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Development of Measurement Probe for Narrow-Space 3D Shapes

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Hitachi’s train in England

About Hitachi, Ltd.

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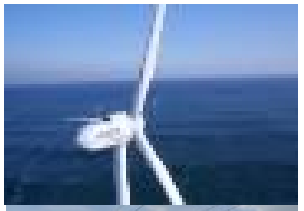
Smart Life &
Ecofriendly Systems

Others

Social Infrastructure &
Industrial Systems



Construction
Machinery

Consolidated Revenue 9,480 billion yen (FY 2018)

Automotive Systems

Information&
Telecommunication Systems

Electronic Systems &
Equipment

High Functional Materials &
Components

Outline

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1. **Background & Purpose**
2. Our Former Probe & Improved Points
3. Accuracy Evaluation
   & Demonstration of 3D Shape Meas.
4. Conclusion & Future Work

Background

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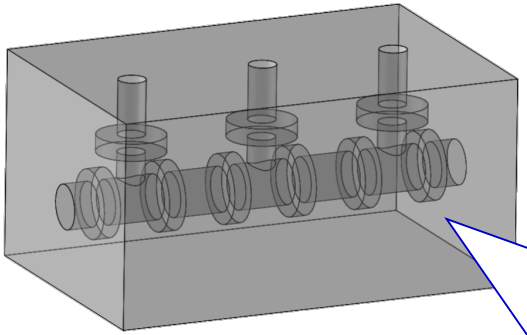
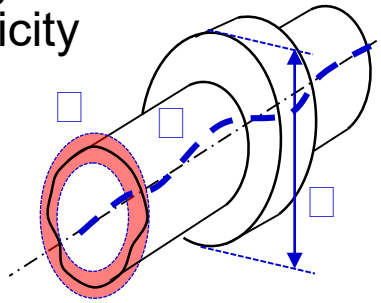
Complex mechanical parts in industrial Field



Example: Oil hydraulic part

Inspection item:
- Circularity
- Concentricity
- Diameter



Geometric & Size tolerance evaluation is demanded

Need for High Accuracy On-machine / Inline Measurement

On-machine Measurement	Inline Measurement
Machine Process → In-process Meas. → Product Fast Feedback to Rework, Finishing, etc.	Machine Process → Inspection → Product Geometric & Size tolerance evaluation

Issue of Conventional Method

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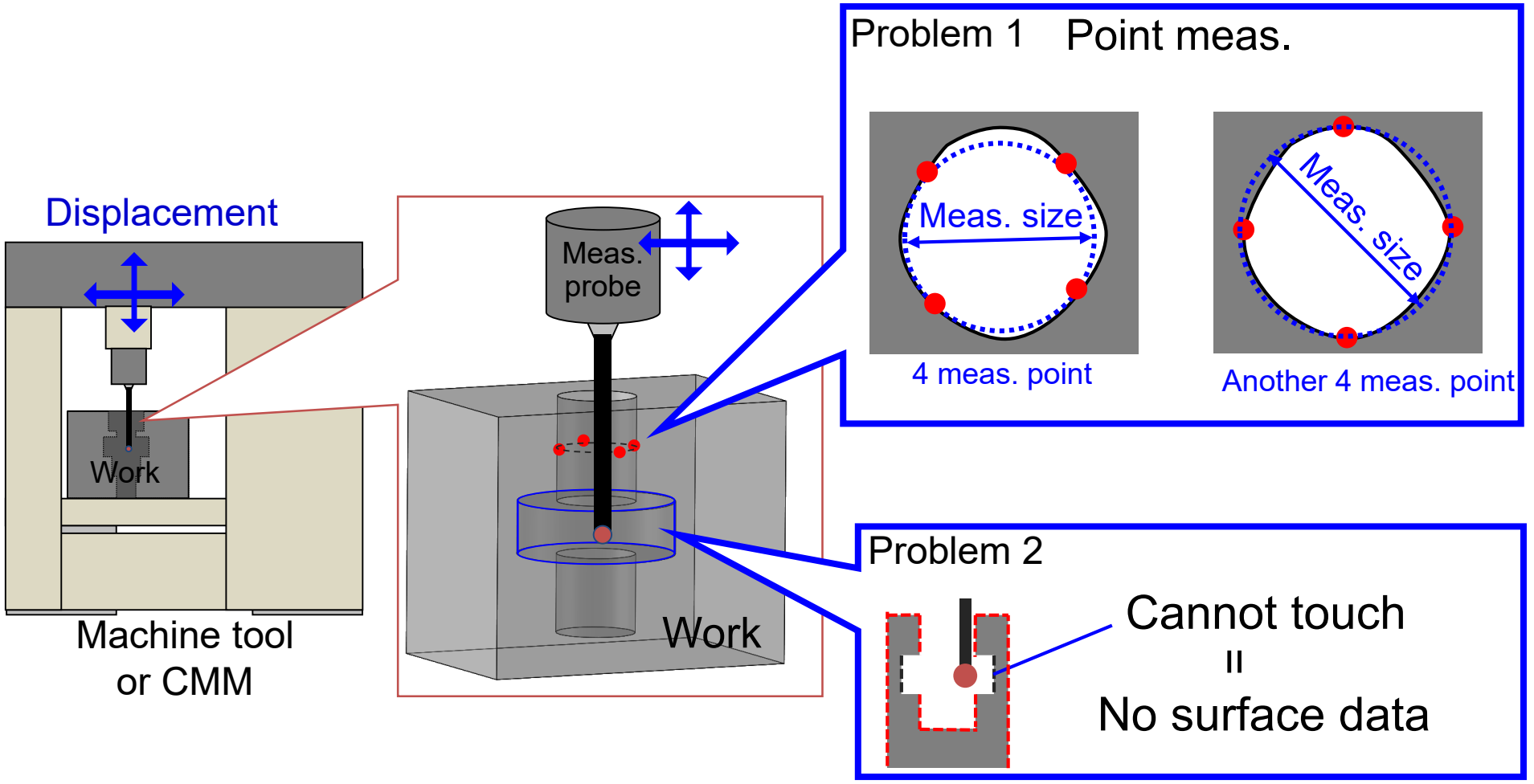
Conventional on-machine/inline measurement probe;
Meas. surface point by touching surface with mechanical displacement



