

A Contribution to Repeatability of 1-D Linear Array Probes Used on Large-Scale Inspection of Low-Pressure Turbine Components

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Abstract

The need for high-reliability and high productivity of industrial inspection of low-pressure turbine components requires the use of a large quantity of identical 1-D phased array probes in combination with multiple instruments. The paper presents specific aspects for assessment of probe repeatability regarding detectability and sizing of small EDM notches. Examples are given for repeatability assessment of linear array probes used for inspecting GEC Alstom 900-MW turbine (L-1 rotor steeple) and Siemens-Parson 580-MW turbine (row-10 blade roots). The tolerances on probe performance (sensitivity, sizing capability, defect location) were set based on experimental results presented in this paper. These results are also used to set realistic tolerances on equipment substitution triggered by the inspection scope.

Introduction

Repeatability of ultrasonic results based on probe performance (same family or different families) is one of the main topics of ultrasonic reliability results. Different aspects of probe performances were presented in *references 1-5*. This paper presents specific aspects of three probes (P27, 37 and 43) when they are used in combination with phased array portable instrument OmniScan 16/16 for in-situ inspection of low-pressure turbine components. Probe 43+60T wedge was used for inspection of GEC Alstom 900-MW turbine (L-1 rotor steeple), while P27+45T and P37 were used for inspection of Siemens-Parson 580-MW turbine (R-10 blade roots). The paper details the experimental program, example of lab results and conclusions regarding the tolerances on probe features to assure a good repeatability. These tolerances were incorporated in the field procedures regarding the defect characterization and the equipment substitution issues.

Experimental Program

The families of probes used in this experimental program are presented in **Table 1**.

Table 1: The families of 1-D linear array probes used for repeatability assessment

Probe ID	Frequency [MHz]	Pitch [mm]	Number elements	Remarks
Family P 43				
43A	7.6	0.6	16	Used in combination with GEIT wedge W042 60°. Tested on L-1 steeple performance demonstration coupons with complex EDM notches; 5 probes + 4 OmniScans; more data regarding sensitivity, height, amplitude and sizing errors
43B	7.8	0.6	16	
43C	6.9	0.6	16	
43D	7.5	0.6	16	
43E	7.1	0.6	16	
Family P 27				
27 RC	5.4	0.5	12	

27 RD	5.4	0.5	12	Used in combination with GEIT wedge W028 - 45°; tested on R-10 blade reference block with 5 x 1.5 mm EDM notch – wing technique CVX→CCV at z=25 mm; cable left or right-sided.; 7 probes + 5 OmniScans
27 RE	5.3	0.5	12	
27 RF	5.4	0.5	12	
27 LC	5.4	0.5	12	
27 LE	5.3	0.5	12	
27 LF	5.2	0.5	12	
Family P 37				
37A	5.1	0.5	10	Used with integral wedge of 36° Plexiglass- cable on top; tested on R-10 blade reference block with 5 x 1.5 mm EDM notch; 9 probes + 8 OMniscans
37B	5.1	0.5	10	
37C	5.1	0.5	10	
37D	5.3	0.5	10	
37E	5.1	0.5	10	
37F	5.1	0.5	10	
37G	5.1	0.5	10	
37H	5.3	0.5	10	
37I	5.3	0.5	10	

Each event was measured, at least three times, and the mean was tabulated. Some measurements were performed in a static mode, using lab tools (see **Figure 1**).



Figure 1: Example of experimental set-up for probe 43+60T on L-1 steple PDI coupons.

Results

The results could be grouped on probe family.

Probe 43+60T (20 events)

The optimum trajectory and probe position (see **Figure 2**) led to a high repeatability for all variables (see **Figure 3**, **Figure 4** and **Figure 5**).

