

Measurement of Inner Shape of Cavity

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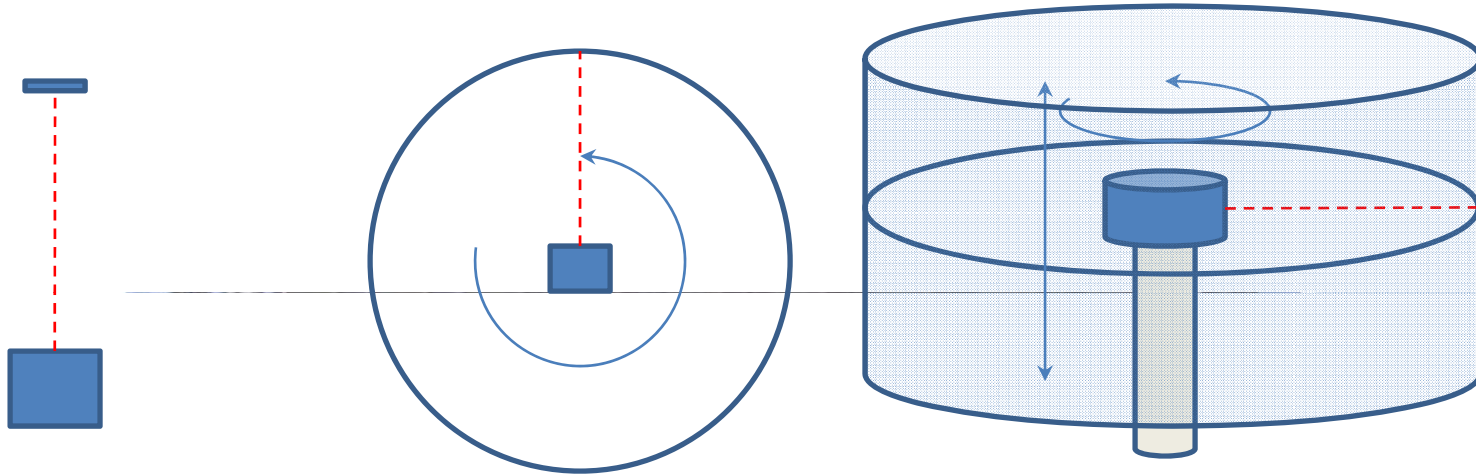
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Purpose

- To Measure Inner Macro Shape of Cavity Directly In accuracy of 0.1mm or higher from Iris to equator
 - Diameter, Coaxialty, Bending, Welding Bead etc
 - Errors in Production
 - Welding
 - HidroForming
 - Deformation By
 - Welding
 - Polishing
 - Gravity

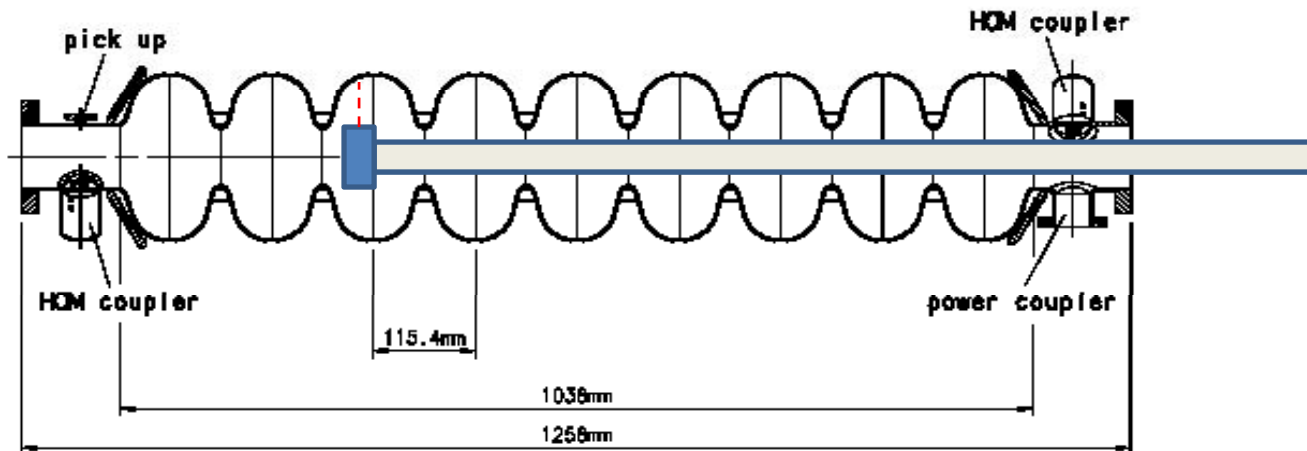
How to measure Inner Shape of a Cavity?



