameter of 88 mm is the smallest one in the application of district heating plan corresponding to the *last mile* of the plant. The sample design is shown in figure 9 and allows to place the probe collar in two position corresponding to weld W1 (6 m from defect) and to weld W2 (2 m to defect).

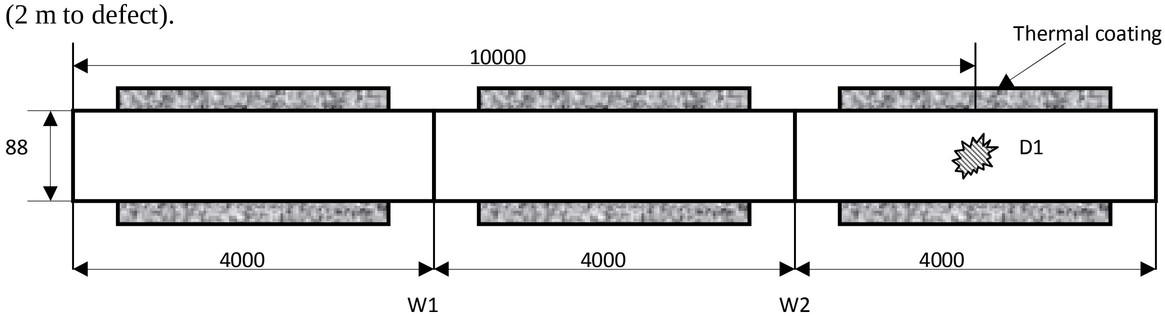

Figure 9: sample 4 sketch

The grinded artificial defect manufactured as in sample 3 is 72 mm width and 45 mm length, with a reduced area of 12%.
When the 12 transducer per ring collar, working only in T(0,1) torsional mode, was placed at position 1 (first welding W1) the best frequency was founded at 36 kHz, and 72 kHz. Figure 11 and 12 show the relevant echo signal with a logarithmic representation vertical scale. Such a representation allows the determination of the maximum inspection length which at a threshold level of 2.5 % is about 8 m at 36 kHz, while is about 6 m of max inspection length at 72 kHz; but assuming a threshold level of 10% DAC the max inspection length at 36 kHz is about 10 m, while at 72 kHz is 8 m.

