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In-situ examination of turbine components (blade roots, rotor steeple grooves and disk-blade rim attachments) of low-pressure steam turbine, using phased array technology.

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Abstract

A feasibility study test and 3 field trials were performed at Darlington NGS in 1996, 1999 and 2000 on ABB LP turbines. The scope of these trials was to commission **in-situ** automatic phased array systems capable to inspect blade roots and rotor steeples of L-0 and L-1 rows. GE disk-blade rim attachments were inspected at Bruce B nuclear station, in fall of 1999. The automated ultrasonic phased array technology is capable of high-speed rate and reliable detection and sizing. The capability demonstration was performed on mock-ups and reference blocks, using EDM notches. A custom built UT simulation software: Imagine 3D interfaces with SimScan to generates the spreadsheets / charts with target and probe coordinates and ultrasonic path and angles (refracted and skew) to hit the reference target. Examination of L-0 blade and rotor steeple grooves was performed with 2 phased array systems under networking. Data analysis was done in near-real time. Manual and automatic phased array were performed on L-1 blade roots (hook 1). Special linear array probes were designed by OPG and manufactured by Imasonic, to fit the specific geometry and to optimize the beam features for detection and sizing. Accuracy in sizing is $\pm$ 0.8 mm for height, $\pm$ 1.8 mm for length. Location of indication is within $\pm$ 4 mm space envelope. Sizing based on Dynamic Depth Focusing (DDF) board is better for specular reflection of EDM notches on disk attachment.

Introduction

ABB recommended in 1995 to de-blade the L-0 row of low-pressure turbine after 50,000 hours of operation and check the blade roots / rotor steeple grooves for possible shallow cracks developed due to corrosion pitting and low-cycle fatigue stress. Should this recommendation be followed, the outage duration will increase by, at least, 10-14 days and

a high probability to damage the rotor grooves / blade roots will reduce the operating hours of 900 MW turbine.
Darlinton NGS power train engineering and Specialized Examination and Maintenance Department (SIMD) funded a 4-year project to build and commission an automated ultrasonic phased array system for **in-situ** examination of the items mentioned above. L-1 row for rotor and blades was added to the final inspection capability.

The parts to be inspected present a complex geometry (see Figure 1), and the ultrasonic examination would require a special approach (development):

- high-frequency linear phased array probes (LPAP)
- forward – inverse problem simulation / ray – tracing software to validate the focal laws
- data acquisition and analysis software capable to plot UT data into 2-D (3-D) specimen
- custom-built manipulators
- custom-built multi-head phased array probes
- a capability demonstration for each item
- systems working independent on different location under networking (Figure 2)
- high-speed acquisition rate and data transfer rate
- data analysis closer to real-time on computers outside LP turbine area
- high accuracy / repeatability of ultrasonic data

As project evolved, some of ultrasonic results were published at EPRI Steam Turbine Workshop – July 1997 (1), EPRI Phased Array Seminar in Portland – Sept. 1998 (2), EPRI Steam Turbine Workshop – August 1999 (3) and QENDE-Montreal – 1999 (4). Since last fall, SIMD designed the new multi-head LPAP with hard-face, improved the manipulator design, built new reference blocks and mock-ups, and built a 4-blade/rotor steeple manipulator to simultaneously inspect L-1 blades/rotor steeple. An extent capability demo lab test on a multitude of targets was done, followed by the field trial #3 in April 2000.

An extra field inspection was performed at Bruce B NGS for disk rim attachment of GE low-pressure turbine of 850 MW, last fall. Specific aspects of these inspections will be presented in the present paper.

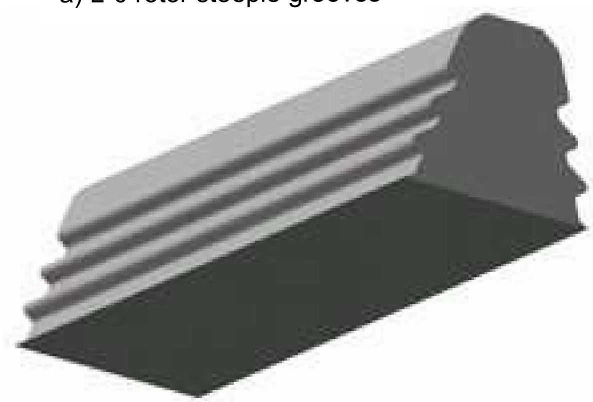
Phased Array Inspection on ABB blades / rotor steeple.