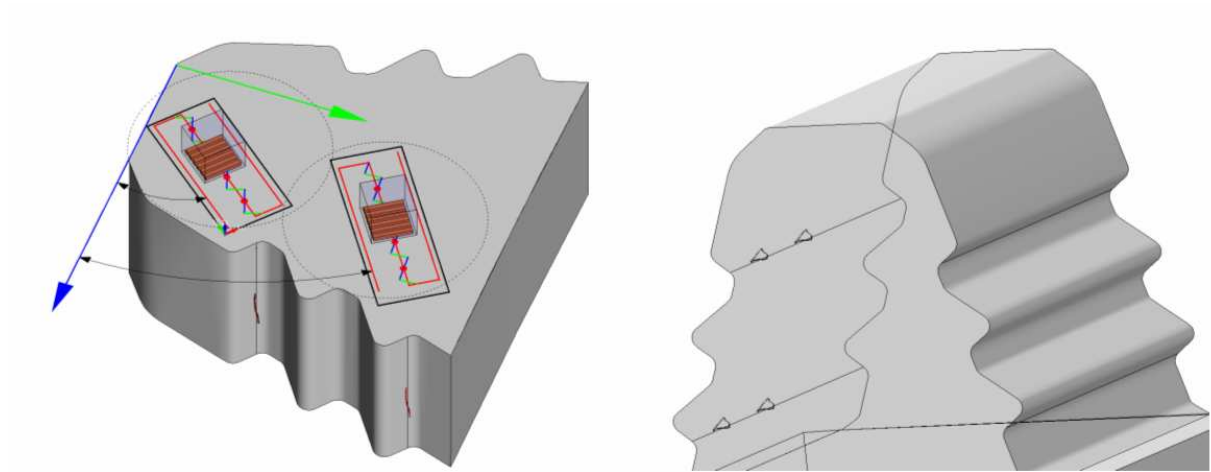


Figure 2: Example of probe trajectory optimization for probe 43+60T inspecting hook 1 and hook 3 of L-1 steeple (left) and target location at 5 mm (10 mm) and 15 mm (30 mm) on hook 1 and hook 3..

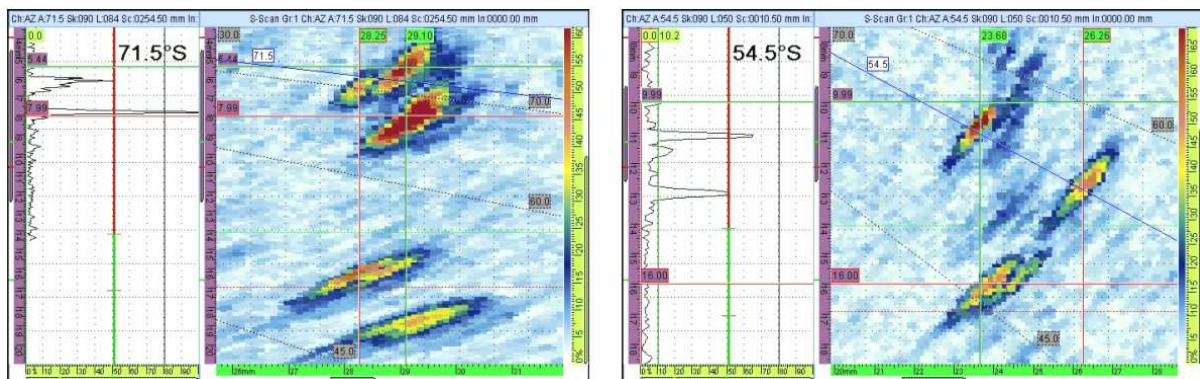


Figure 3: Example of detection and sizing of 3x1 mm EDM notch at z=5 mm (left) and 6 x 2 mm at z = 10 mm.