Concept of Novel Developed Probe

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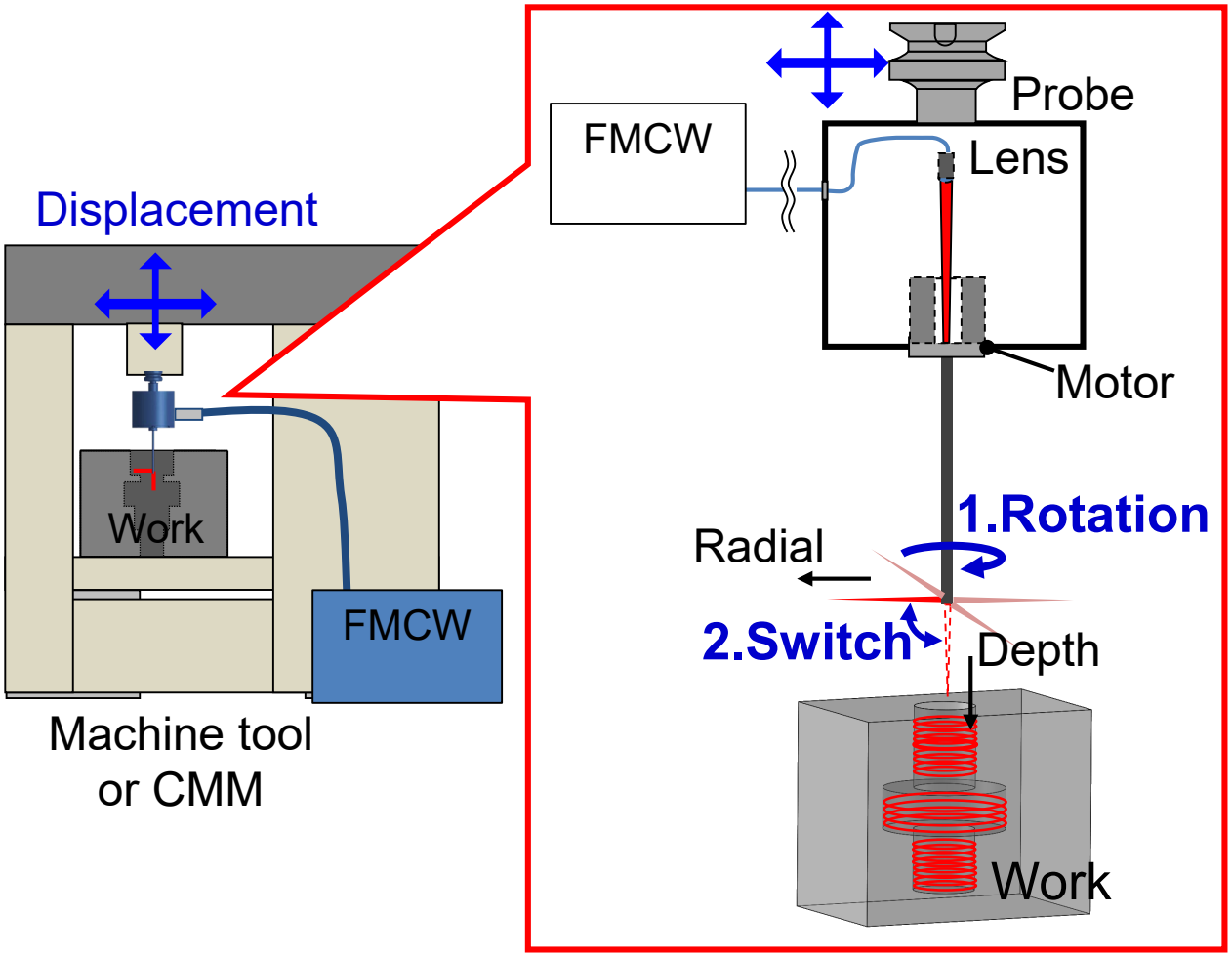
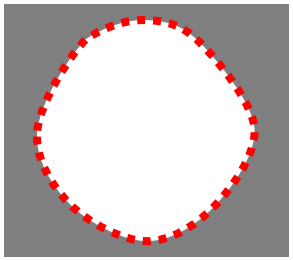
Multi-directional meas. probe which overcomes the conventional problems is proposed.

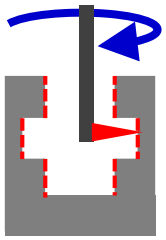
Purpose;
- **Development of fast on-machine/Inline measurement probe for 3D-shape inspection using FMCW***
- **Target accuracy ± 5μm**