The inspected zones and the history of field trials inspection are presented in Table 1. The hardware/software development along the 4-years project is summarized in Table 2.
Due to the complex trajectory of LPAP on L-0 blade / steeple part, the ultrasonic acquisition is based on phased array technology. The ultrasonic beam is delayed and focused, without moving the probe. Negative and positive angles could be generated (see Figure 3 a), and one the scanning is preformed in one line for both side (if the part is symmetrical). The inspection of L-0 steeple is performed in one line scanning, with custom-built manipulators. The ultrasonic probe has 3 independent heads, which fire ultrasonic beams to hook 1, hook 2 and hook 5 (see Figure 3b). The L-0 blade is inspected on platform and hook 1 in one-line scanning. A specific analysis procedure was developed for each item. B-scans corrections

and correspondence plotting were commissioned. Along the blade / steeple length, the UT path is not constant, and detection / sizing is performed in different focal laws (A-scans), as is illustrated in Figure 4 and 5.

a) L-0 rotor steeple grooves

b) L-0 Blade roots



c) L-1 rotor steeple grooves

d) L-1 Blade roots

Figure 1: L-0 and L-1 rows of rotor steeples and blades to be inspected using phased array technology.

Table 1: Field trial history [1996 – 2000]

Year	Item	Side / Face / Location*	Scanning zones [mm]	UT technique		
				top	side	wing
1996 /May	L-0 blade	CCV/CVX; I/O; P, H1, H2	0-100	√	√	x
1999/ Jan.	L-0 blade	CCV/CVX; I/O; P, H1, H2	0 – 125	√	√	x
	L-0 steeple	CCV / CVX ; I/O ; H1, H2	160-350	√	x	x
1999 / May	L-0 blade	CVX / CCV ; O / P, H1	90 – 350	x	x	√
	L-0 steeple	CVX / CCV ; O, H1, H2	0 – 450	√	x	x
	L-1 blade	CCV / CVX ; I/O ; H1	0 – 100; CCV 60 – 120 CVX	√	√	x
2000 / April	L-0 Blade	CVX / CCV ; O / P, H1	90 – 350	x	x	√
	L-0 Steeple	CVX / CCV ; O, H1, H2, H5	0 – 450	√	x	x
	L-1 blade	CCV / CVX ; I/O ; H1	0 – 85; CCV 20 – 140 CVX	√	√	x
	L-1 steeple	CCV / CVX; I/O ; H1	10 – 55	x	√	x

* Side = Concave (CCV) / Convex (CVX) ; Face = inlet (I) / outlet (O) ; Location : Platform (P), hook 1 (H1), hook 2 (H2), hook 3 (H3), hook 4 (H4), hook 5 (H5).

Table 2: Hardware – software development [1996 – 2000]

Trial	Phased array [RD Tech]	UT machine [RD Tech]	Manipulator [SIMD / RD Tech]	Probe [Imasonic]	Software [RD Tech / SIMD]
1996	Lab / 16	Tomoscan	Rover / Traker	7 MHz	Tomoscan, v. 3R8 , Tomoview 1.2B
1999 / Jan	Focus 32	µ Tomo	X-Y Blade	7, 10 MHz	Tomoview v.1.3R1 Imagine 3D v. 1.2, Simscan 1.0
			Prototype 1	5 MHz	
1999 / May	Focus 32	µ Tomo	X-Y Blade 1	7 MHz	Tomoview v. 1.4R2, Imagine 3D v. 2.0, Simscan v.1.3R1
			Prototype 2	10 MHz / 2	
			Prototype 3	10 MHz	
2000 / April	Focus 32 / DDF	µ Tomo	Custom L-0 Blade	8 MHz / 2	Tomoview v.1.4R4, Imagine 3D, v.2.2 Simscan v.2.0R1
			Custom L-0 steeple (3)	10 MHz / 2, 8 MHz /1	
			Custom L-1 blade (4-blades)	10 MHz / 4	

Detection and sizing accuracy is presented in Table 3. The statistics was performed on EDM notches of different shapes (short rectangular, long rectangular, long elliptical, 2-D "crack-like", 3-D "crack-like), and sizes (length = 2 – 13 mm; height = 0.18 – 4 mm, orientation :from -15° to + 50°).

