

October 18, Hamburg

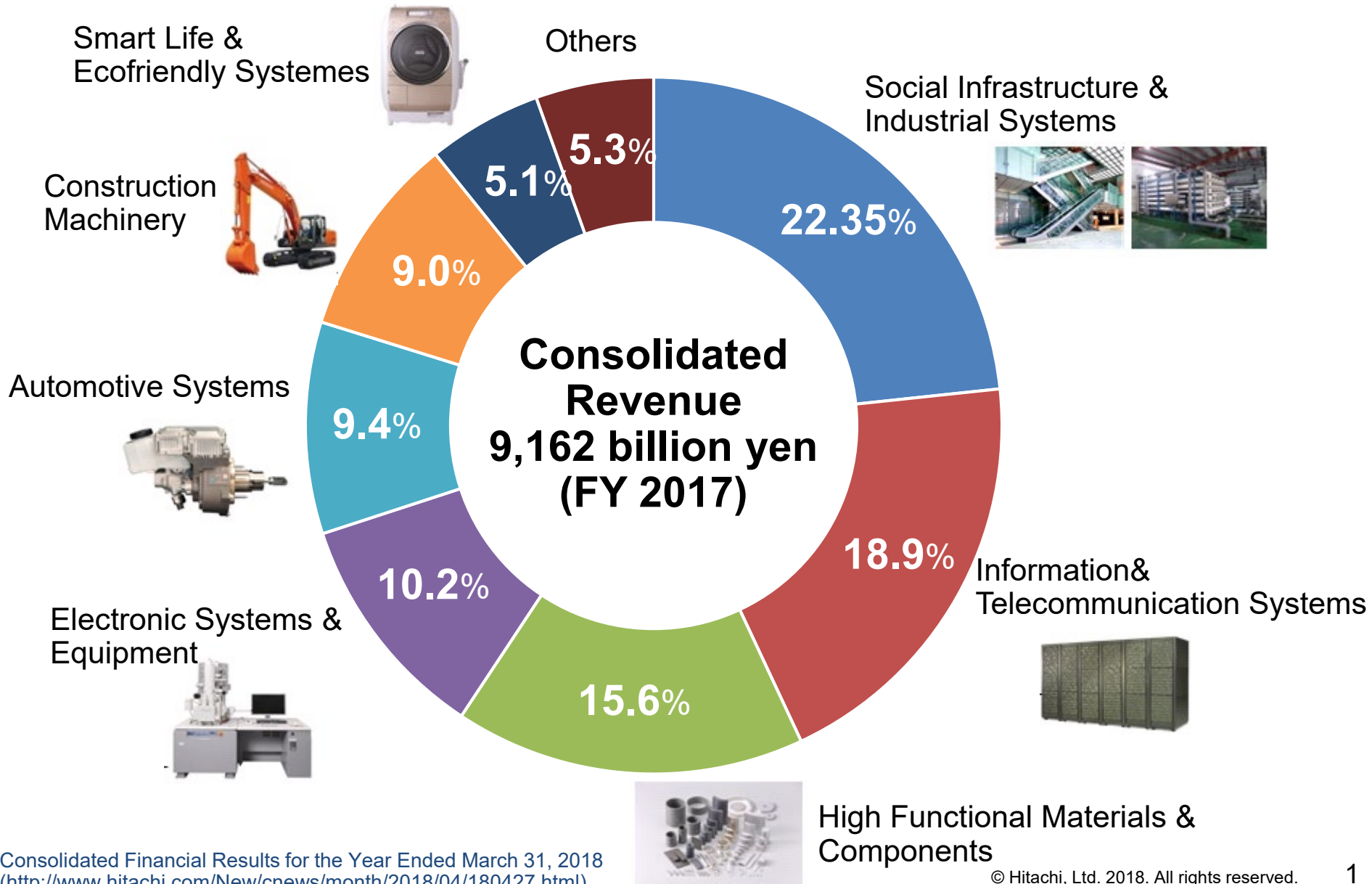
3rd 3D Metrology Conference 2018

Development of a Multi-Directional Optical Probe

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Hitachi Ltd. Research & Development Group, Japan

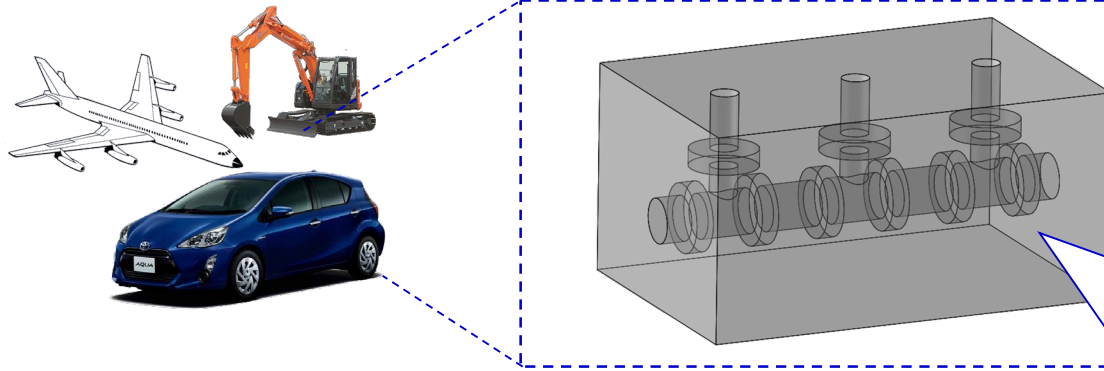
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About Hitachi, Ltd.



- 1. Background & Purpose**
- 2. Principle**
- 3. Evaluation for 3D Measurement**
- 4. Conclusion & Future Work**

Complex mechanical parts in industrial Field

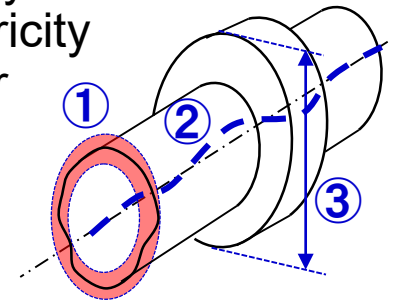


Example: Oil hydraulic part

Inspection item:

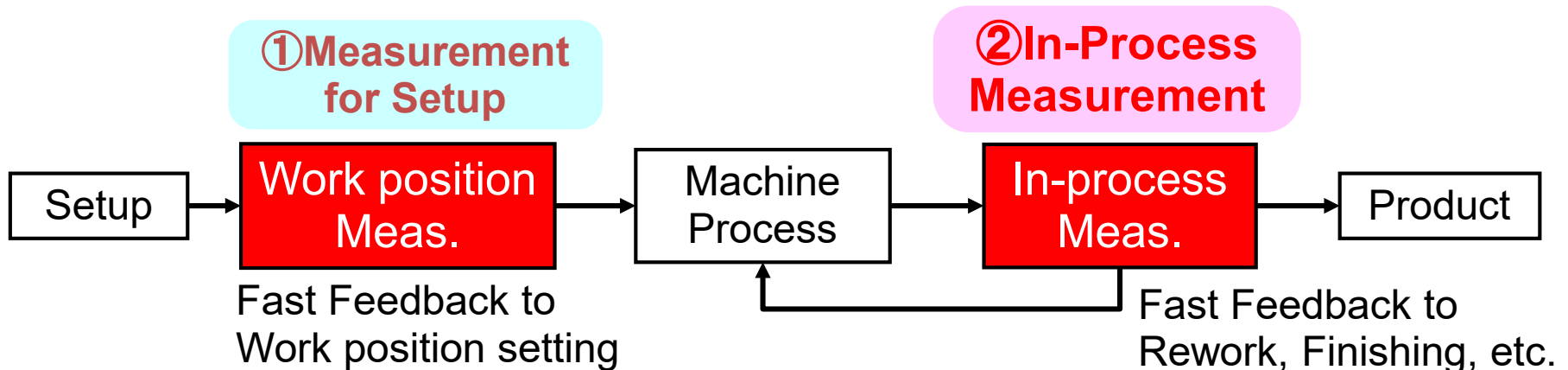
- ① Circularity
- ② Concentricity
- ③ Diameter