*FMCW:Frequency Modulated Continuous Wave

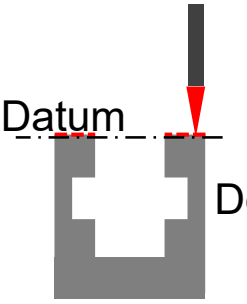




Concept 1
Rich data rate



Concept 2
Thin shaft & Rotation for getting complex surface data



Concept 3
Depth direction meas. for getting datum plane

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Our Former Probe

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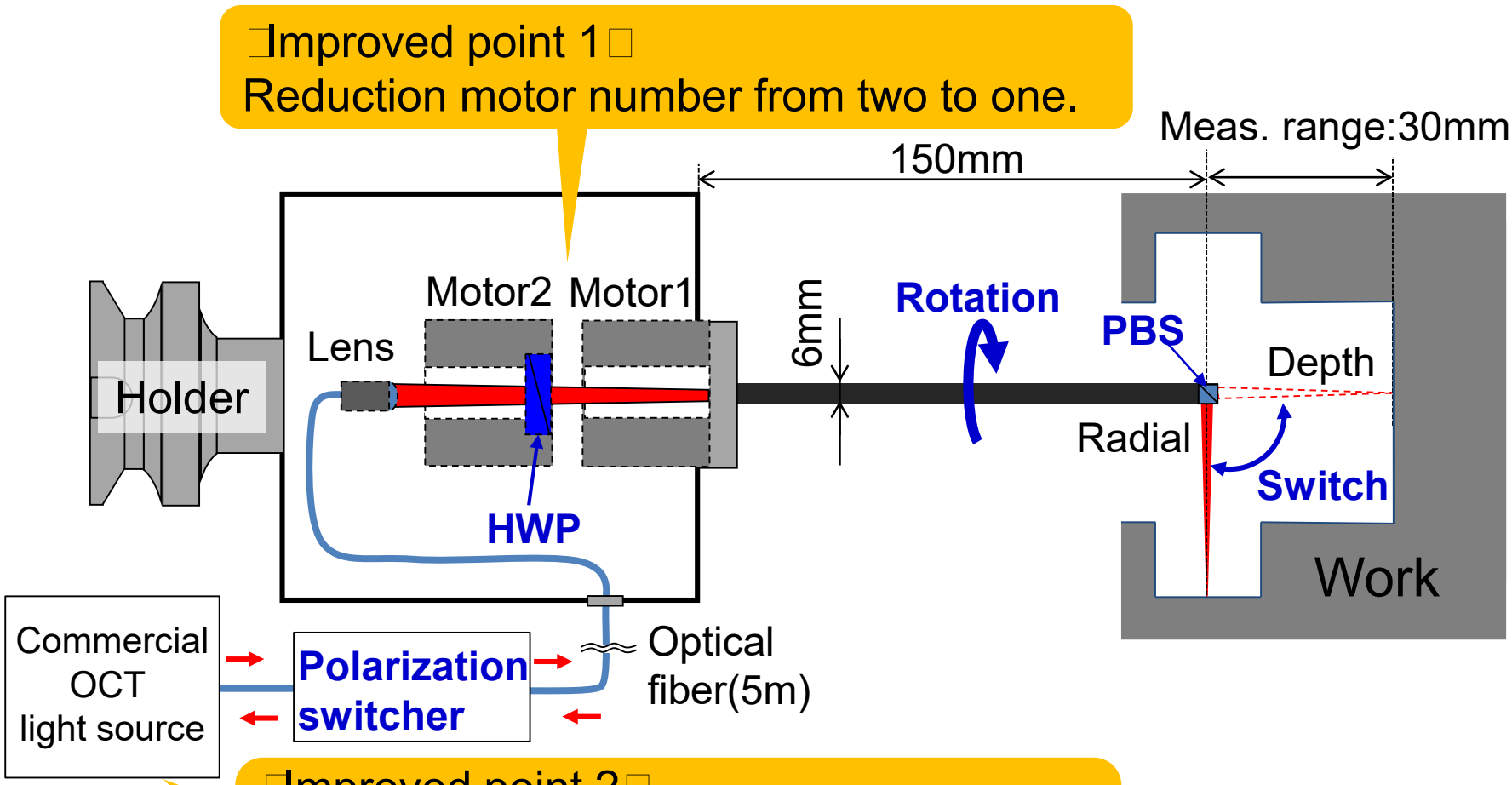
A multi-direction measurement probe which we have reported in 3D Metrology Conference 2018.



□Point 1□Our Former Beam Rotation System

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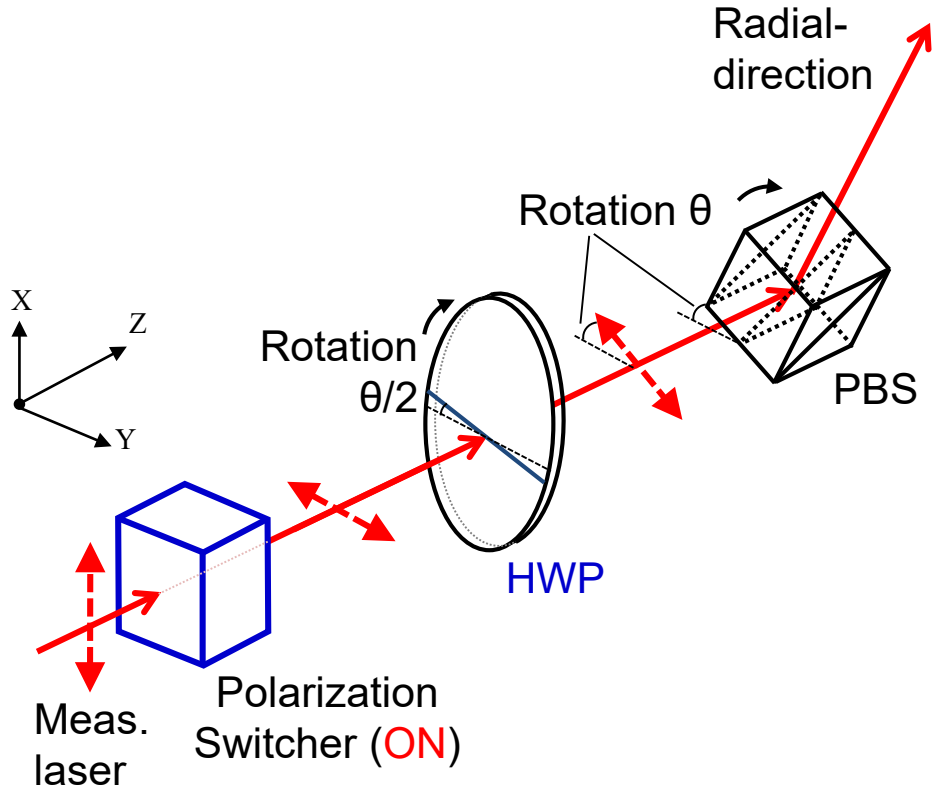
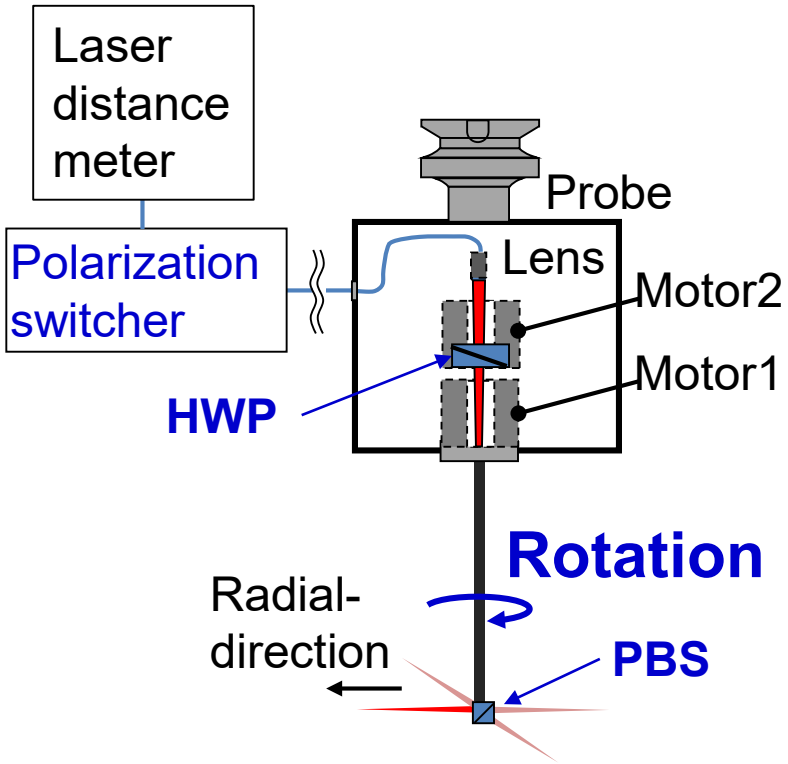
HWP(Half-Wave Plate) is adopted for rotating a beam