(1D) Distance Measurement

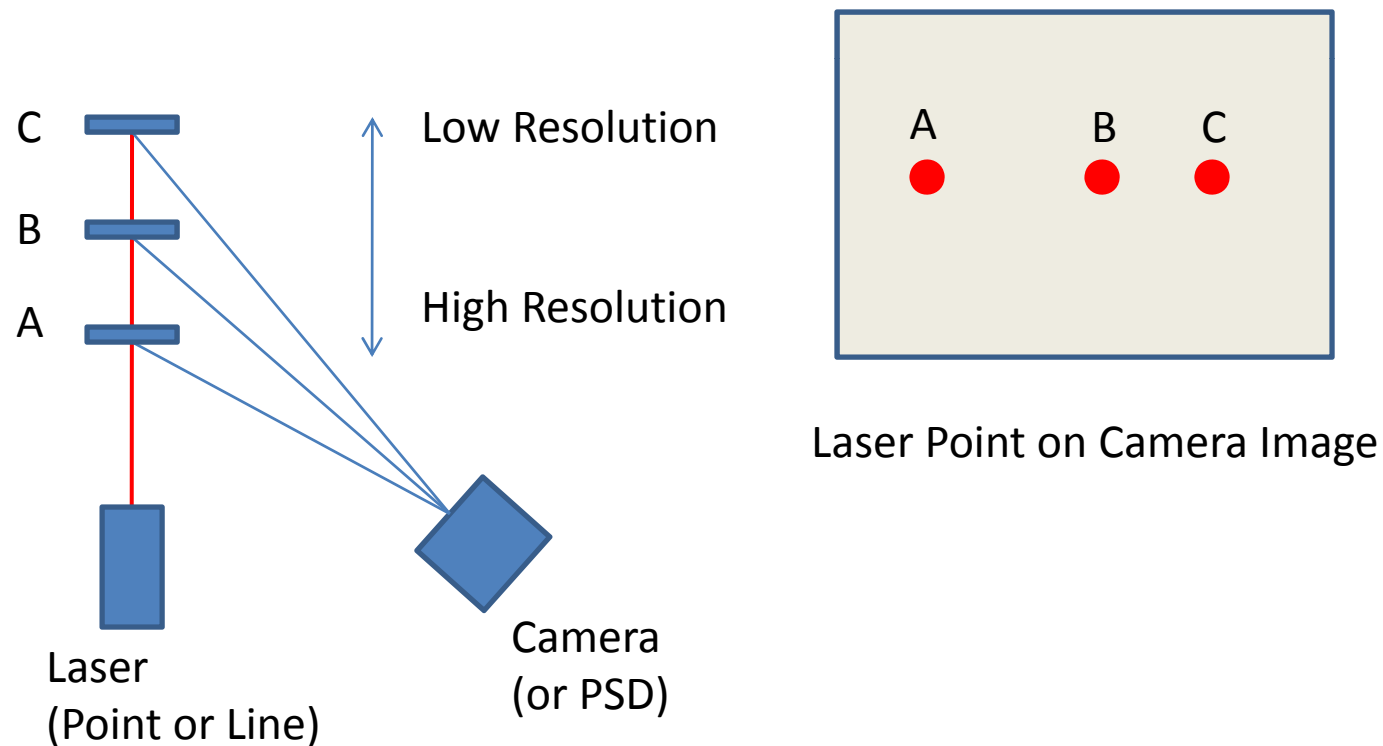
(2D) Shape Measurement
Rotate a measuring Unit