Figure 10: photo showing the defect on sample 4

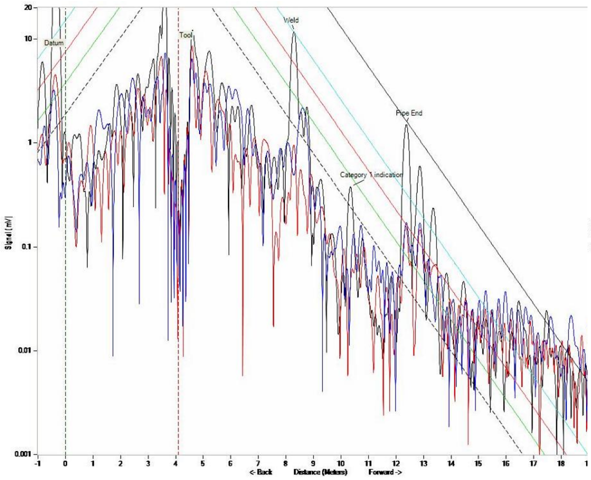

Figure 11: echo signal A-scan @ 36 KHz on sample 4

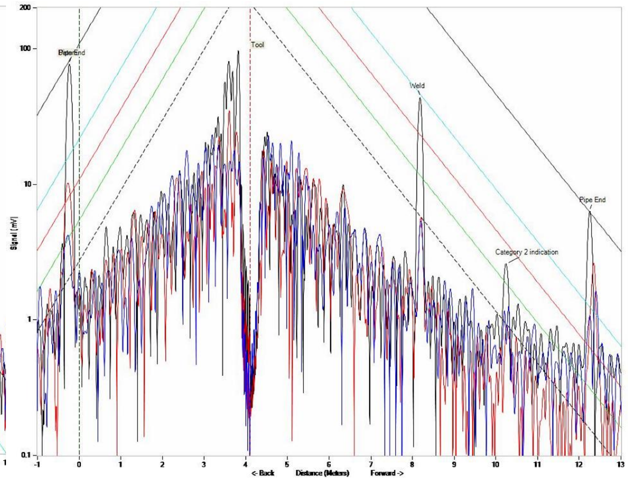

Figure 12: echo signal A-scan @ 72 KHz on sample 4

Figure 13 shows the A-scan at 72 kHz relevant to T(0,1) torsional wave with linear representation and with the collar probe in position 2 (second welding W2). The 72 kHz defect echo amplitude at both position 1 and 2 is in quite good agreement with defect reduced area even if at 36 kHz amplitude is slightly underestimated.