⋮



Geometric & Size tolerance evaluation is demanded

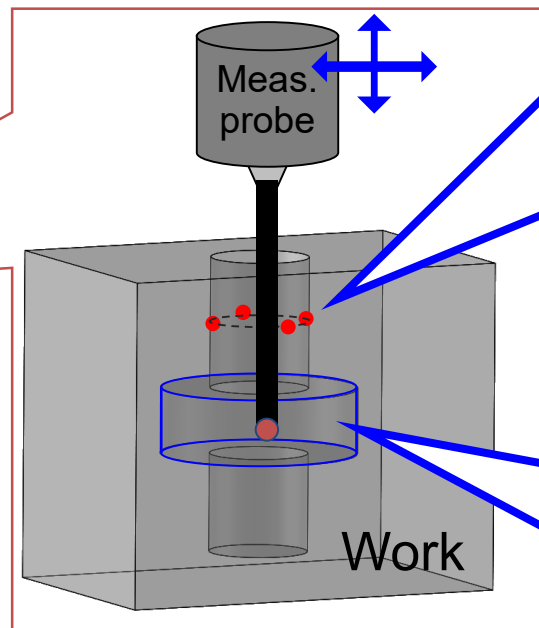
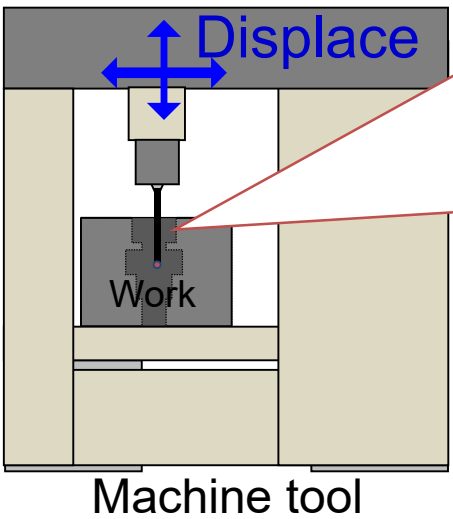
Need for High Accuracy On-machine Meas.



Faster feed-back compared to off-line meas. method (e.g. CMM (Coordinate Measuring Machine))

Issue of Conventional Method

Conventional on-machine meas. probe;
Meas. surface point by touching surface with mechanical displacement



Problem 1 Point meas.

Two diagrams illustrating point measurement on a circular surface. The left diagram shows a circle with four red dots on its circumference and a horizontal blue double-headed arrow labeled "Meas. size" spanning the diameter. Below it is the text "4 meas. point". The right diagram shows the same circle with four red dots at different positions on the circumference and a diagonal blue double-headed arrow labeled "Meas. size" spanning the diameter. Below it is the text "Another 4 meas. point".

Problem 2

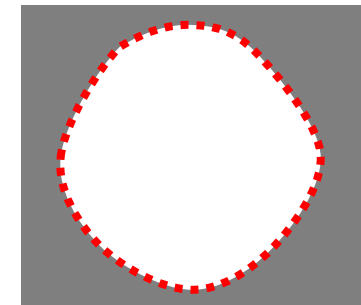
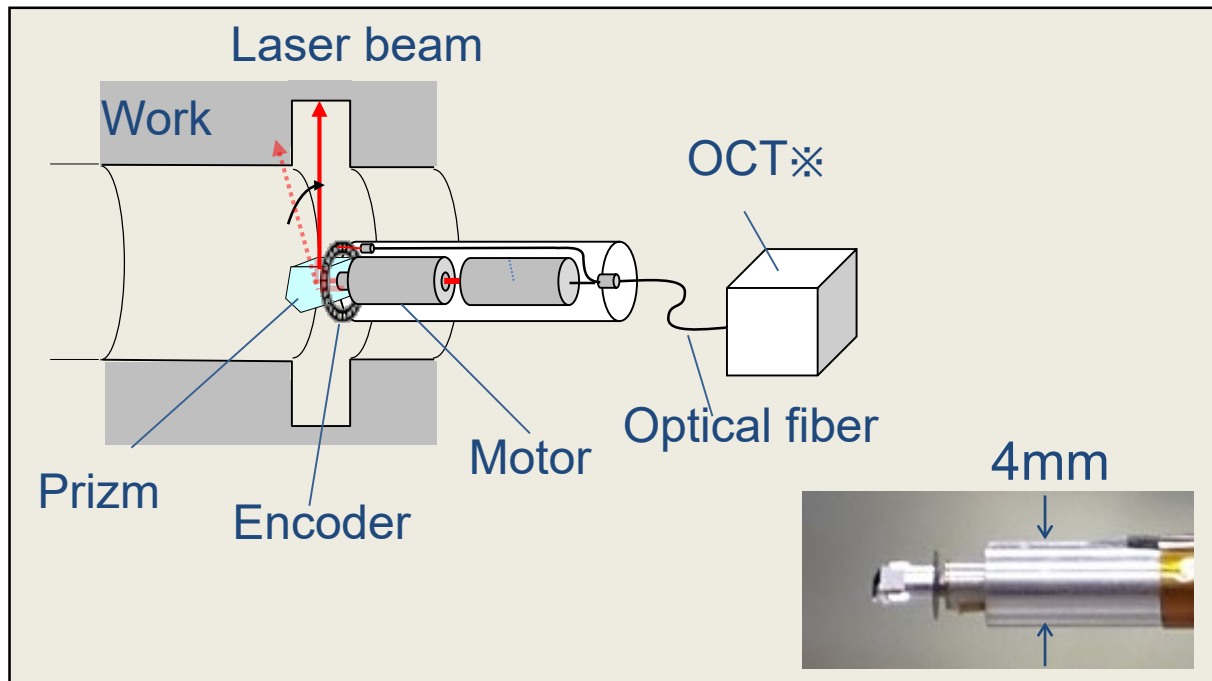
A diagram showing a probe tip positioned in a U-shaped groove. The probe is shown in red dashed lines, indicating it is not touching the surface. Below the diagram is the text "Cannot touch" followed by "||" and "No surface data".

Our Previous Approach for Complex Shape Meas.

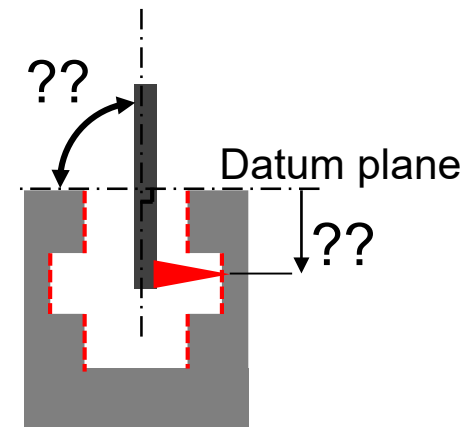
Meas. system until now:

Flexible OCT* meas. system with robot arm for complex shape meas.