(3D) Shape Measurement
Slide a measuring Unit



Measurement Using Laser and Camera System

- Laser-Camera Measurement can measure distance with 0.01mm resolution

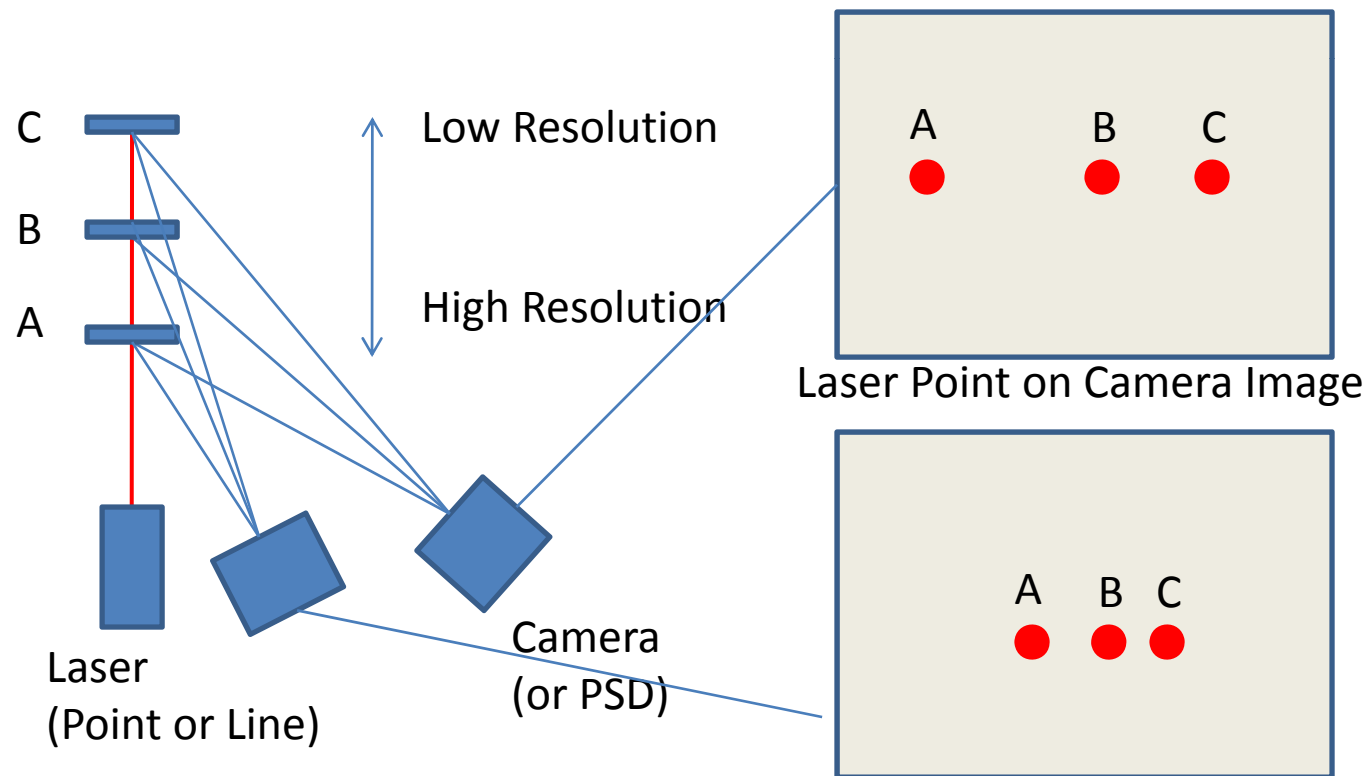


Difficulty in measurement of Inner Shape

- To Measure distance with high resolution, following conditions are required
 - Long Distance between Laser and Camera
 - Close to an Object
 - Small Measureable Distance
 - Good Camera and Lenz
 - Good Surface Condition
- To Measure shape with high resolution, following conditions are required
 - Accurate 3-Dimensional Location of measuring unit
- It is difficult to satisfy these conditions in measurement of inner shape

Downsizing of typical system

- Down-sized $\Phi 80\text{mm}$ Measurement Unit can measure distance only in 1mm resolution !

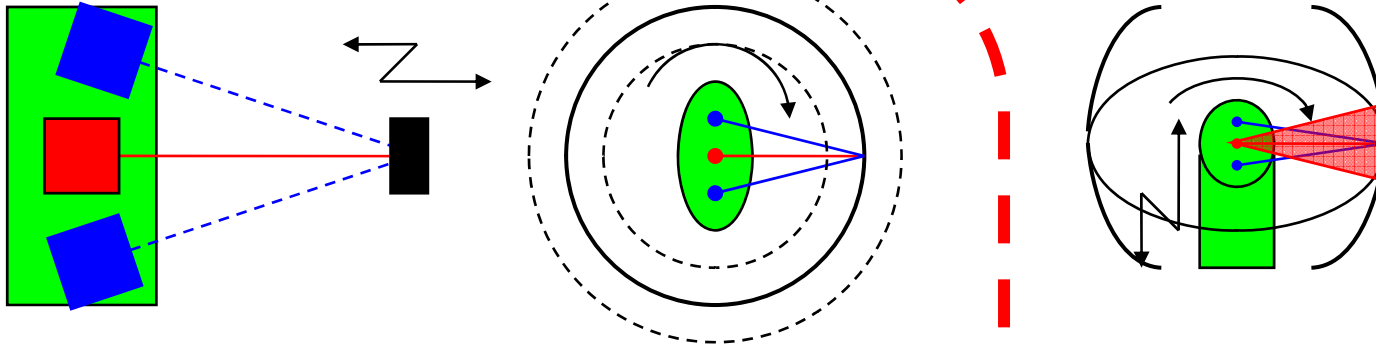


Solution of Problems

- Image Processing
 - Break through CCD Pixels and Width of Laser Spot
- Error Canceling System using Multi Cameras
- Calibration of Distance Measurement
- Calibration of Shape Measurement
- Detection of 3-Dimensional Position and Orientation of a Measuring Unit