Table 3: Capability demonstration [1996 – 2000]

Year	ABB item	Detection [L x h] mm	Accuracy [± mm] Length	Height	Location	Remarks
1996 / May	L-0 Blade	3 x 1 6 x 2	1	0.5	2	0- 40 for 3 x 1 41 – 100 for 6 x 2
1999 / Jan	L-0 Blade	as 1996	1	0.5	2	as 1996
	L-0 Steeple	3 x 1 – H1 4 x 1.5 – H2	1	0.5	4	Min. detection: 9 x 0.15 mm-crack-like
1999 / May	L-0 Blade	5 x 1 – P, H1	1.5	0.7	3.5	Manual P.A.;Min.detection 5 x 0.5 mm; limited aut.
	L-0 Steeple	9 x 0.5 - H1 9 x 1 – H2, H5	1.5	0.5	4	Min. detection 9 x 0.15 Special plotting for location
	L-1 Blade	3 x 1 – H1	1.2	0.7	2	Manual P.A.
2000/ April	L-0 Blade	5 x 1 – P, H1	1.5	0.7	3.5	Min.detection 5 x 0.5 mm
	L-0 Steeple	9 x 0.5 - H1 9 x 1 – H2, H5	1.5	0.5	4	Min. detection 9 x 0.15 Special plotting for location
	L-1 Blade	3 x 1 – H1	1.2	0.7	2	Scan 4-blades same time ;manual scans in parallel.
	L-1 Steeple	4 x 1.5 – H1	1.8	0.8	3	Automated scan – 4 items simultaneously