OCT: Optical Coherence Tomography



Rich data rate



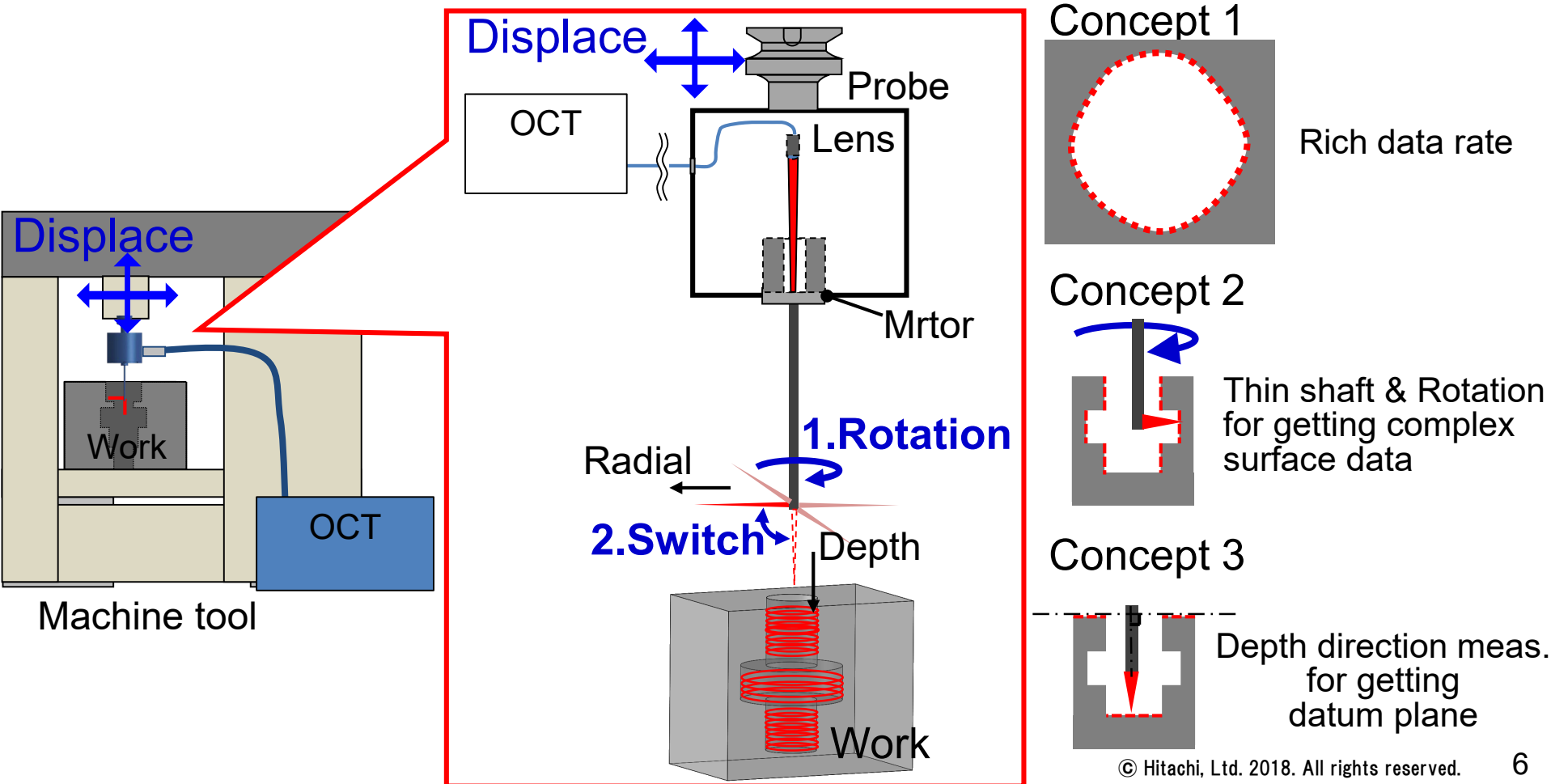
Problems for on-machine meas.:

- Hard to meas. a datum plane to evaluate relative position & geometric tolerance of holes
- Low throughput due to an offline measurement

Concept of Novel Developed Probe

Multi-directional meas. probe overcoming the conventional problems is proposed

- Development of fast on-machine measurement probe for Purpose; 3D-shape inspection using an OCT✕
- Target accuracy: $\pm 5\mu\text{m}$



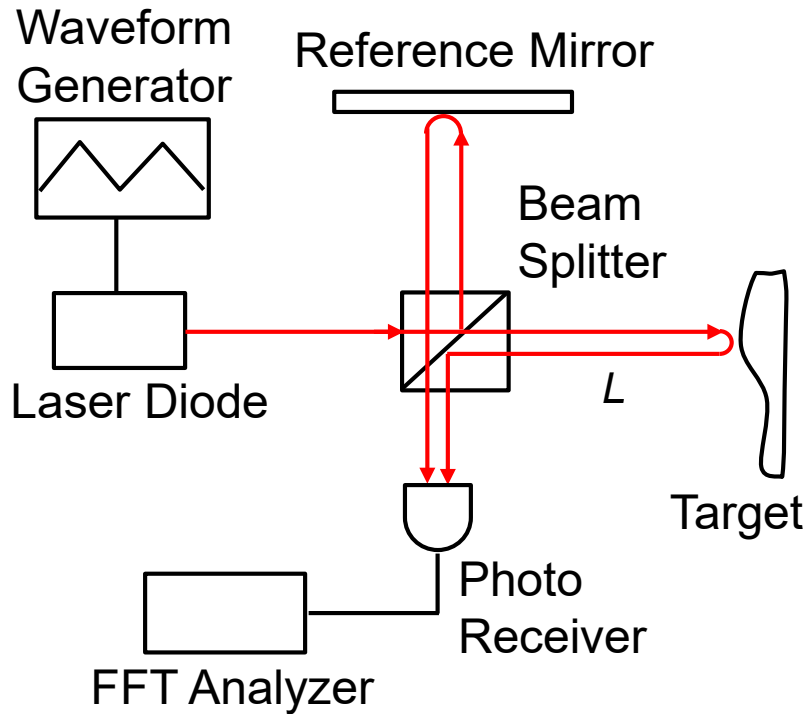


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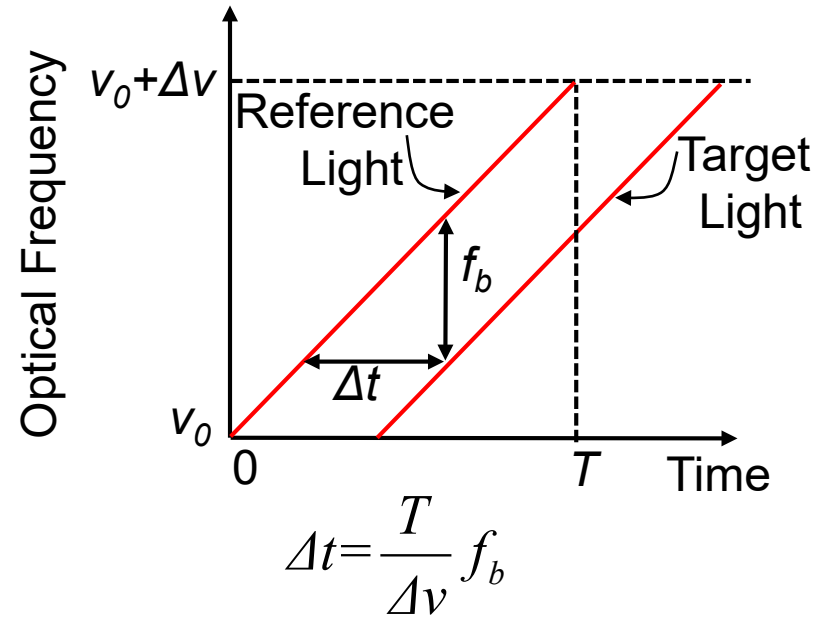
Principle of OCT