■ Principle of beam rotation



■ Beam rotation system



This system uses two motors for rotating a beam.

□Point 1□New Beam Rotation System

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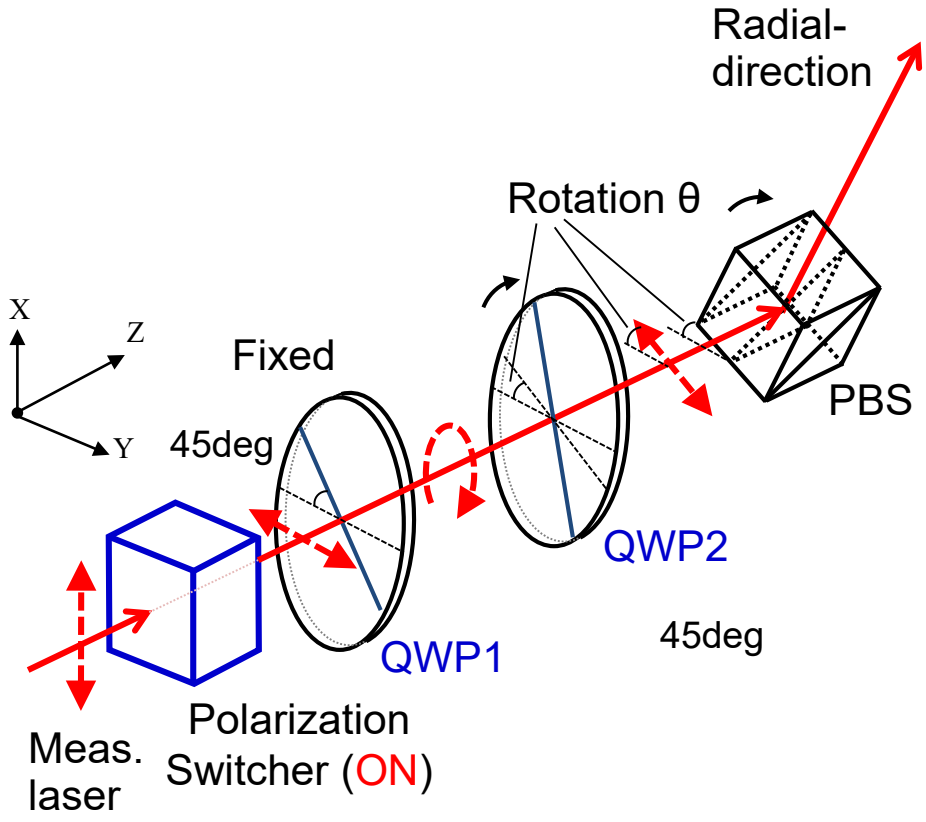
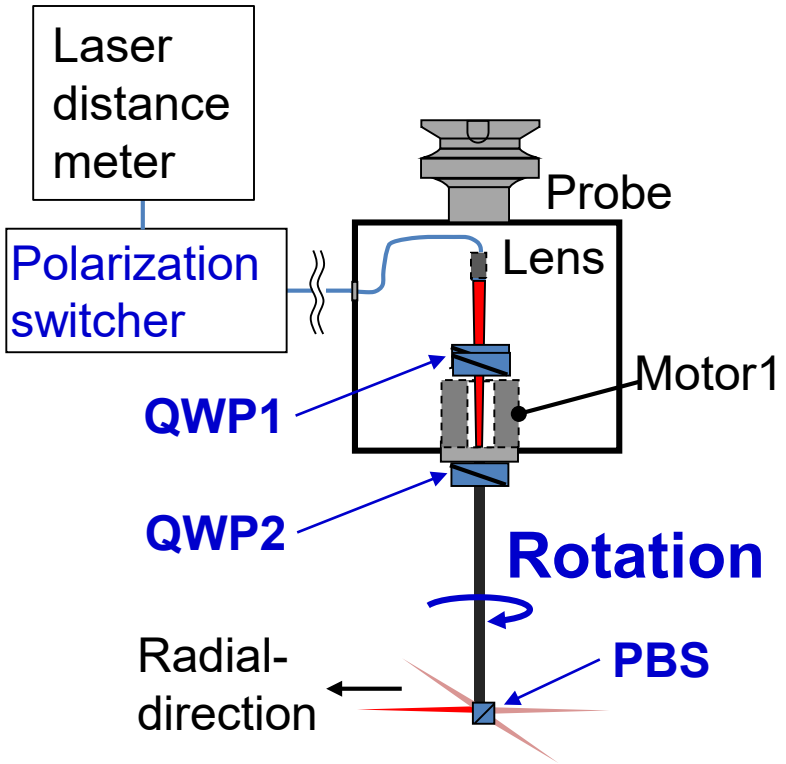
Two QWP(Quarter-Wave Plate) are adopted for rotating a beam

■ Principle of beam rotation



■ Beam rotation system



New system uses only one motor for rotating a beam.