P43-60T-PDI EVALUATION. OPS									
L-1 REF BLK D-5									
Omni Scan MX 105659-04									
Hook 1 Notch1 (complex notch depth = 10mm; length = 3mm; width = 1mm)									
PROBE	Location	G (db)	Z (mm)	X (mm)	β (Degree)	A (%)	X 1mm +/-	Z 3mm +/-	
43A	Top	59.1	9.7	25.0	59.0	83.0	-0.4	-0.1	
	Tip		10.2	25.6	59.0	13.0			
	Tail		12.7	24.6	53.0	33.0			
Cumulative values			2.9	0.6					
Comments 30 degrees from parallel, 1mm back from the notch.									
PROBE	Location	G (db)	Z (mm)	X (mm)	β (Degree)	A (%)	X 1mm +/-	Z 3mm +/-	
43B	Top	61.1	9.9	24.4	58.5	83.0	0.0	-0.1	
	Tip		10.3	25.4	58.5	12.0			
	Tail		12.7	24.4	52.5	47.0			
Cumulative values			2.9	1.0					
Comments 30 degrees from parallel, 1mm back from the notch.									
PROBE	Location	G (db)	Z (mm)	X (mm)	β (Degree)	A (%)	X 1mm +/-	Z 3mm +/-	
43C	Top	59.0	9.4	25.1	60.0	82.0	-0.1	0.1	
	Tip		9.9	26.0	60.0	14.0			
	Tail		12.5	24.8	53.5	52.0			
Cumulative values			3.1	0.9					
Comments 30 degrees from parallel, 1mm back from the notch.									
PROBE	Location	G (db)	Z (mm)	X (mm)	β (Degree)	A (%)	X 1mm +/-	Z 3mm +/-	
43D	Top	64.1	10.0	26.4	60.5	82.0	0.0	-0.3	
	Tip		10.6	27.4	60.5	17.0			
	Tail		12.7	26.2	55.0	49.0			
Cumulative values			2.7	1.0					
Comments 30 degrees from parallel, 1mm back from the notch.									
PROBE	Location	G (db)	Z (mm)	X (mm)	β (Degree)	A (%)	X 1mm +/-	Z 3mm +/-	
43E	Top	61.1	9.6	24.8	59.5	84.0	0.0	0.0	
	Tip		10.1	25.8	59.5	12.0			
	Tail		12.6	24.6	53.0	50.0			
Cumulative values			3.0	1.0					

P43-60T-PDI EVALUATION. OPS									
L-1 REF BLK D-6									
Omni Scan MX 105659-12									
Hook 3 notch2 (Complex Notch depth = 30mm; length = 6mm; width = 2mm)									
PROBE	Location	G (db)	Z (mm)	X (mm)	β (Degree)	A (%)	X 2mm +/-	Z 6mm +/-	
43A	Top	57.0	10.5	23.8	56.0	83.0	0.8	-1.2	
	Tip		12.3	26.6	56.0	30.0			
	Tail		15.3	24.7	48.5	33.0			
Cumulative values			4.8	2.8					
Comments skewed toward the root 5 degrees									
PROBE	Location	G (db)	Z (mm)	X (mm)	β (Degree)	A (%)	X 2mm +/-	Z 6mm +/-	
43B	Top	60.5	10.4	23.3	55.5	81.0	0.6	-1.1	
	Tip		12.3	26.0	55.5	35.0			
	Tail		15.3	24.0	47.5	42.0			
Cumulative values			5.0	2.6					
Comments skewed toward the root 5 degrees									
PROBE	Location	G (db)	Z (mm)	X (mm)	β (Degree)	A (%)	X 2mm +/-	Z 6mm +/-	
43C	Top	56.5	10.4	23.3	55.5	83.0	0.5	-1.2	
	Tip		12.2	25.8	55.5	18.0			
	Tail		15.1	24.0	48.0	15.0			
Cumulative values			4.8	2.5					
Comments skewed toward the root 5 degrees									
PROBE	Location	G (db)	Z (mm)	X (mm)	β (Degree)	A (%)	X 2mm +/-	Z 6mm +/-	
43D	Top	62.5	10.4	22.9	55.0	83.0	0.8	-0.7	
	Tip		12.3	25.7	55.0	45.0			
	Tail		15.6	23.5	46.5	81.0			
Cumulative values			5.3	2.8					
Comments skewed toward the root 5 degrees									
PROBE	Location	G (db)	Z (mm)	X (mm)	β (Degree)	A (%)	X 2mm +/-	Z 6mm +/-	
43E	Top	57.2	10.6	24.0	56.0	81.0	0.7	-1.0	
	Tip		12.4	26.7	56.0	26.0			
	Tail		15.6	24.6	48.0	25.0			
Cumulative values			5.0	2.7					

Figure 4: Example of data evaluation for 5 probes and OmniScan nr.12 machine in detecting and sizing 3 x 1 mm targets (top) and with OmniScan nr.4 machine in detecting and sizing 6 x 2 mm targets (bottom).