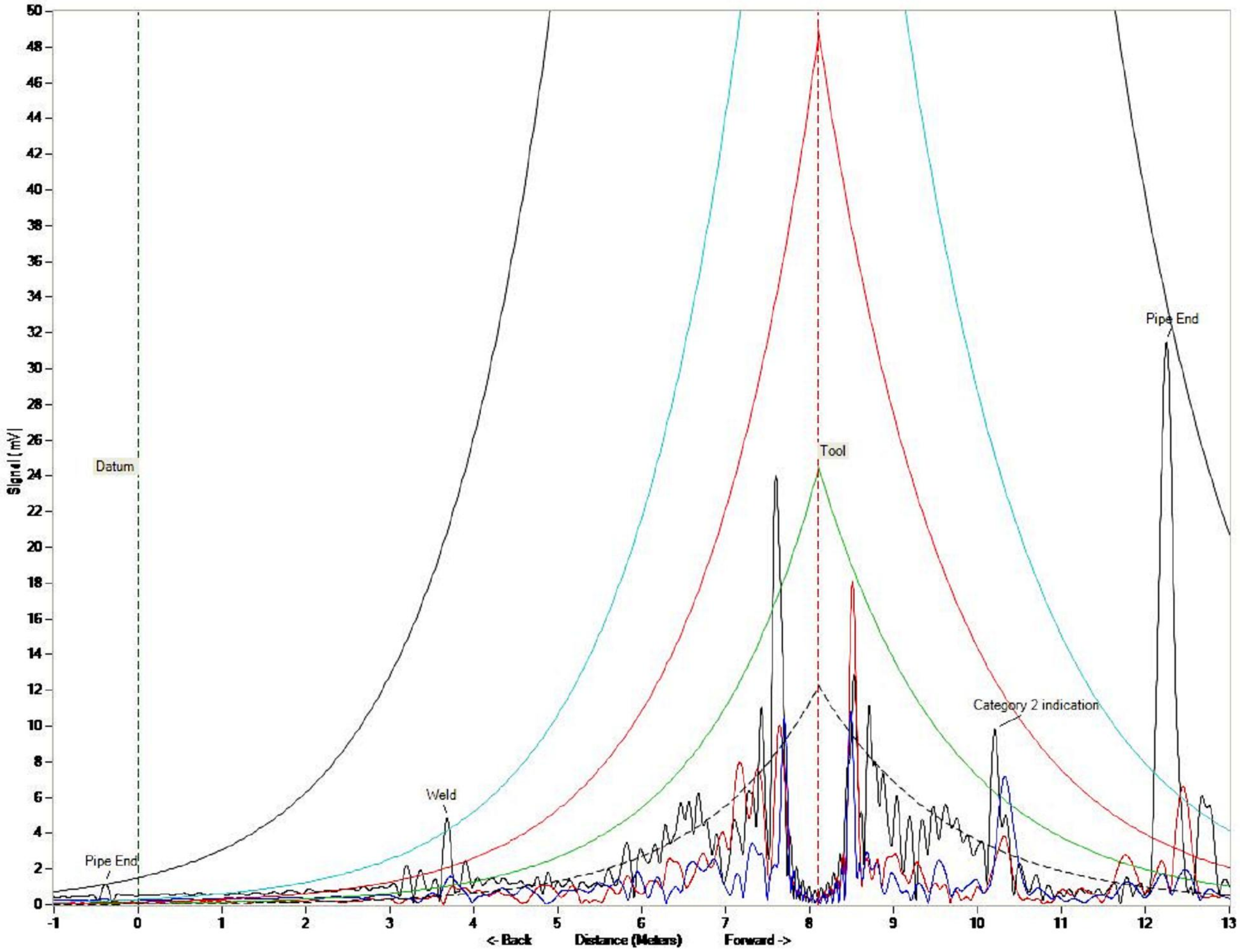

Figure 13: echo signal A-scan @ 72 KHz on sample 4 in position W2

2.5 Sample 5

The second coated sample has 220 mm of outer diameter; figure 14 shows the sample sketch of the sample which exhibits two defects.

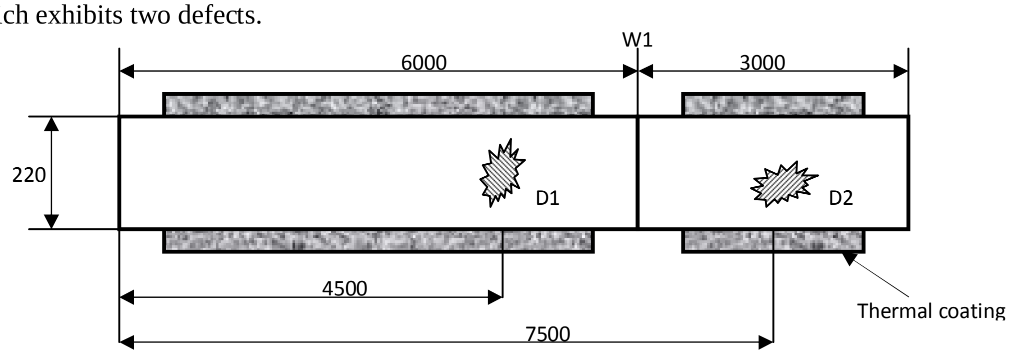

Figure 14: sample 5 sketch

Figure 15: Defect D1 (left): width 100 mm, length 80 mm, reduced area 2,6%.

Figure 16: defect D2 (right): width 80 mm, length 92 mm, reduced area 5,8%

Since this sample has a sufficiently high diameter, a 24 transducer per ring collar working in multimode has been used and placed at the beginning of sample. Figure 17 shows A-scan at 46 kHz L(0,2) longitudinal wave. In this case the maximum inspection length is about 20 m, while at 81 kHz T(0,1) torsional wave, shown in figure 18, the maximum distance is about 15 m of max. Again, if we assume a 10% DAC threshold, this distance reaches 25 m. In all he case the defect echo amplitudes are in quite good coherence with the relevant reduced area.