Laser distance meter based on optical coherence tomography

Optical setup



Distance Measurement Principle



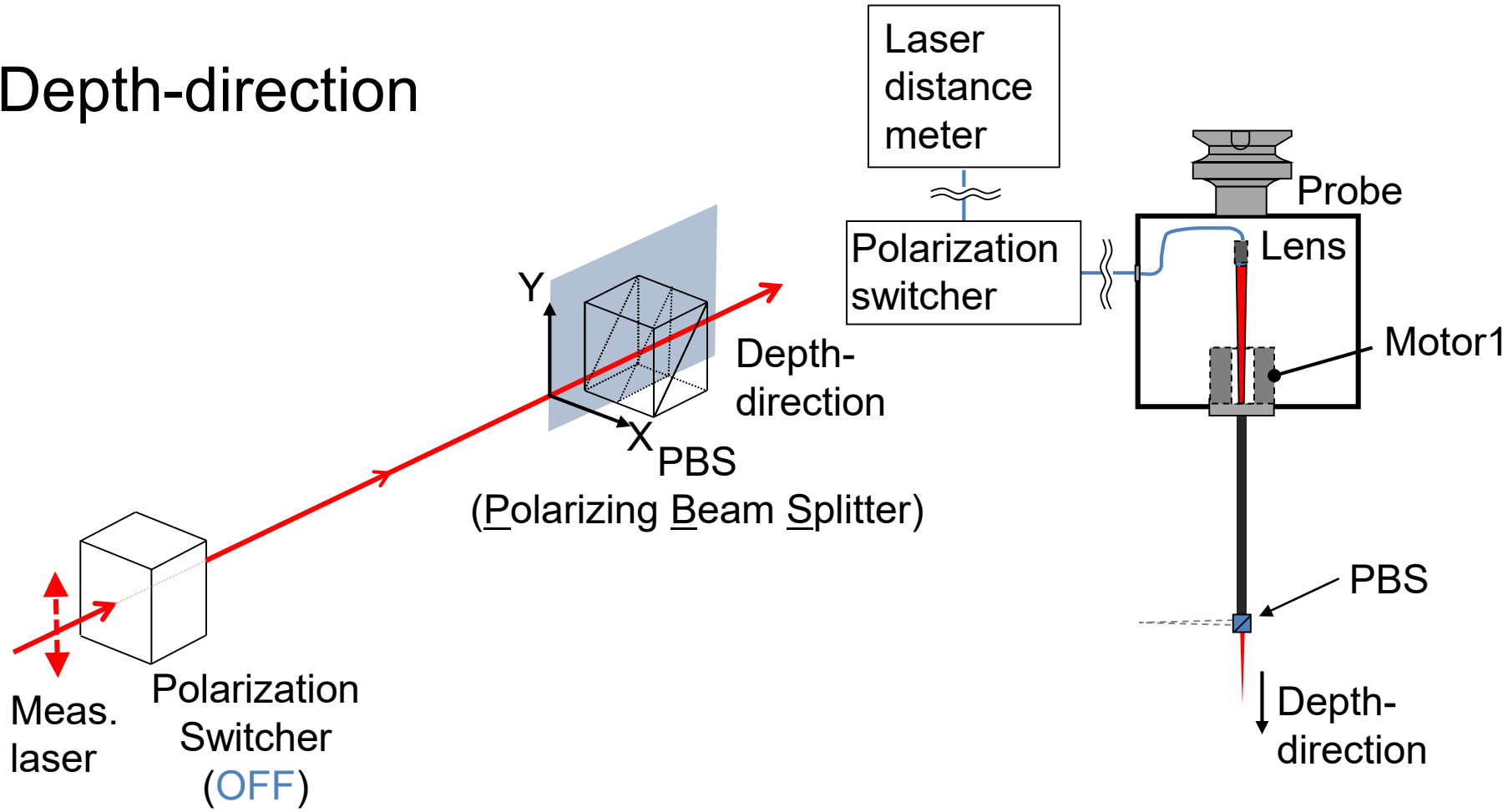
Light travels a roundtrip distance L during Δt .
 L is expressed using light speed c .

$$\underline{L} = \frac{1}{2} c \Delta t = \frac{cT}{2\Delta v} \underline{f_b} \quad \text{Distance } L \propto \text{Beat Frequency } f_b$$

Feature; 1. High speed (3kHz)
2. High accuracy ($< \pm 5 \mu\text{m}$)

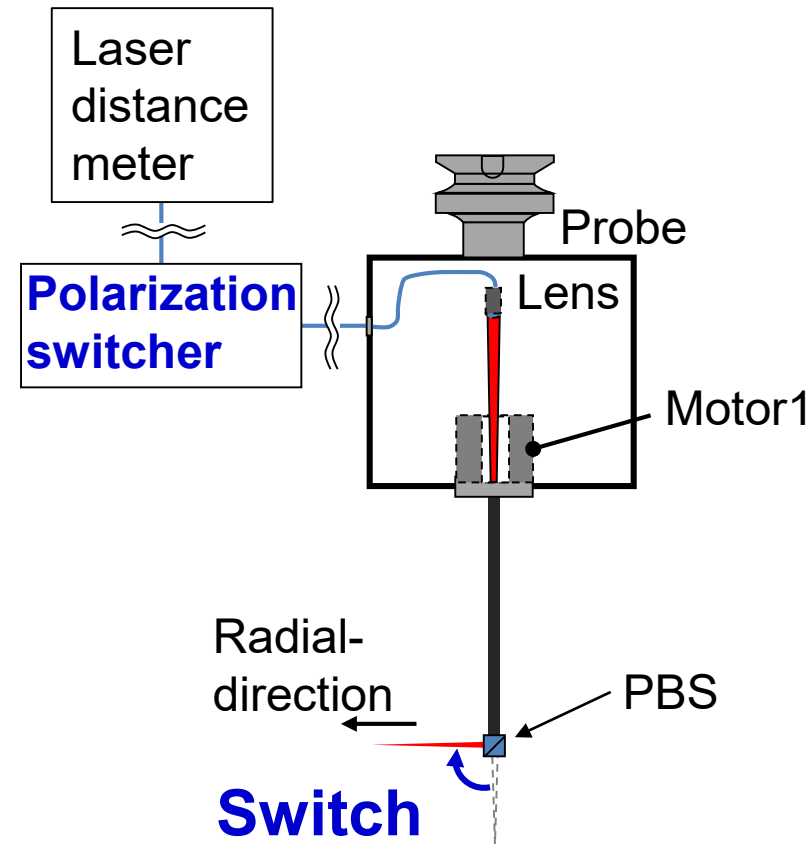
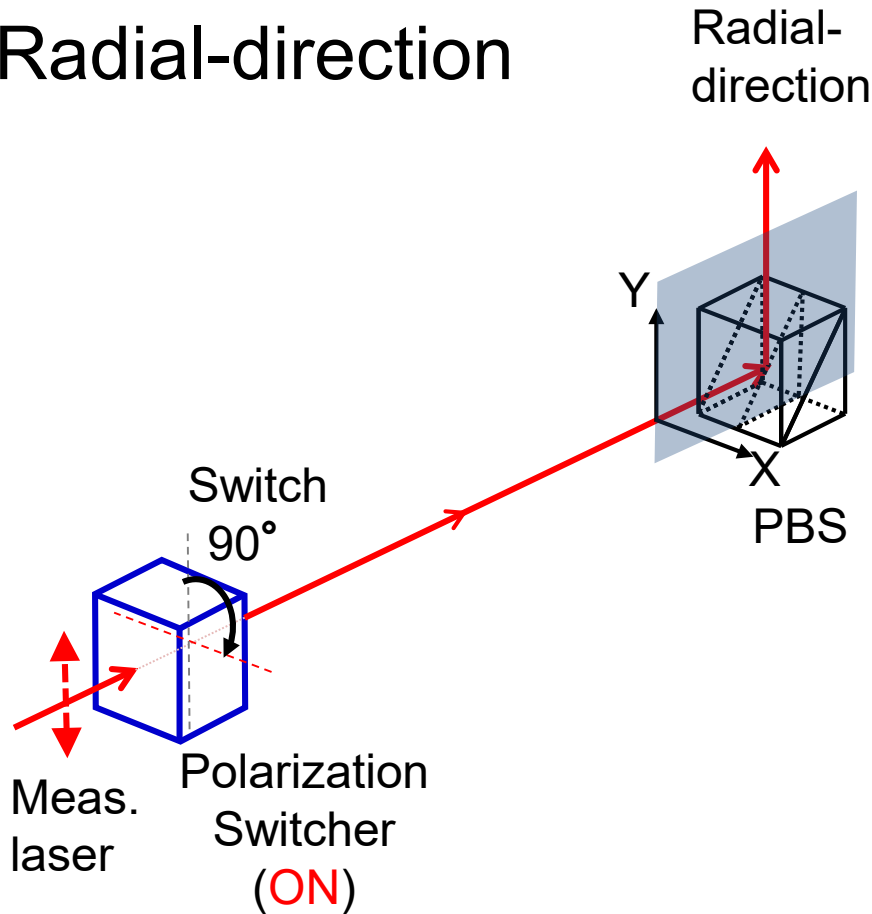
Depth/Radial-Direction Switching Principle