The over-all tolerances for P43+60T family may be summarized:

- Detection gain: ± 3 dB
- Target depth: ± 2 mm
- Target length: ± 2 mm
- Target height: ± 1 mm
- Detection angle: $\pm 2^\circ$
- Amplitude variation: (-2 dB to +1 dB)

Probe 27+45T (35 events)

The inspection results performed with seven probes in combination with five OmniScans on the inlet part, convex side of the blade wing (see **Figure 5**) are presented in **Figure 6**, **Figure 7** and **Figure 8**.

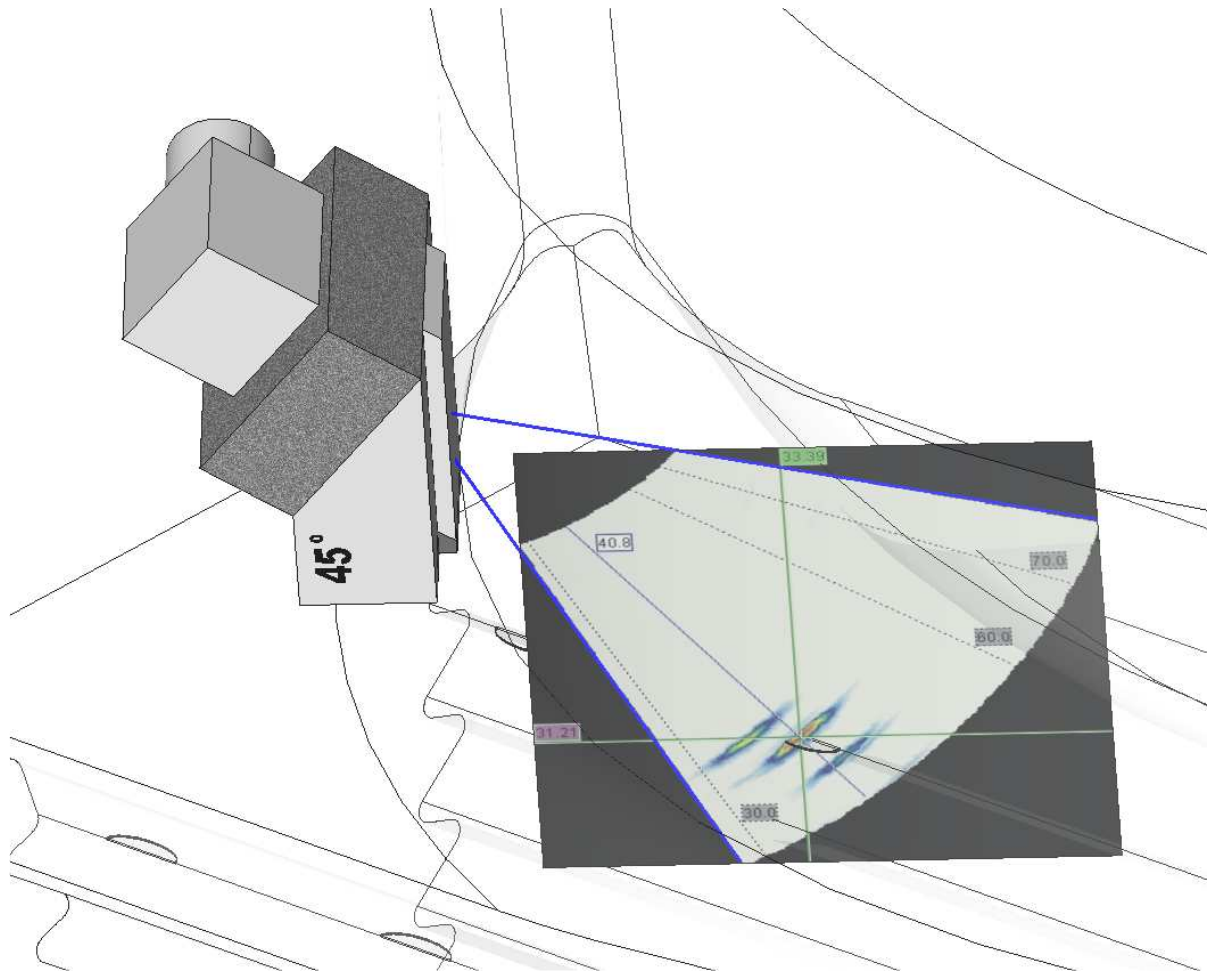


Figure 5: Example of data plotting into 3-D reference block of R-10 blade for probe 27+45T.