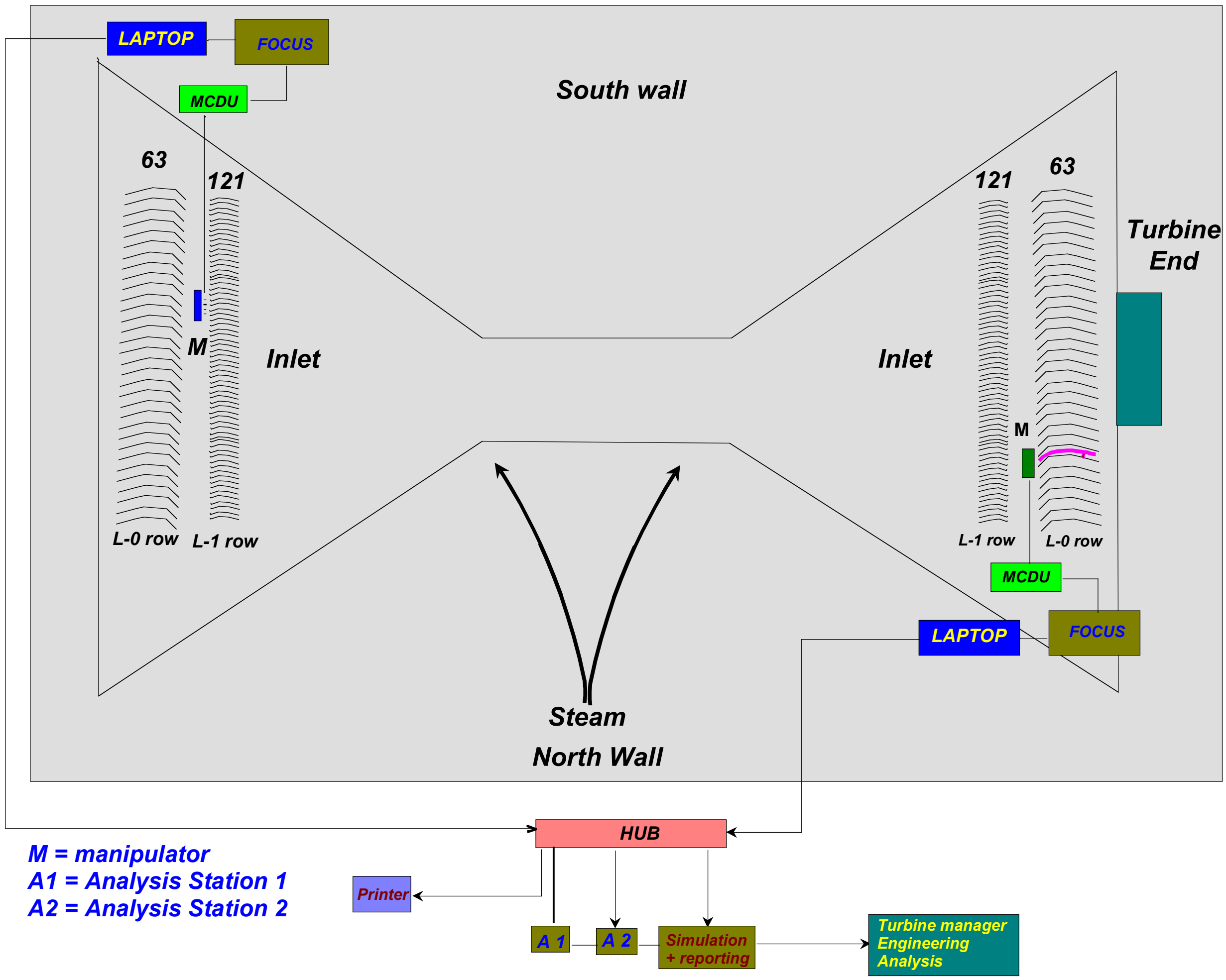


Figure 2: Inspection of LP turbine L-1 and L-0 rotor grooves / blades with 2 phased array systems.

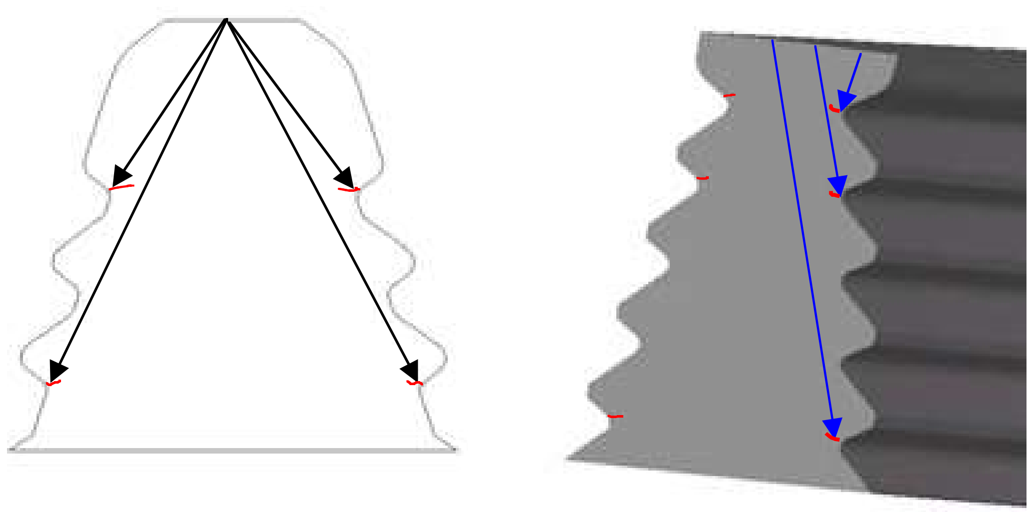


Figure 3: Line scanning of L-1 and L-0 rotor steeples by phased array probe (principle).

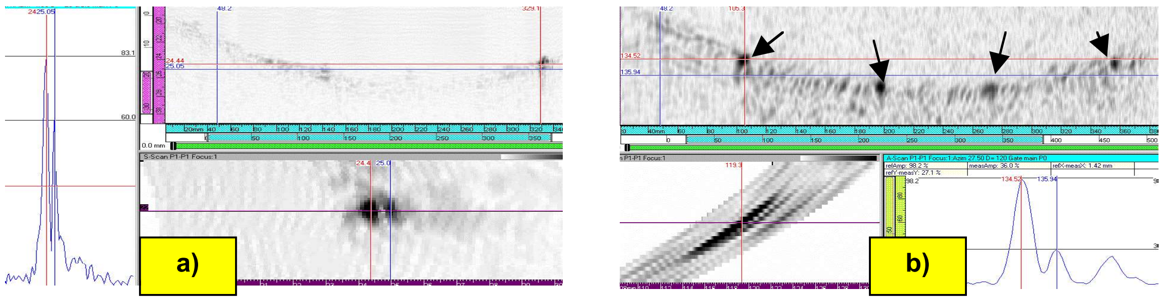


Figure 4: Detection and sizing of 9 x 0.5 mm target on L-0 steeple-Hook 1 (a); H_{UT} = 0.6 mm. Detection and sizing of 9 x 1 mm EDM notch on hook 5 (b); H_{UT} = 1.4 mm.