■ Depth-direction



※ PBS: Polarizing Beam Splitter

Radial-direction

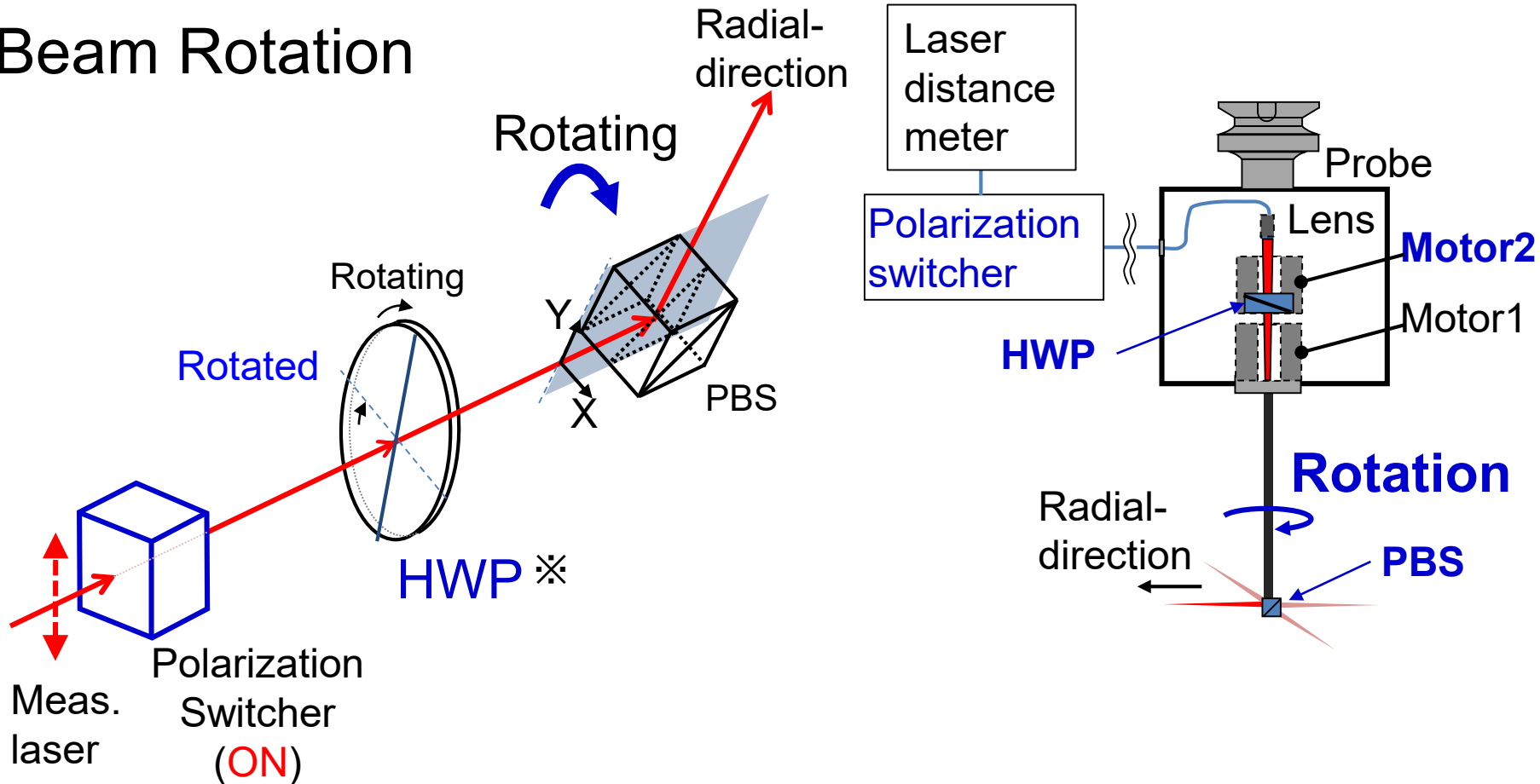


**Change direction quickly (100μsec)
without dropping throughput**

Measurement Beam Rotation Principle

To rotate the beam, HWP(Half-Wave Plate) is adopted

Beam Rotation

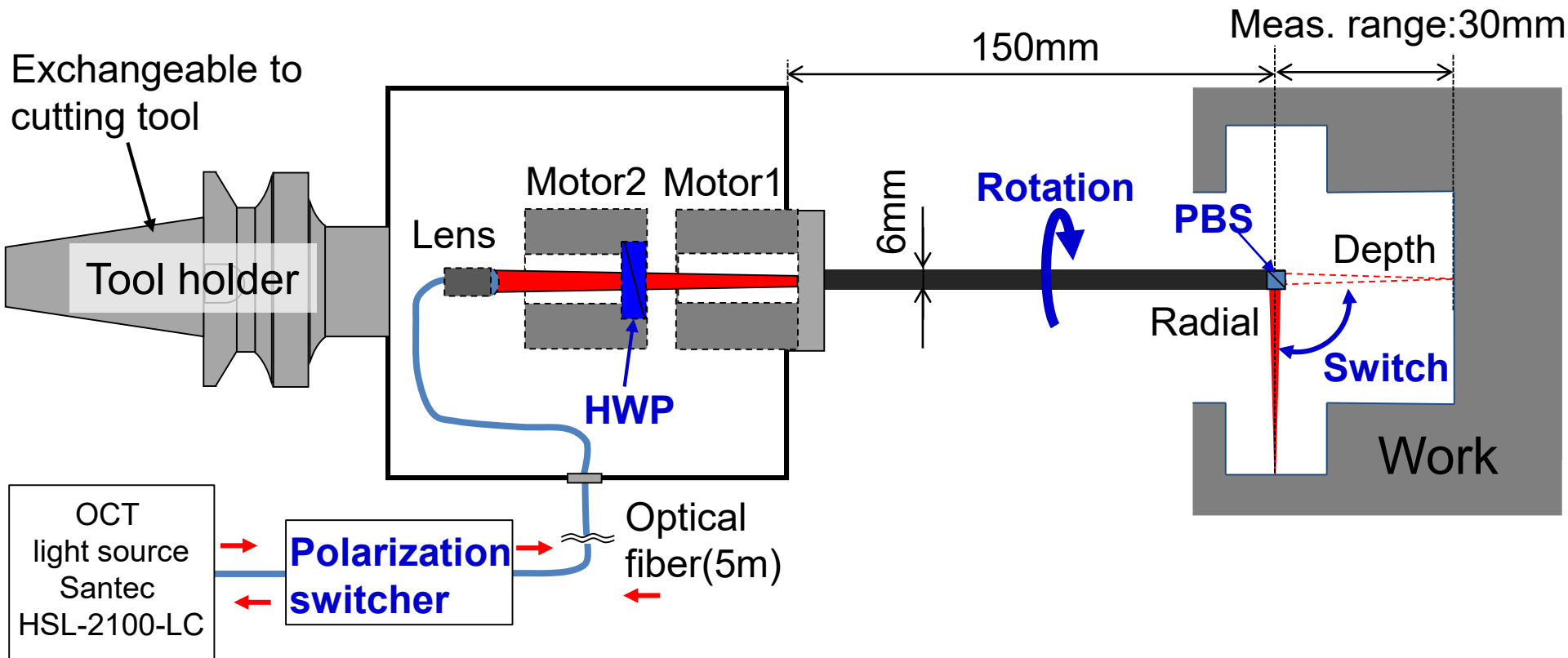


Able to measure fast by rotating meas. beam at max. 450rpm

※ HWP: Half Wave Plate

Developed Optical Meas. Probe

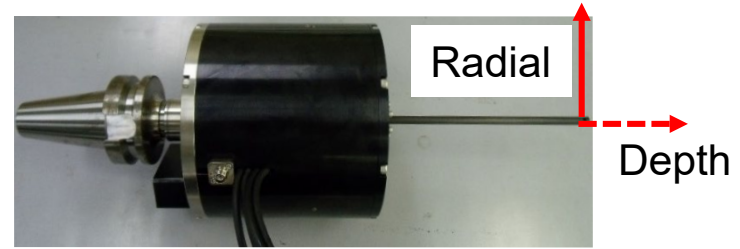
A multi-direction measurement probe for 3D-shape inspection using the devised technologies.