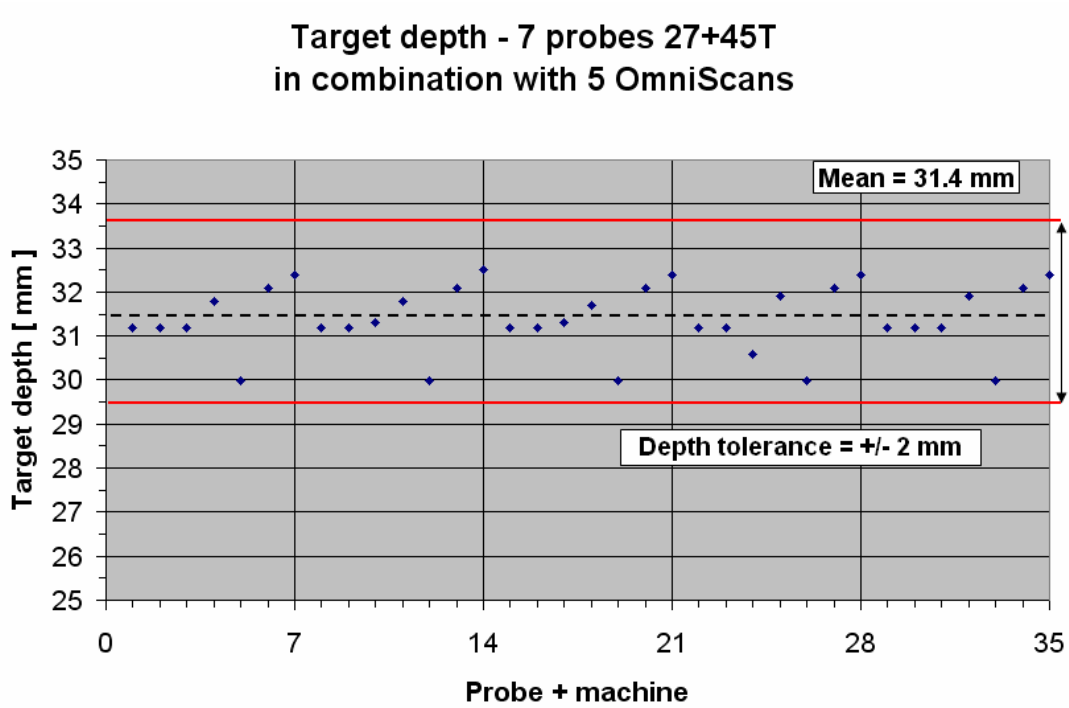


Figure 6: Target location value for 35 events – probe 27+45T on inlet CVX side of R-10 blade.