□Point 2□In-house Distance Measurement System

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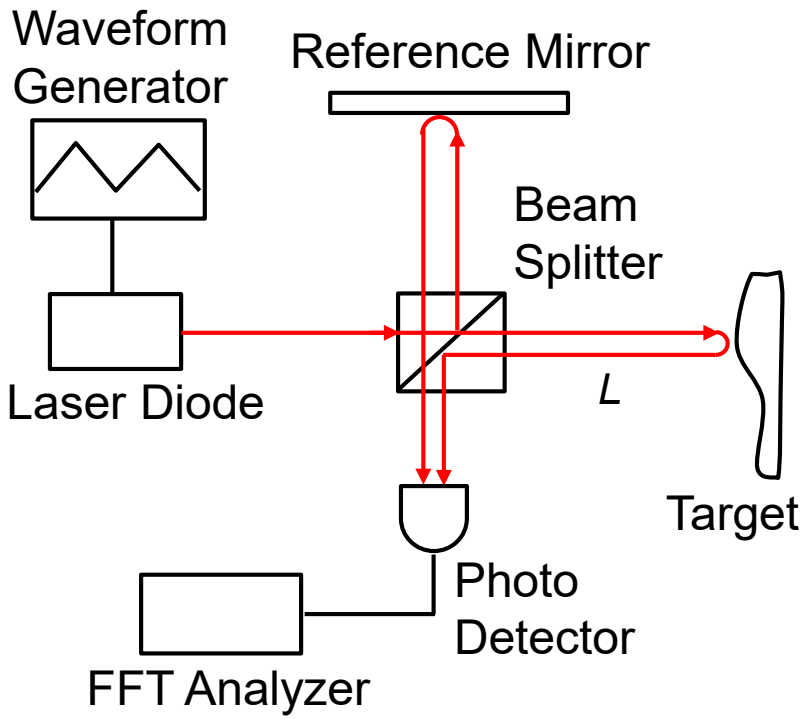
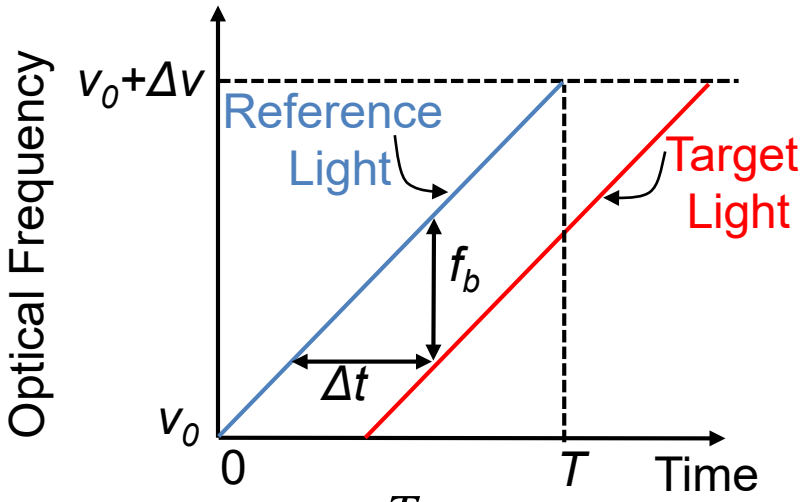
Laser distance meter based on Frequency Modulated Continuous Wave

■Optical setup



■Distance Measurement Principle



$$\Delta t = \frac{T}{\Delta v} f_b$$

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

$$L = \frac{1}{2} c \Delta t = \frac{cT}{2\Delta v} f_b$$

Distance L ∝ Beat Frequency f_b

□Point 2□Stable Measurement of Long Distance

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■Long distance measurement

	Commercial System	In-house System
Laser Type	ECL*1	VCSEL*2
Coherent Length	60mm	9m
Measurable Distance	30mm	300mm*3
Wavelength Swept Range	25nm	10nm
Data Rate	3kHz	10kHz
Light Source Cost	☹	☺

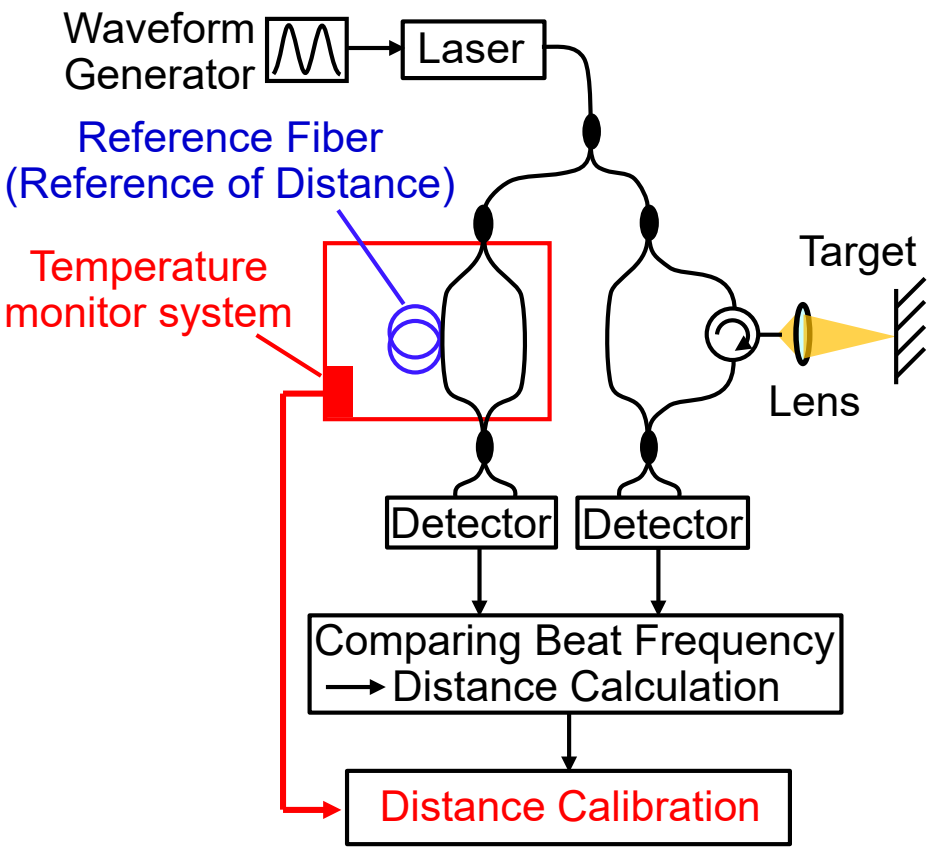
Distance Resolution $\Delta L = \frac{c}{2\Delta\nu}$ Wavelength Sweep Range

Improvement of the distance resolution by
1.Calibrating a non-linearity of frequency sweep
2.Interpolating FFT peak position

⇩

In-house system achieves high-accuracy long distance measurement.