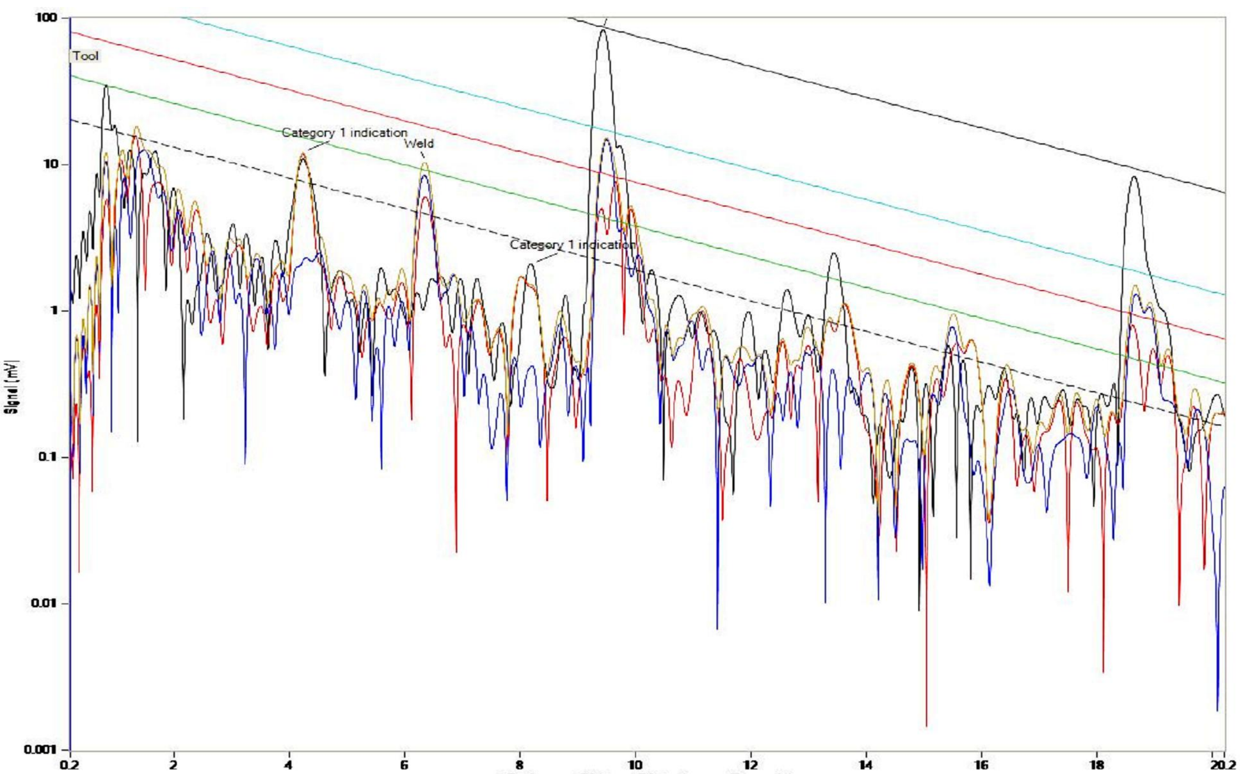

Figure 17: echo signal A-scan @ 46 KHz, L(0,2) wave on sample 5

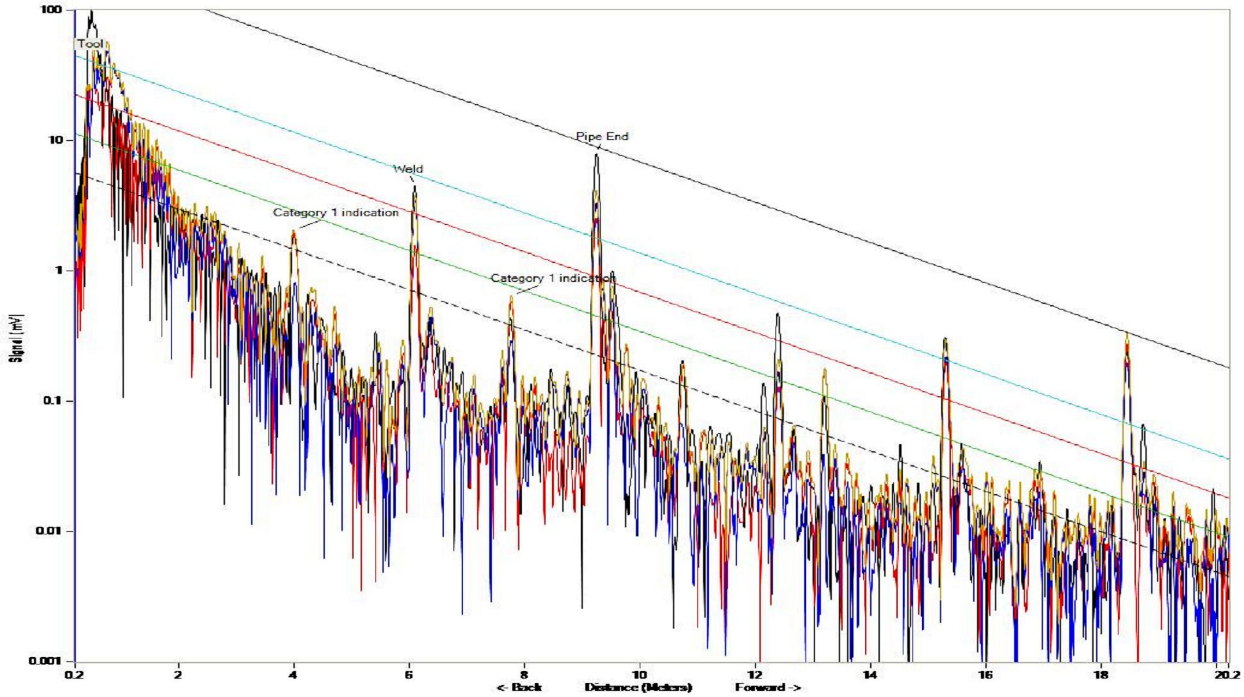

Figure 18: echo signal A-scan @ 81 KHz, T(0,1) wave on sample 5

3 CONCLUSION

The experiments carried out on the two last coated sample demonstrate the feasibility of the inspection for this type of plant; in the worst case maximum inspection length is of the order of 8 m, but this length can increase to about 12 ï 15 m if we take account that for the pipe of this plant type an effective alarm threshold for reduced area could be greater than 10 %. Table II summarizes defect echo amplitudes compared defect by defect with the relevant real reduced area.

sample ID	defect n°	reduced area [%]	estimated reduced area [%]	Attenuation [as max inspection length in meter]