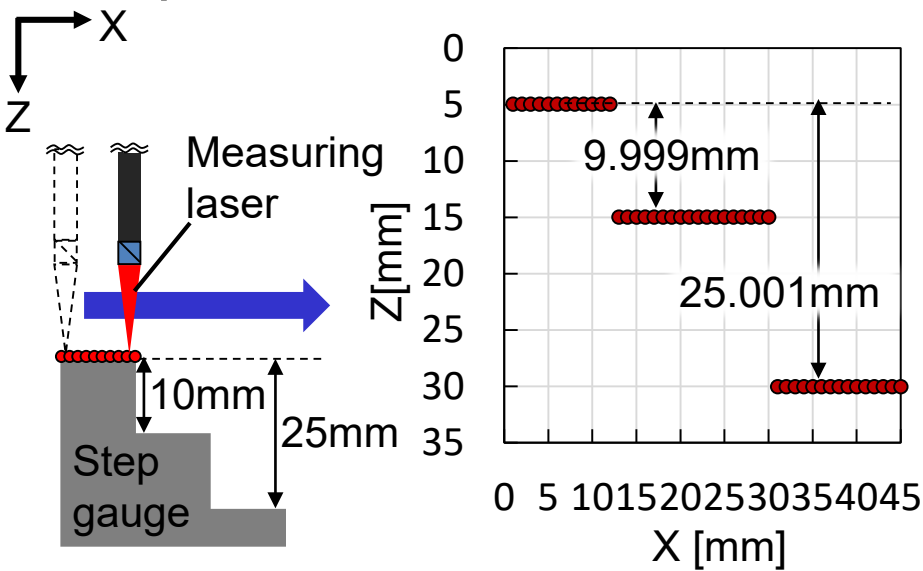
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Accuracy Evaluation of Developed Probe

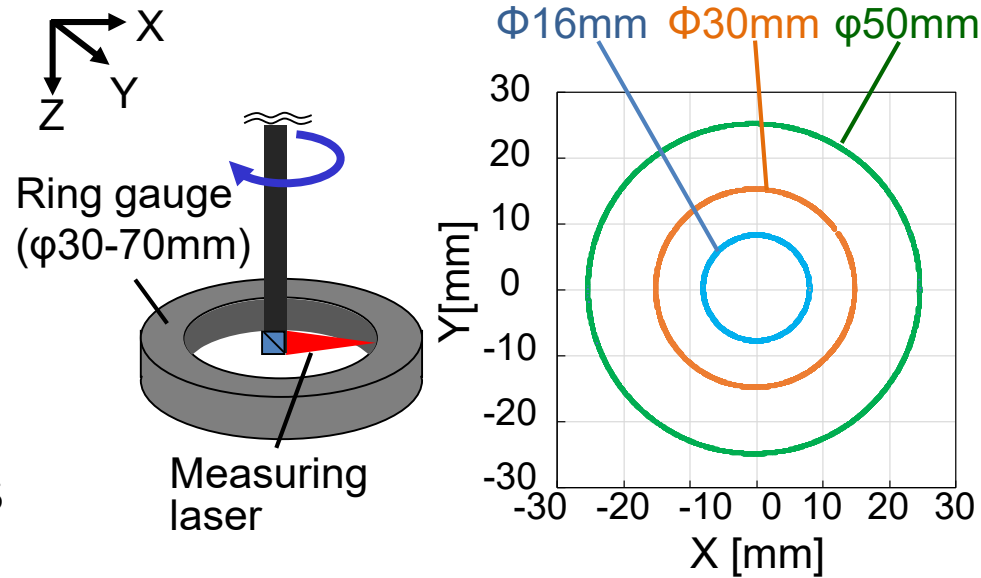
**Achieved meas. accuracy:
 $\pm 1.3\mu\text{m}$ (<target $\pm 5\mu\text{m}$)**



Depth direction meas.



Radial direction meas.



	Depth meas.		Radial meas.		
Value [mm]	10	25	16.001	30.001	49.996
Meas. result [mm]	9.999	25.001	16.0009	30.0023	49.9962
Error [μm]	1.0	1.0	-0.1	1.3	0.2

Comparison with On-Machine Touch Probe

Mechanical part was measured by developed probe.
Measured results are compared with results by touch-probe.