Development of Inner Shape

Measurement



Red: Laser Blue: Camera Green: Measuring Unit

Distance Measurement

直動ステージ上の資料測定実験をおこない、測定精度、測定範囲が要求を満たすことを確認する。

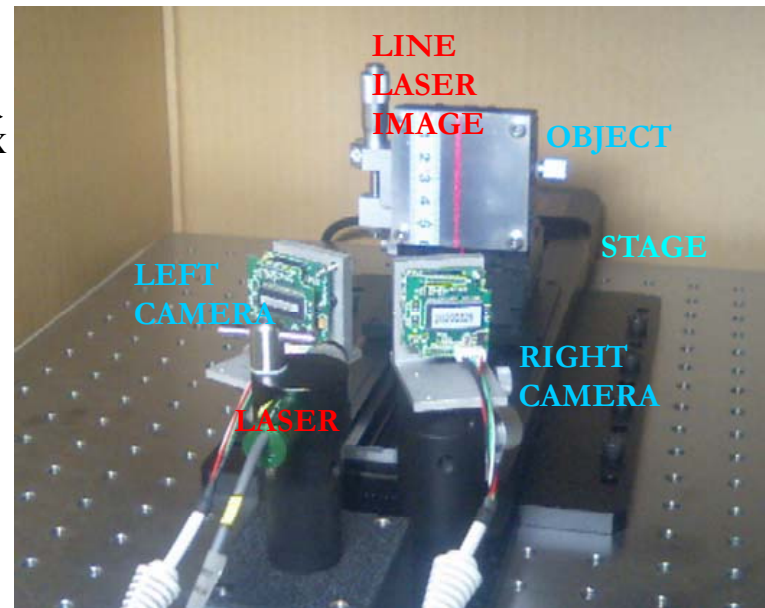
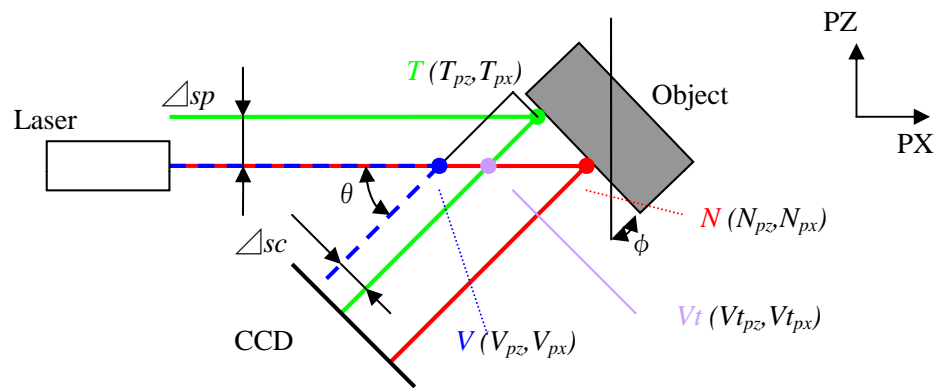
Circle Shape Measurement

基礎実験で作製した測定装置を、 θ 回転ステージにのせ円筒状の試料を測定し、内径測定ができることを確かめる。

3D Measurement

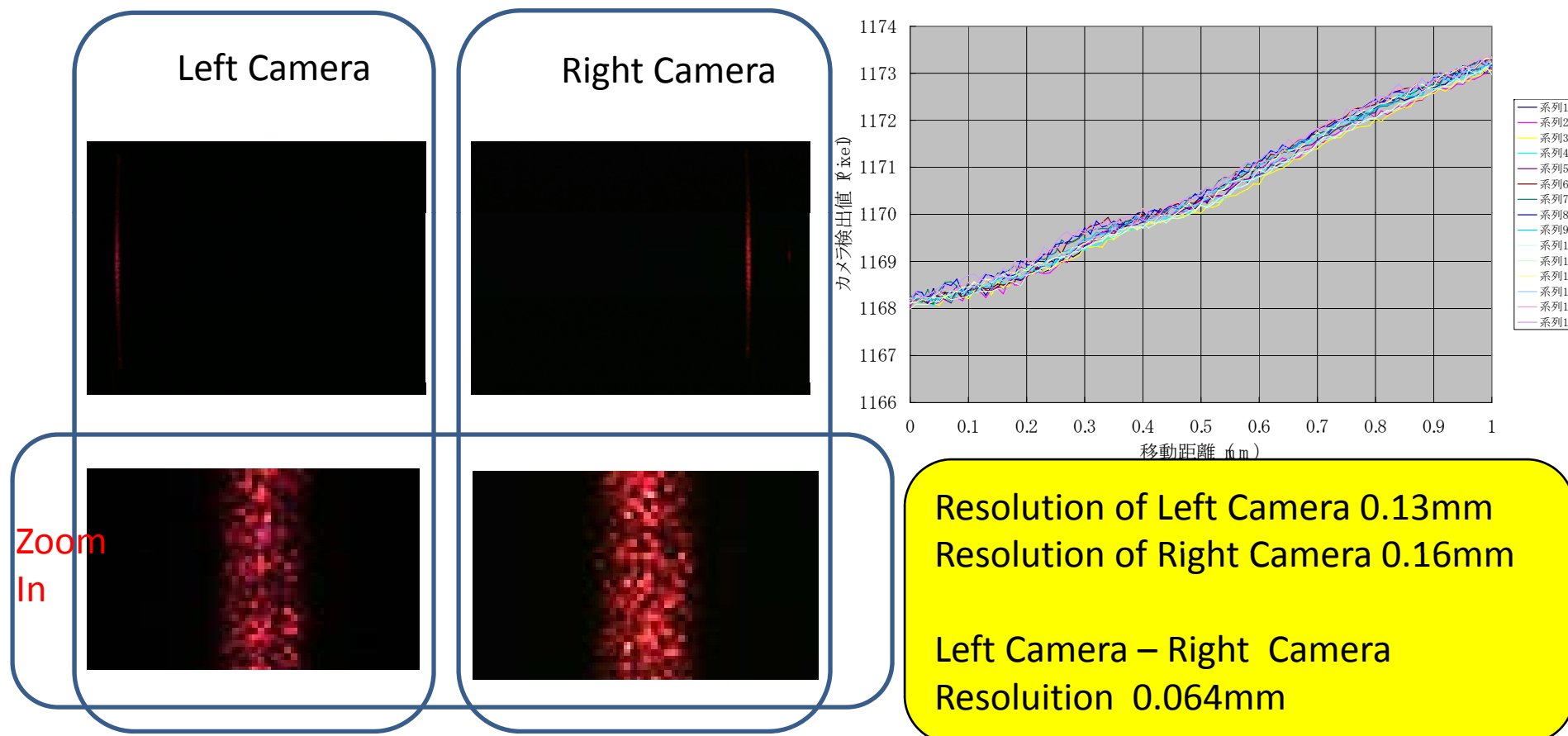
直動、回転機構をそなえ、 $\phi 60\text{mm}$ におさまる実機を作製し、加速管サンプルの測定をおこなう。内部を三次元測定機で測定した結果との比較をおこない、測定機の性能を確認する