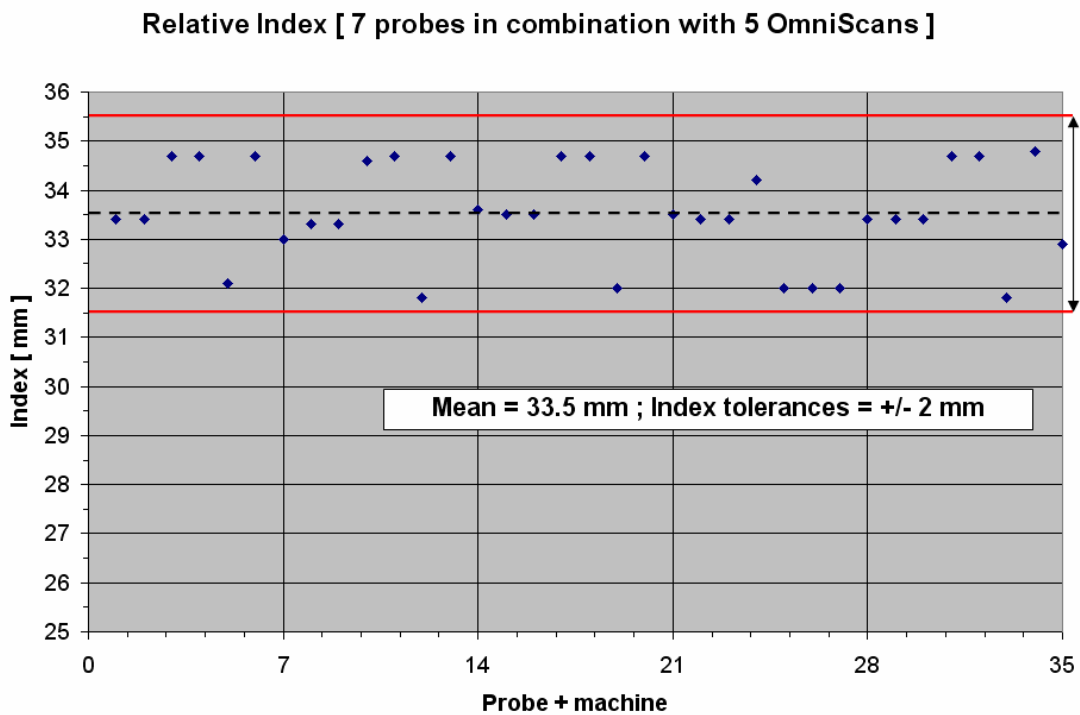


Figure 7: Relative index (projected distance) for 35 events in detection 5 x 1.5 mm EDM notch through the wing; Probe 27+45T on R-10 blade inlet CVX.

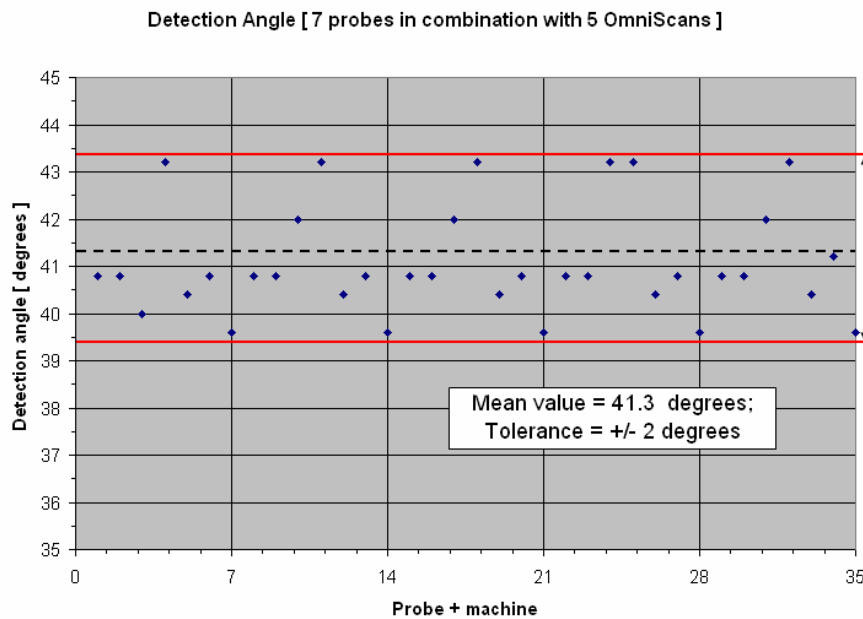


Figure 8: Detection angle for 35 events. Probe 27+45T on R-10 blade ref block with 5 x 1.5 mm EDM notch; inlet CVX-wing technique.

The tolerances for probe 27+45T are:

- Target location: ± 2 mm (depth and projected distance)
- Detection angle: $\pm 2^\circ$

Family P37 (72 events)

The sizing technique using specular reflection (see **Figure 9**) of 5 x 1.5 mm EDM notch led to smaller errors (see **Figure 10**).

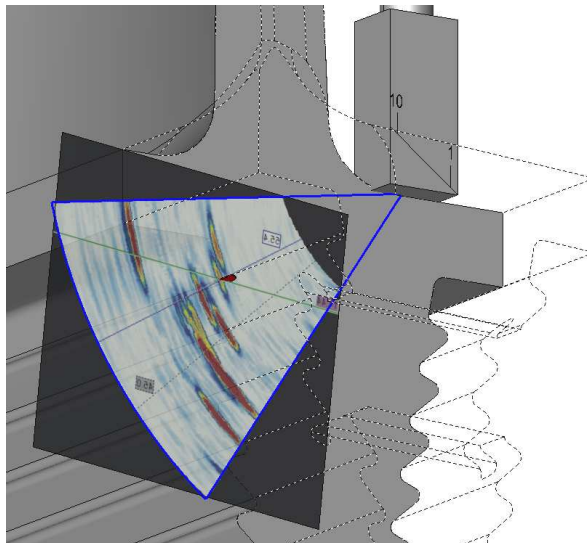


Figure 9: Example of sizing technique for probe P37 on the platform of R 10 blade.