■Stable distance measurement



Optical path change of reference fiber is calibrated by temperature monitor system.

*1ECL:External Cavity Laser, *2VCSEL:Vertical Cavity Surface Emitting Laser, *3Limited by the A/D converter frequency

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Evaluation of Short Time Accuracy

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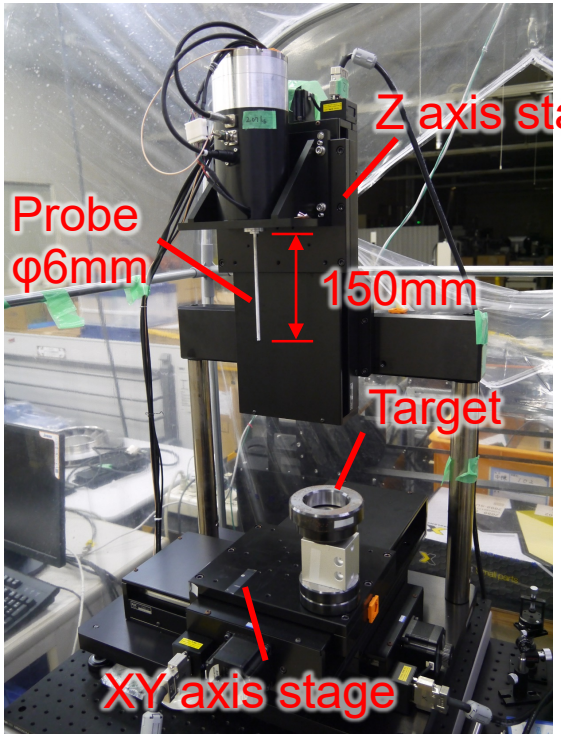
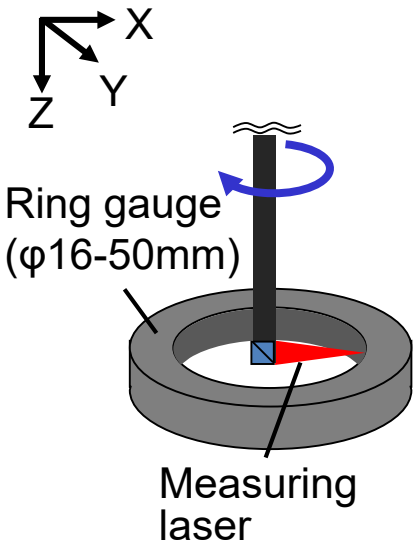
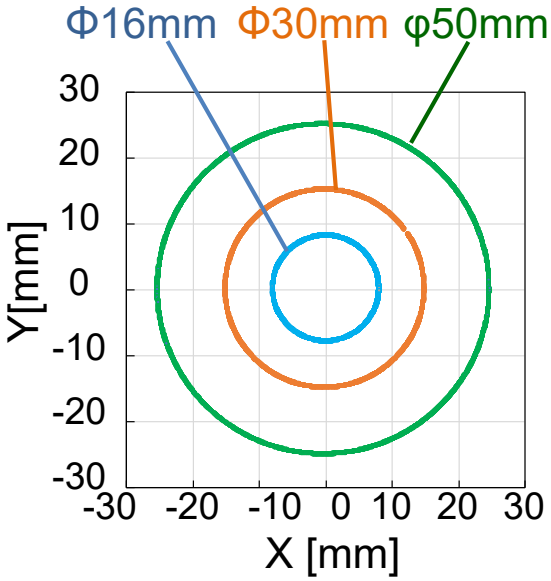
■ Developed system



Control box
(Laser, Stage controller, etc)

■ Ring gauge measurement





Value [mm]	15.999	30.001	49.996
Meas. result [mm]	15.9992	30.0013	49.9949
Error [μm]	**0.2**	**0.3**	**-1.1**

Short time accuracy is better than target accuracy ± 5μm

Evaluation of Measurement Stability

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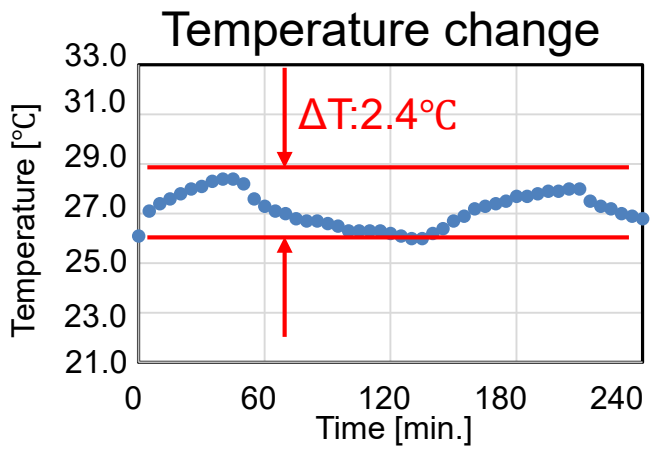
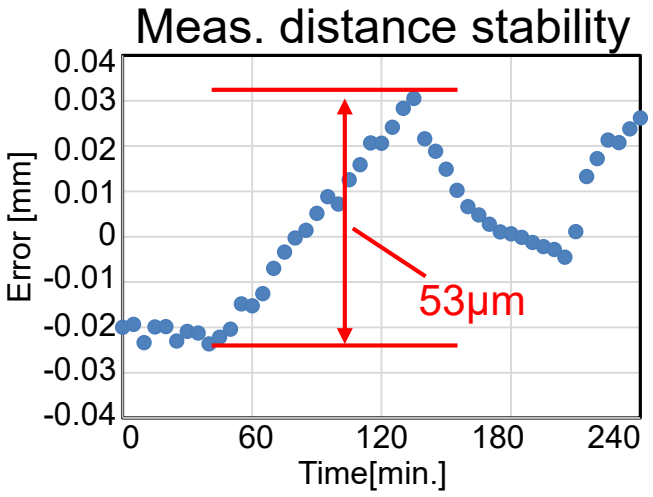
- Measurement stability is evaluated by changing a temperature surrounding the system.