Measuring Experiment using Image Processing and two Cameras



測定装置

Result Under Worst Conditions

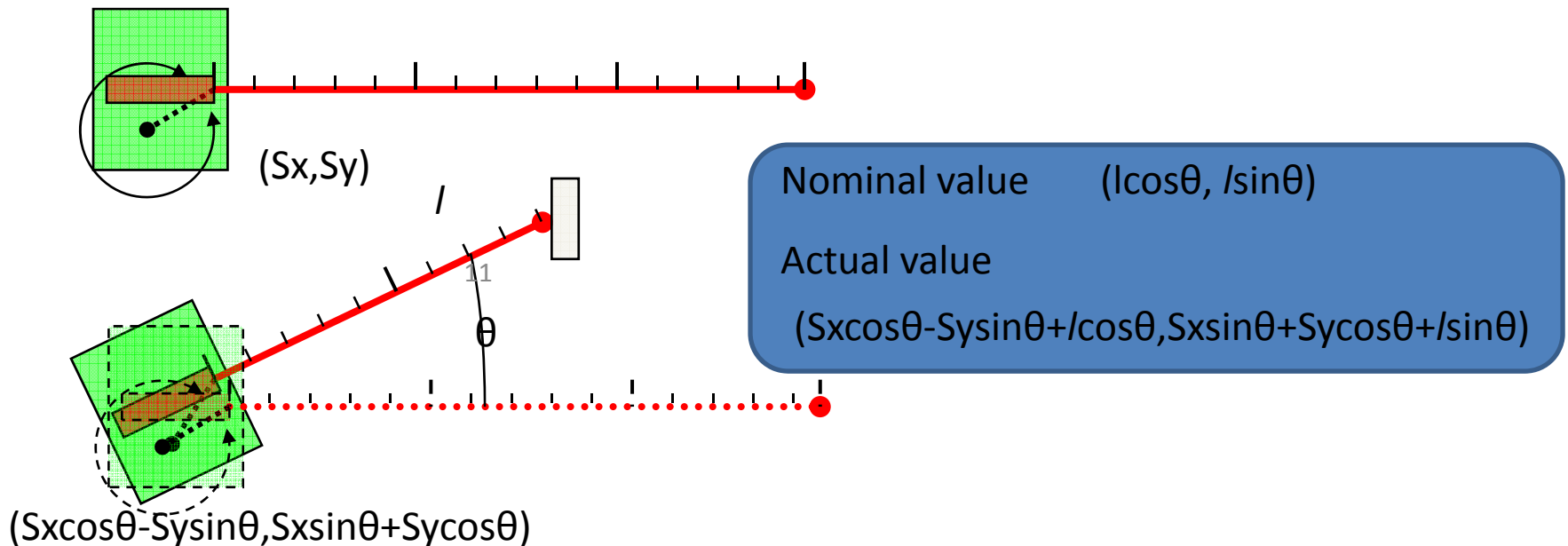


Images

Line Image is disturbed by Speckle Pattern

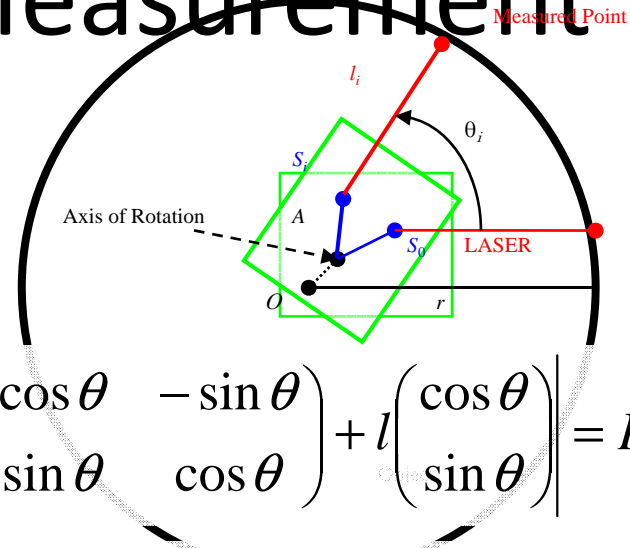
Calibration by Identification of Parameters