sample 1	D1	26	>30	>50
sample 2	D1	2.5	9	>50
ñ	D2	5	7	>50
ñ	D3	7.5	10	>50
ñ	D4	10	17	>50
sample 3	D1	16,32	9	>50
ñ	D2	7,76	3	>50
sample 4	D1	12	6	8
sample 5	D1	2,6	3	15
ñ	D2	5,8	4	15

Table II: estimated reduced area against real values

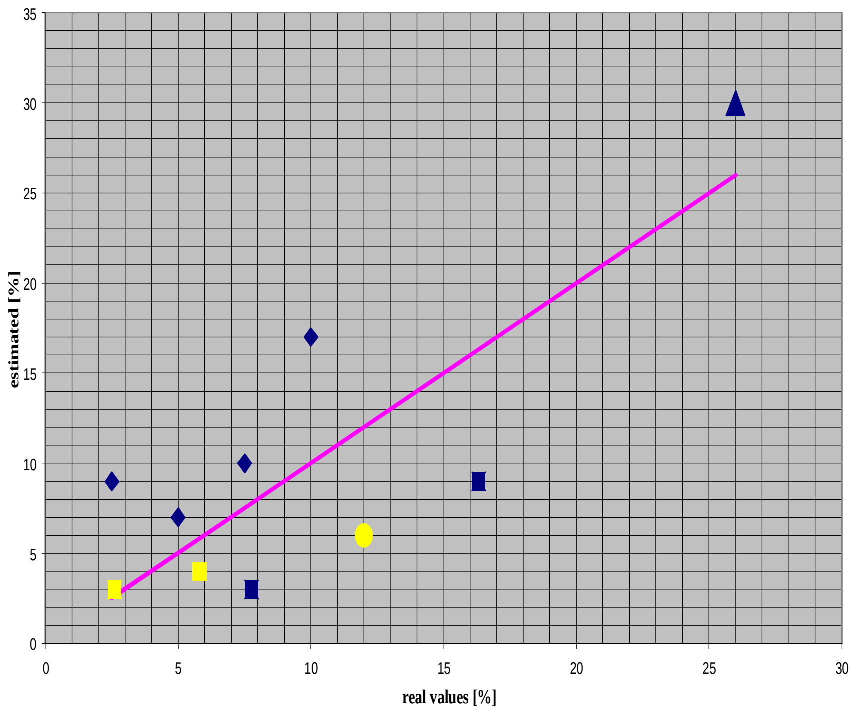

Figure 19: graphical comparison of estimated reduced area against real values.
Yellow dots are relevant to coated pipes sample 4 and 5

We can observe that corrosion like defects on coated sample are generally a bit underestimated but, since GW method is of screening type, this is not really a problem. What is important is that all the defects are always well detectable and this means that the inspection of district heating plant can be reliable carried out with the Guided Wave method.