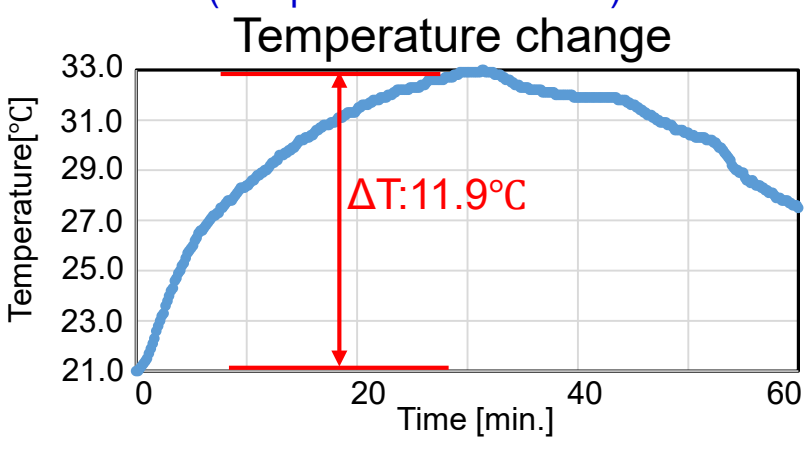
Our former system

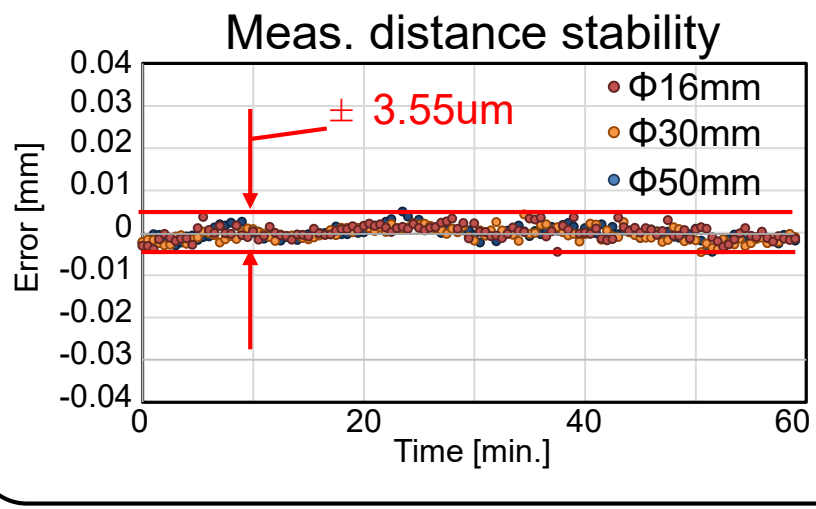




Developed system

(Temperature calibration)





Measurement stability is better than target accuracy ± 5μm

Evaluation of Long Distance Measurement

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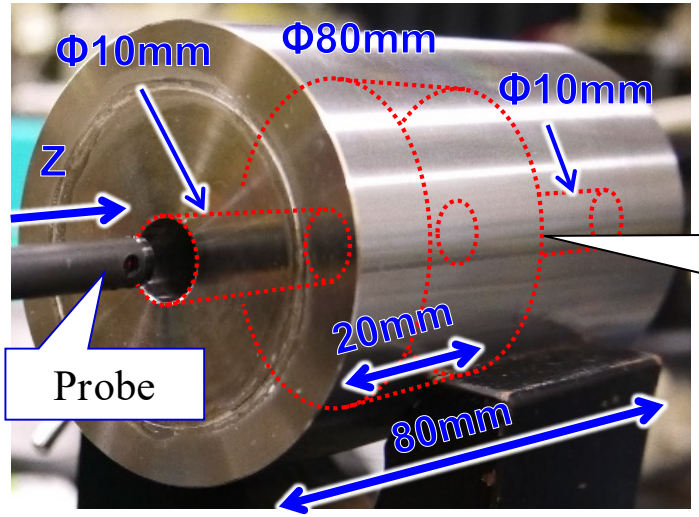
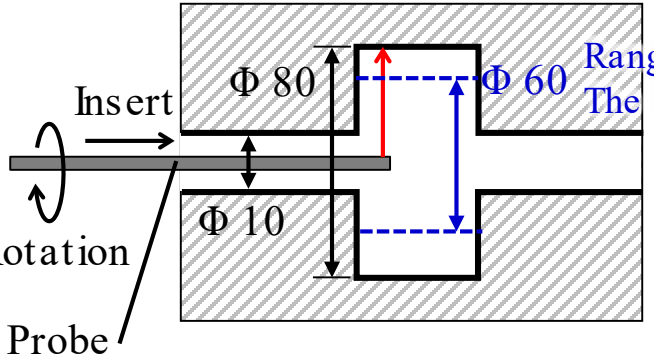
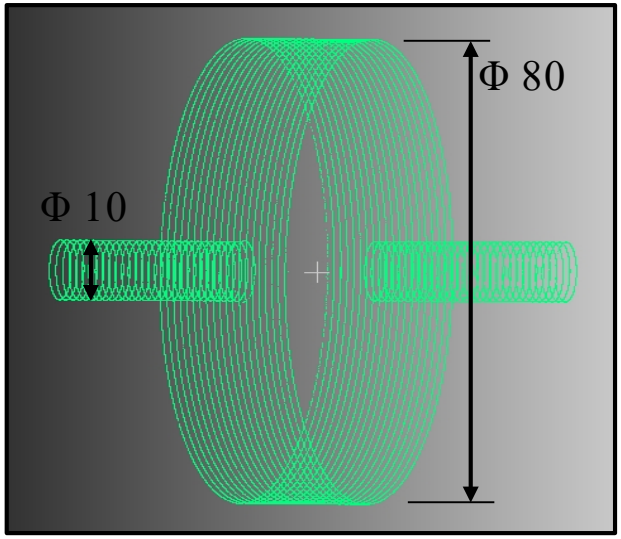
- Inner shape measurement of a cylinder which has different size holes inside



The former system can not measure the whole shape by a single scan.



- Measurement result



Developed system can measure the whole shape by a single scan.