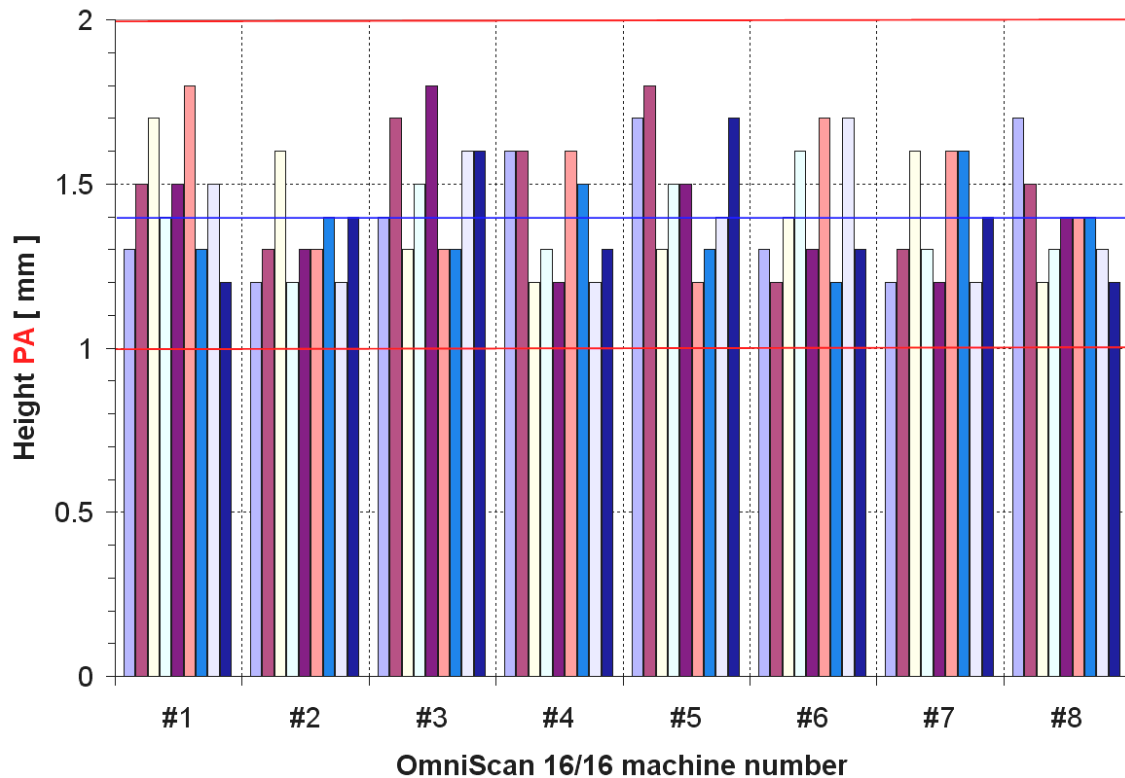


Figure 10: Sizing results for P37 (72 events). Target: 5 x 1.5 mm EDM notch located at 5 mm from outlet face on R 10 blade.

The height mean value is 1.4 mm with tolerances of ± 0.3 mm.

Conclusions and future developments

The repeatability of phased array results for a large quantity of probes and machines concluded the results may be expected within the following tolerances:

- Target location: ± 2 mm
- Target length: ± 2 mm
- Target height: ± 1 mm
- Detection angle: $\pm 2^\circ$

The repeatability program was expanded to other probe family (P 3 and 30, P36+45T, P28, P 23, P2, P 52+45T) used for manual and automatic scanning of different turbine components. Part of the results will be presented in *reference 5*. More details could be found in OlympusNDT new book-*reference 6*.

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