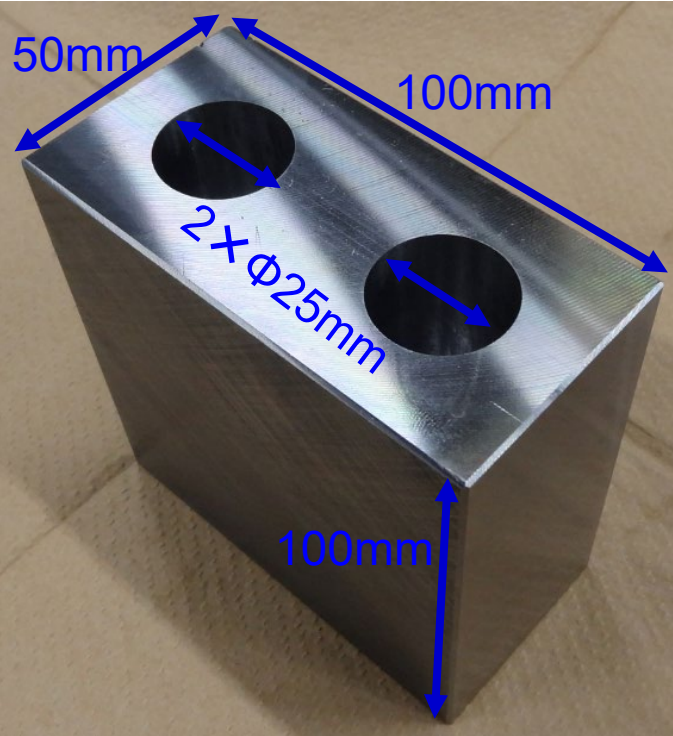
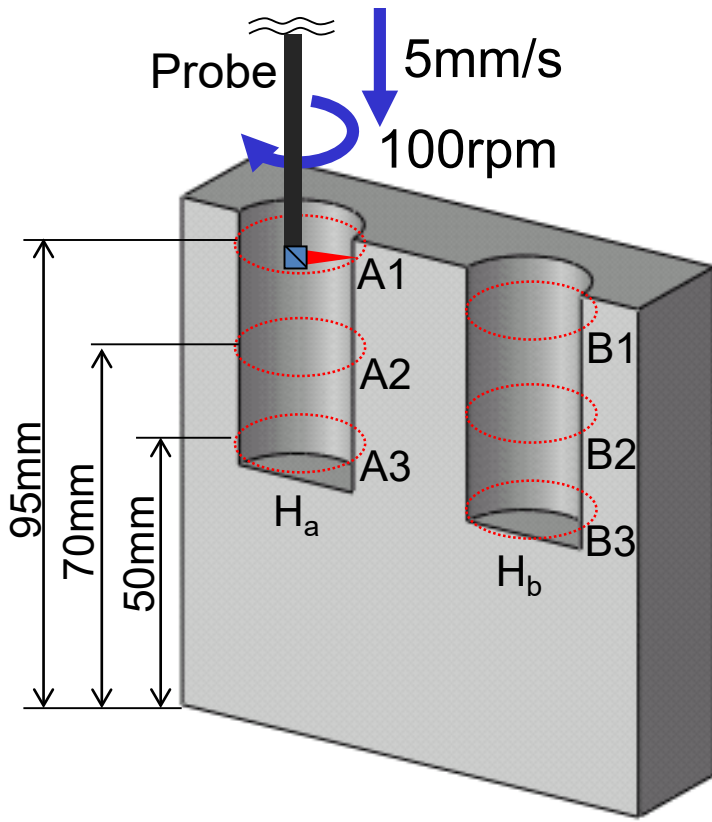


Image of measured part



Cross section of measured part



Touch Probe⁽¹⁾
(Renishaw, OMP60)

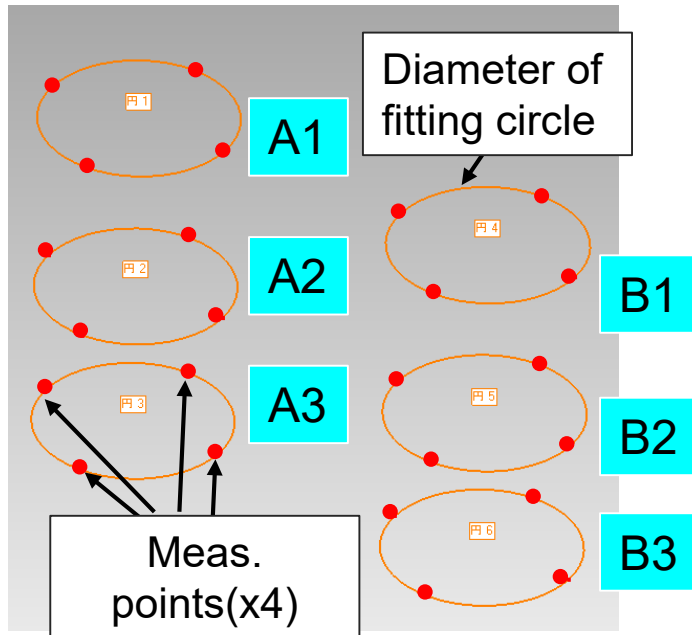
(1)<http://www.renishaw.com/en/omp60-optical-transmission-probe-6101>

The developed probe can measure 3D-shape faster than the point meas. touch-probe.

Point meas. touch-probe

Meas. time: 40sec/section

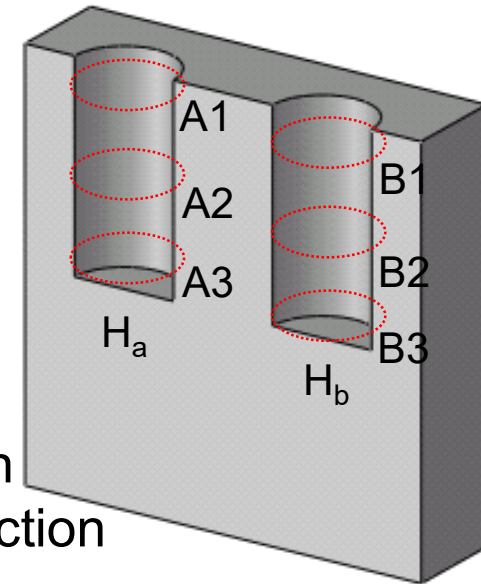
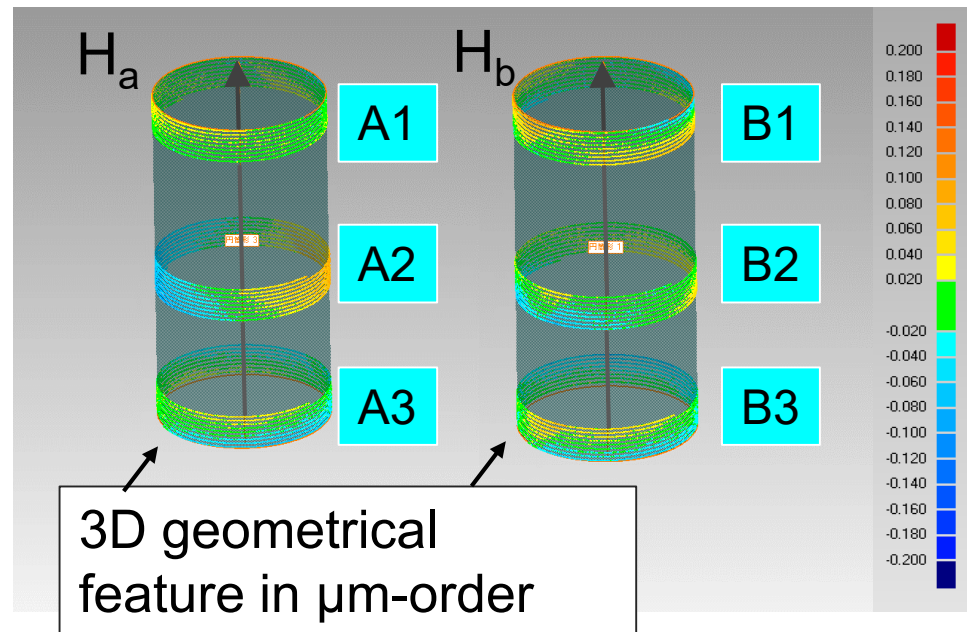
Meas. point: 4point/section