Application Data to a Ball Screw

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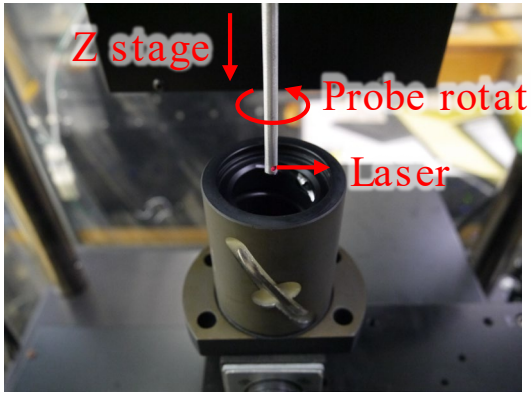
■ Sample

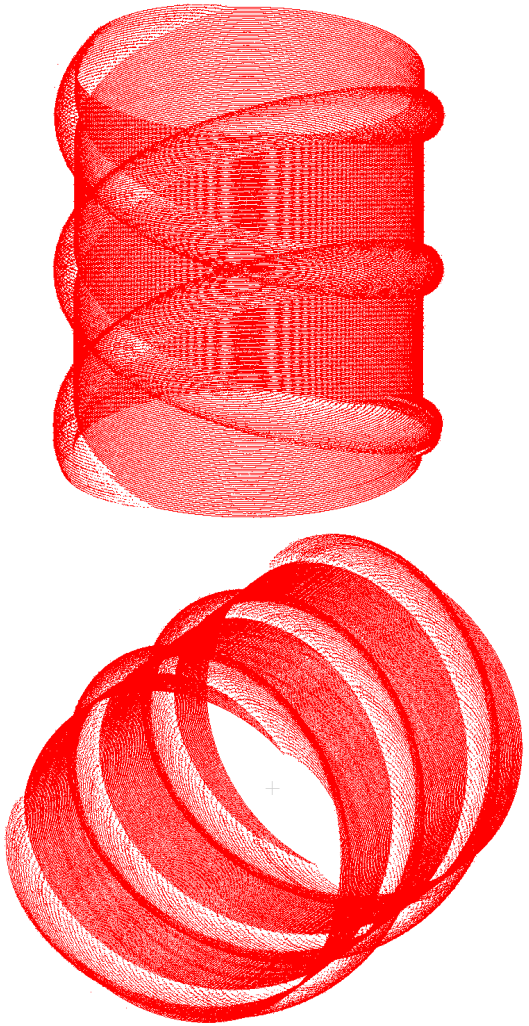
Misumi BSSZ3232

■ Measurement condition



■ Measurement result

655,690points



Developed system can measure complex inner shape.

Application Data to a Torque Converter

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■ Sample

Impeller of a torque converter for automobile

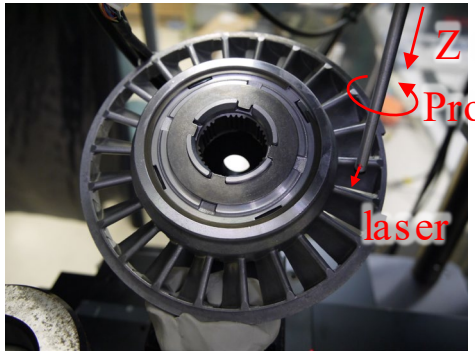
https://www.exedy.com/ja/product/passenger/at_torque/

Actual figure

Toyota

□□□□□□ □□□□□

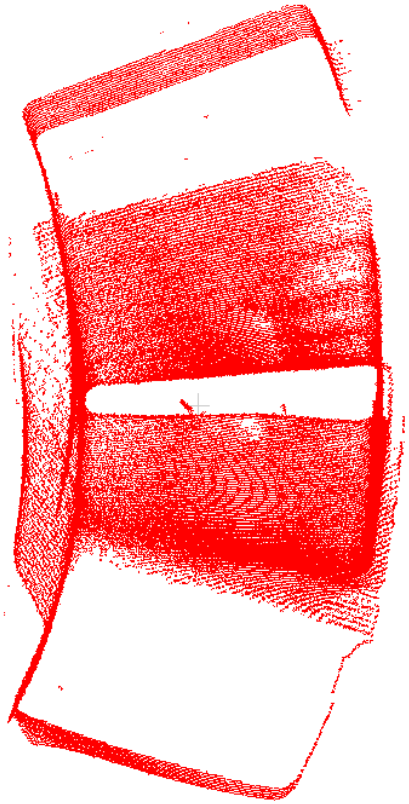
■ Measurement condition



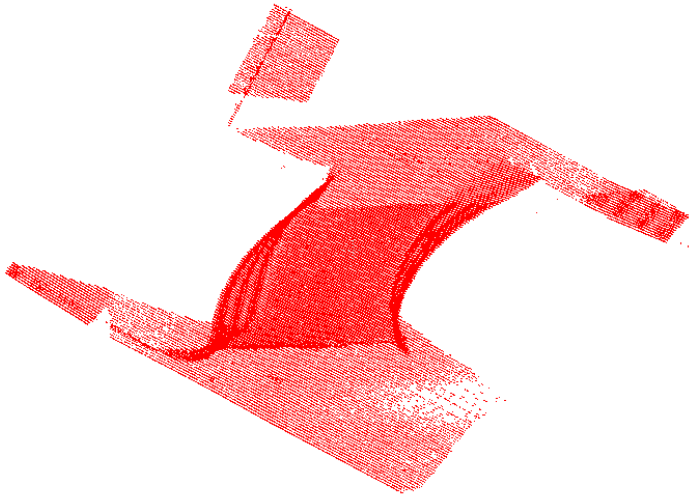
■ Measurement result

311,966points

Front view



Side view



Developed system can measure complex inner shape.

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4. **Conclusion & Future Work**

Conclusion & Future Work

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■ Conclusion

Developed:

Our former multi-directional optical measurement probe is Improved by
1.Reduction of motor number from two to one.
2.In-house distance measurement system for measuring long distance stably.

Achieved:

- Stability of long term measurement is ±3.55μm(<Target:±5μm).
- Long range measurement r5~40mm is demonstrated(max range:300mm).
- Measuring complex 3D-shape of such as ball a screw and a torque converter.

■ Future Work

- Application of the developed probe to various products being made in Hitachi's factories.
- Feedback of the measurement data to the machine processing condition.

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