- Original Point of Measuring Unit is different from Rotation axis
- To measure correct shape, It is necessary to Identify vectors from Rotation axis to Origin of Measuring Unit



Parameter identification by Pipe Artifact Measurement

- Parameter vector
 - Center of Pipe → Rotation Axis
 - (a_x, a_y)
 - Rotation Axis → Origin of Header
 - (s_x, s_y)
- Observed value
 - Angle
 - θ
 - Distance
 - l
 - Radius of a Pipe
 - r



$$\begin{bmatrix} a_x \\ a_y \end{bmatrix} + \begin{bmatrix} s_x \\ s_y \end{bmatrix} \begin{bmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{bmatrix} + l \begin{bmatrix} \cos \theta \\ \sin \theta \end{bmatrix} = R$$

$$A = \begin{pmatrix} -p_{x1}/r_1 & -p_{y1}/r_1 & (p_{x1} \cos \theta_1 + p_{y1} \sin \theta_1)/r_1 & -(p_{x1} \sin \theta_1 + p_{y1} \cos \theta_1)r_1 \\ \vdots & \vdots & \vdots & \vdots \\ -p_{xn}/r_n & -p_{yn}/r_n & (p_{xn} \cos \theta_n + p_{yn} \sin \theta_n)/r_n & -(p_{xn} \sin \theta_n + p_{yn} \cos \theta_n)r_n \end{pmatrix} \quad d = \begin{pmatrix} r_1 - R \\ \vdots \\ r_n - R \end{pmatrix}$$

Non Linear Least Square Least
Square method
→ Gauss-Newton Method

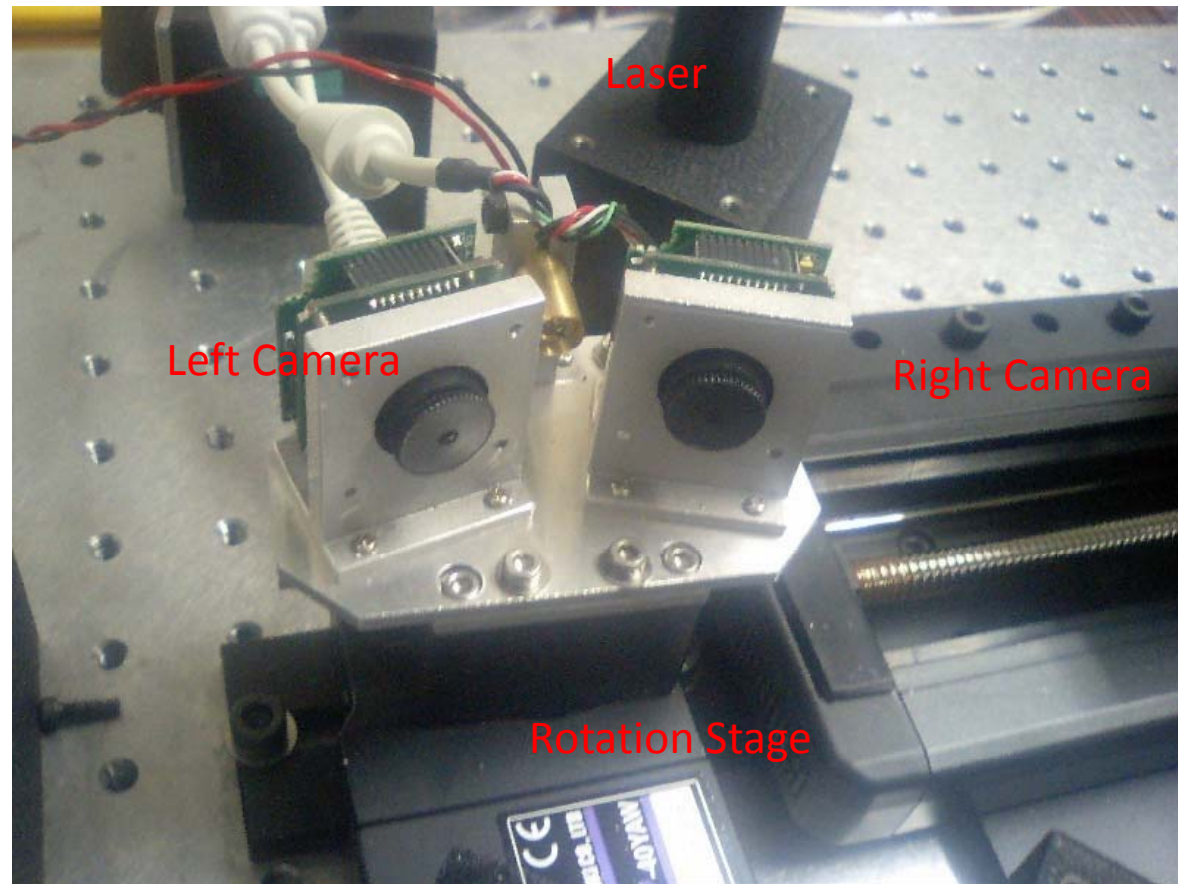
$$p_{xi} = (a_x + s_x \cos \theta_i - s_y \sin \theta_i + l_i \cos \theta_i)$$