Developed probe

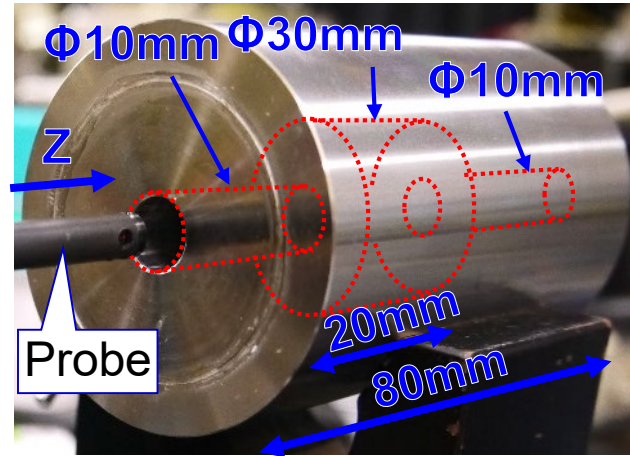
Meas. time: 0.6sec/section

Meas. point: 3000point/section

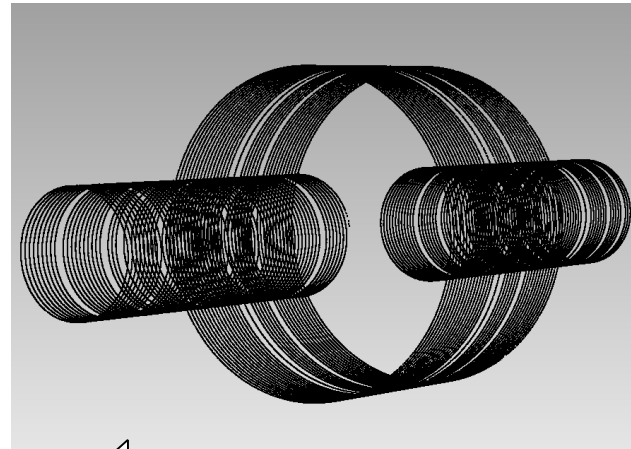


Application for Radial Direction Meas.

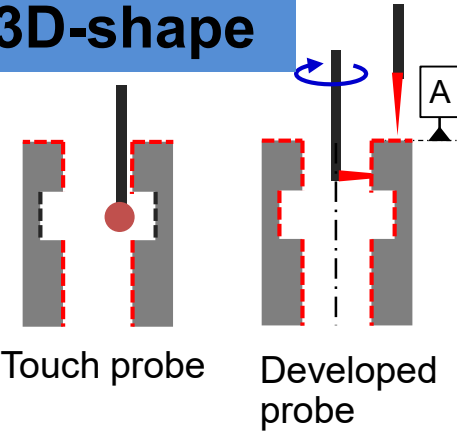
Developed probe can measure & inspect complex 3D-shape



Sample



Meas. data



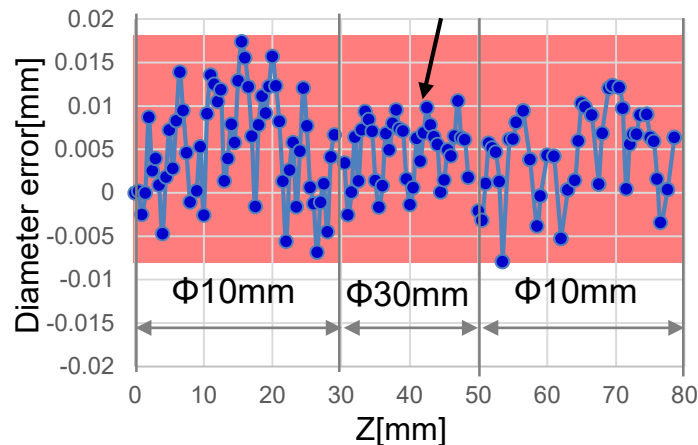
Touch probe

Developed probe

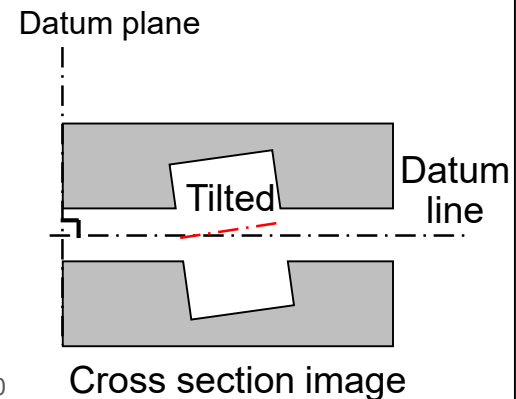
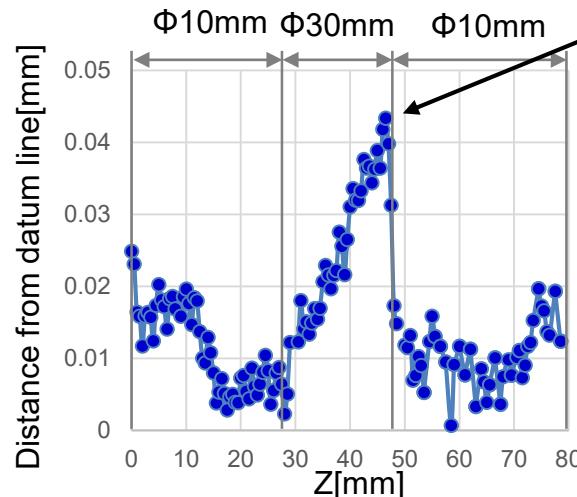
Meas. time: 5min.

Meas. point: 410,000

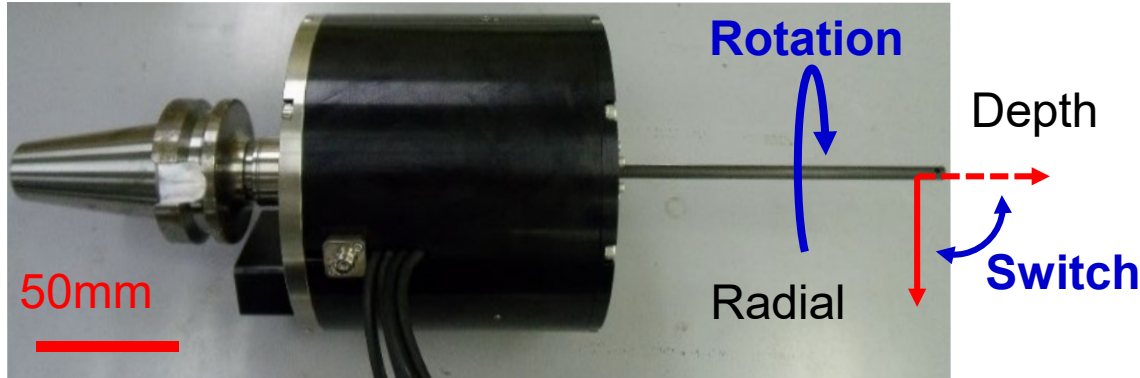
Diameter error:
-0.008 ~ +0.017mm



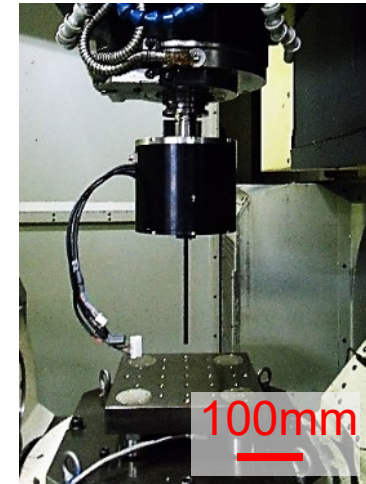
Concentricity of
central axis : 0.043mm



Cross section image



On processing machine



On machine tool

Specification	Value
Measurement accuracy	$\pm 1.3 \mu\text{m}$
Scanning rate	3 kHz
Coherent length	30 mm
Probe length	150 mm
Probe diameter	6 mm
Max. rotation speed	450 rpm
Measurable direction	Depth & radial
Switching time of meas. direction	100 μsec



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■ Conclusion

Developed:

- Multi-directional optical meas. probe for on-machine shape inspection based on devised polarization control technologies & OCT system.

Achieved:

- Measurement accuracy of $\pm 1.3\mu\text{m}$ ($<$ Target : $\pm 5\mu\text{m}$)
- Higher density 3D-shape meas. than conventional method
- Measure complex 3D-shape part and rich 3D data.

■ Future Work

- Development of a scanning meas. system which synchronizes with tool position displacement of a machine tool.
- Development of a light source for higher-accurate probe.

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