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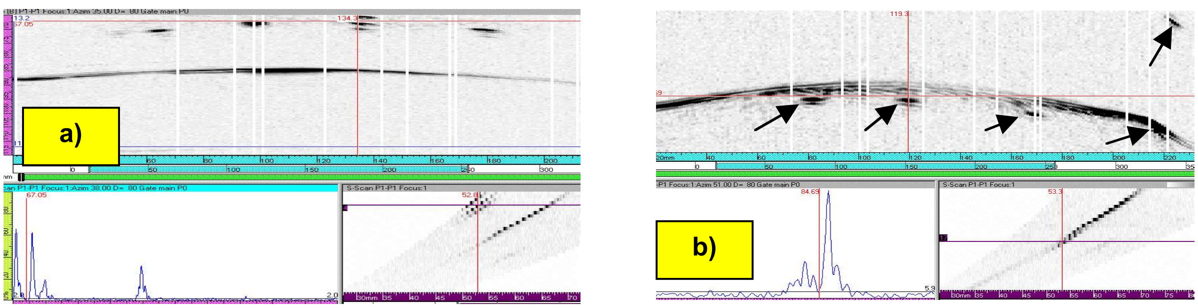

Figure 5: Detection of 5 x 1 EDM notches on platform – L-0 blade. Three EDM notches of 5 x 1 mm, 5 x 1.5 mm and 5 x 0.5 mm were machined at the same location, with a spatial distribution of 2.5-3 mm (a). Targets on hook 1 are 1.5-2 mm behind the geometric echo (b).

The detection and sizing is performed from side, namely in L-waves. Accuracy is lower due to multiple scattering from the target facets. Crack-like EDM notches are sized within ± 1 mm for height and about ± 2 mm for length (see Figure 6).

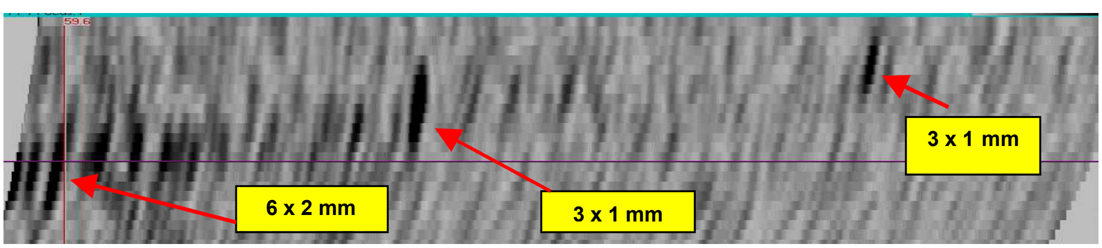

Figure 6: Detection of 3 EDM targets of 6 x 2 mm (crack-like) at 60 mm depth, 3 x1 mm rectangular at 80 mm and 3 x 1 rectangular at 105 mm depth. Crack-like EDM notch produced 7-9 signals, which could contribute to errors in sizing.

Phased Array Inspection of GE Disk-Blade Rim Attachment

SIMD was asked to perform an **in-situ** ultrasonic inspection of GE disk-blade rim attachments on an LP rotor, at Bruce B NGS. Due to disk geometry, high productivity and reliability, phased array technique was considered the best method to be used. Some problems were successfully overcome:

- lack of technical drawings
- lark of reference blocks with EDM notches
- interface between Bonnie arm (SIMD manipulator for disk inspection) and phased array holding device
- interface between Bonnie arm and X-Y manipulator to perform raster scan for specific patches
- optimizing the scanning speed, reduce the number of focal laws and optimize the scanning pattern
- use DDF for better sizing and evaluation (differentiate between corrosion pits and stress corrosion cracks) with Tomoview 1.4R2
- combine L-, and T-waves focal laws in the same sectorial scan
- simulate and optimize the inspection scenario, namely for disk #1 and #5.
- perform the inspection of all 10 disks, both inlet and outlet faces, within 2 days outage window.

EPRI played a major contribution to the success of this inspection providing 2 reference blocks with EDM notches and corrosion pits and guidelines for inspection strategy. SIMD performed a capability demonstration on TVA disk (similar with disk #3), EPRI disks and ray-tracing simulations for disk #1 and #2.

The inspected disks present different thickness and limited accessibility (see Figure 7-8). Simscan / Imagine 3D was used to technically justify the focal laws, virtual index value and mode converted signals on upper hook (H1).

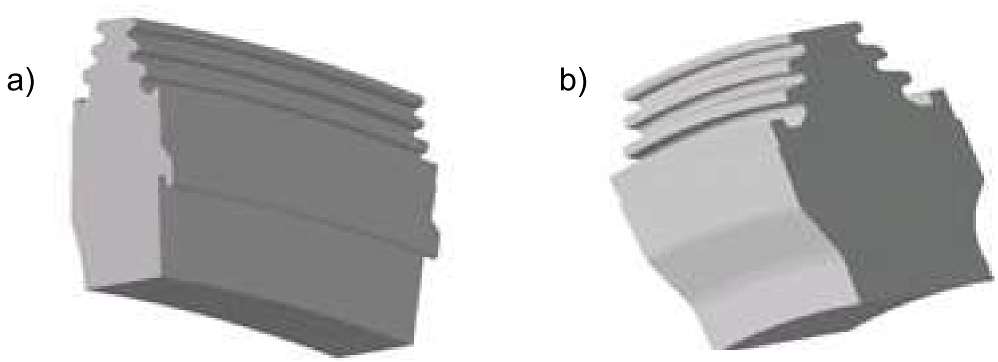

Figure 7: Isometric view for GE disk #1(a) and 2-4 (b) generated by Imagine 3D / Simscan.

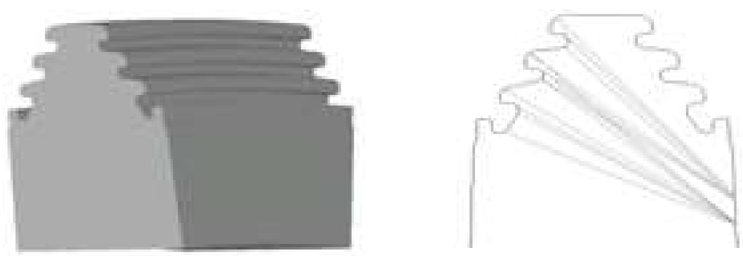

Figure 8: GE disk #5 and the sketch for using a double-head phased array probe.

The possible cracks are upward oriented, and a specular reflection makes sizing very difficult. DDF board and steeper angles of attack contributed to a better sizing for both length and height. Height is undersized by a factor of 2, and length is oversized by 1.1-1.5 mm (see Figure 9).

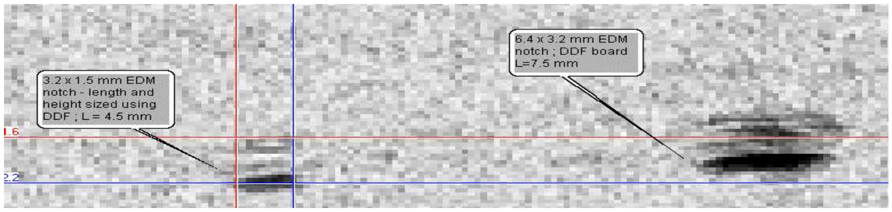

Figure 9: Sizing of EDM notch length using DDF board.

Further improvements were identified, and the capability demonstration for all 5 disks is in progress.

Conclusions

The development of DNGS capital project based on multi field trials is almost completed, and a mature technology for ISI section will be available for the next outage inspection in April 2001. Inspection of 10 disks at Bruce B was done within the outage window. A systematic approach of this inspection is in progress. Detection and sizing accuracy of small targets are within the fitness-for-purpose acceptance tolerances.

References

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