$$p_{yi} = (a_y + s_x \sin \theta_i - s_y \cos \theta_i + l_i \sin \theta_i)$$

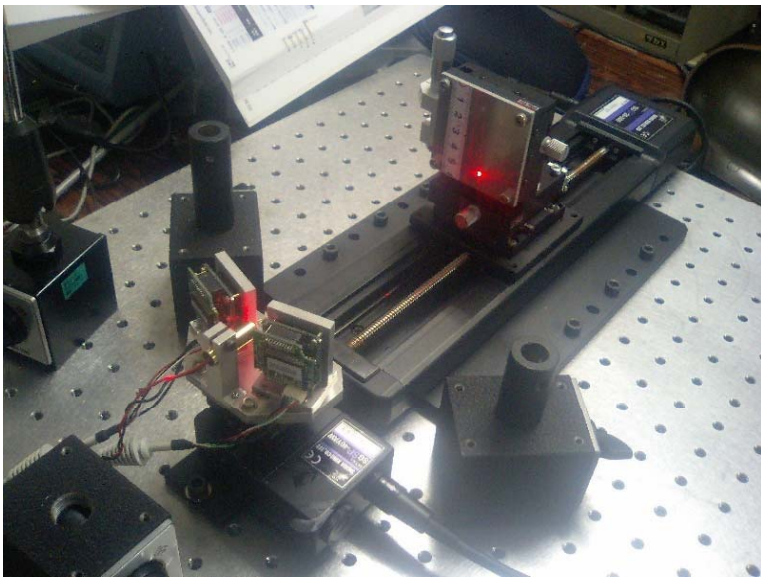
$$r_i = \sqrt{p_{xi}^2 + p_{yi}^2}$$

Measuring Unit

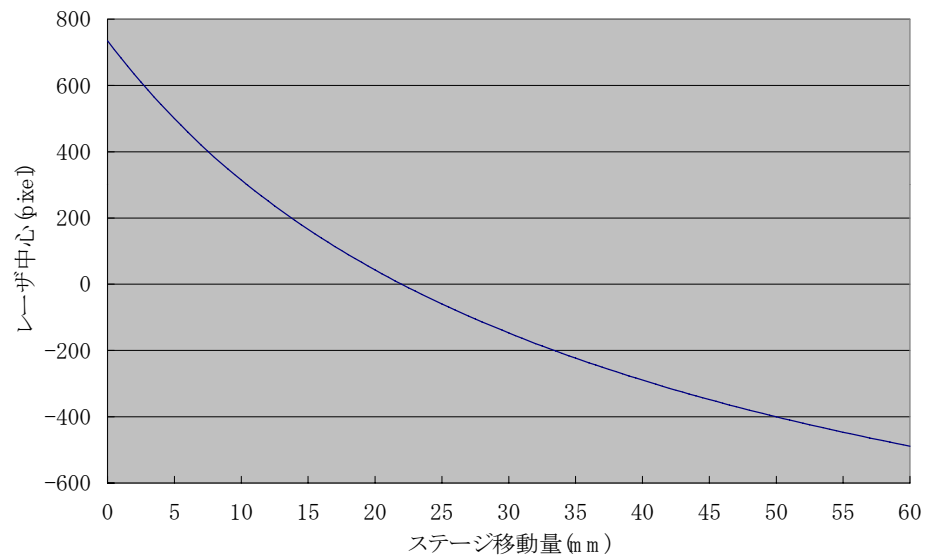
- $\Phi 80 \times 50\text{mm}$
- 180g:



Measurement of Distance

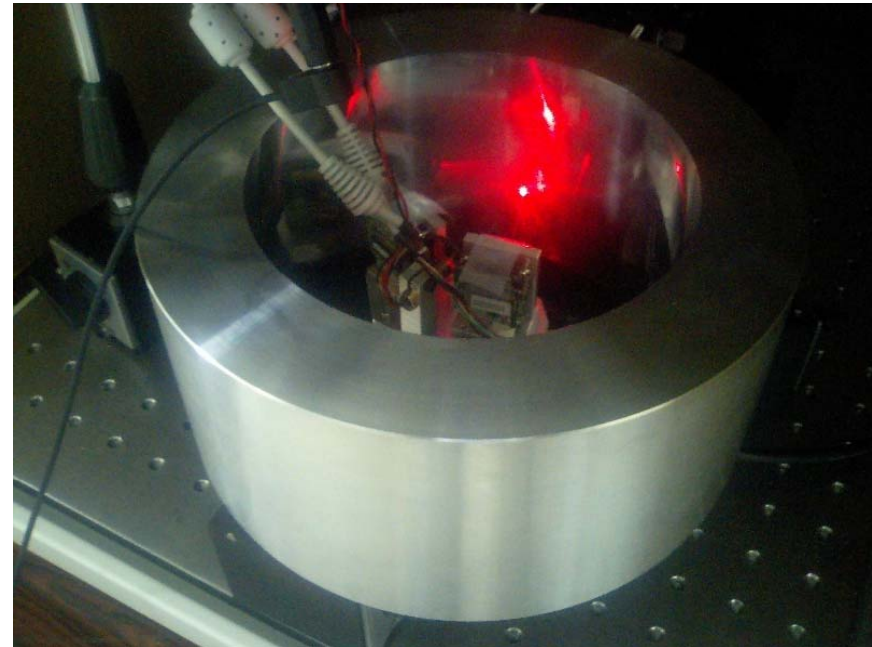
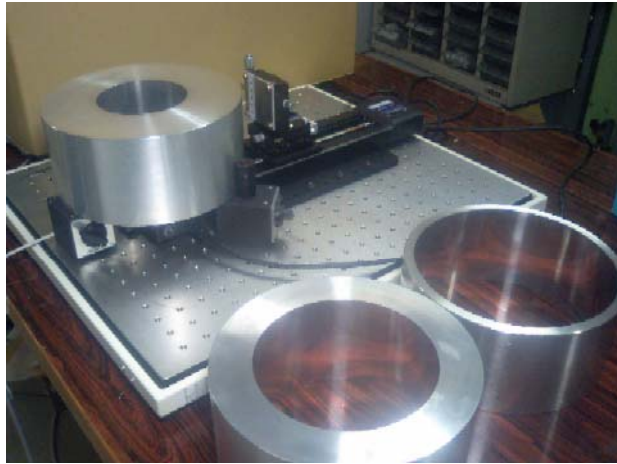


Measure a Distance to object on Linear Stage using Point Laser



Relation between Position of Laser Image and Position of Object

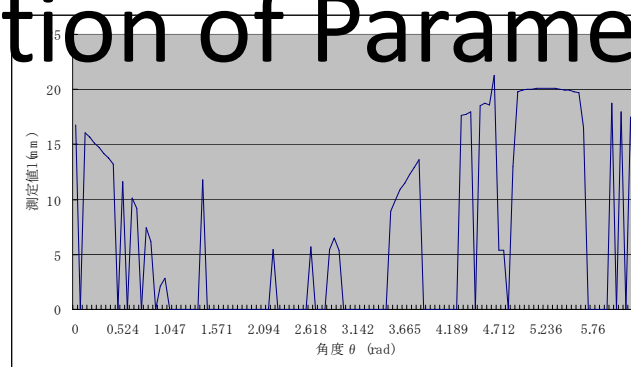
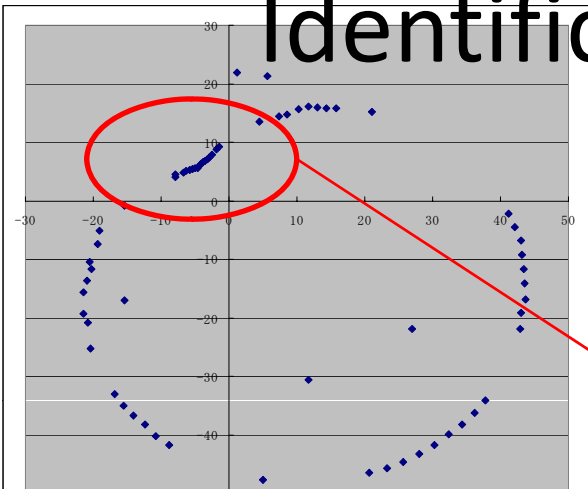
Calibration using Pipe Artifact



- Aluminum
- Outer Diameter
 - $\phi 220\text{mm}$
- Height 100mm
- Inner Diameter
 - $\phi 100\text{mm}$,
 - $\phi 150\text{mm}$,
 - $\phi 200\text{mm}$

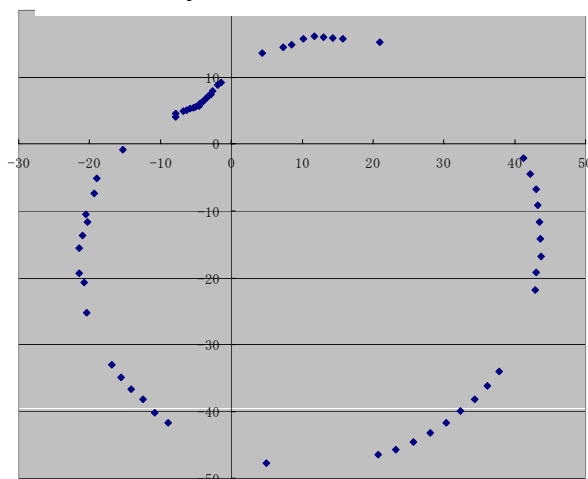
Calibration Experiment
Without Setting in high
accuracy

Error Elimination of Raw Data and Identification of Parameters



✘ These Points are not errors !

Elimination of Uncertain Data By Software



Error Elimination By Human

regular reflection

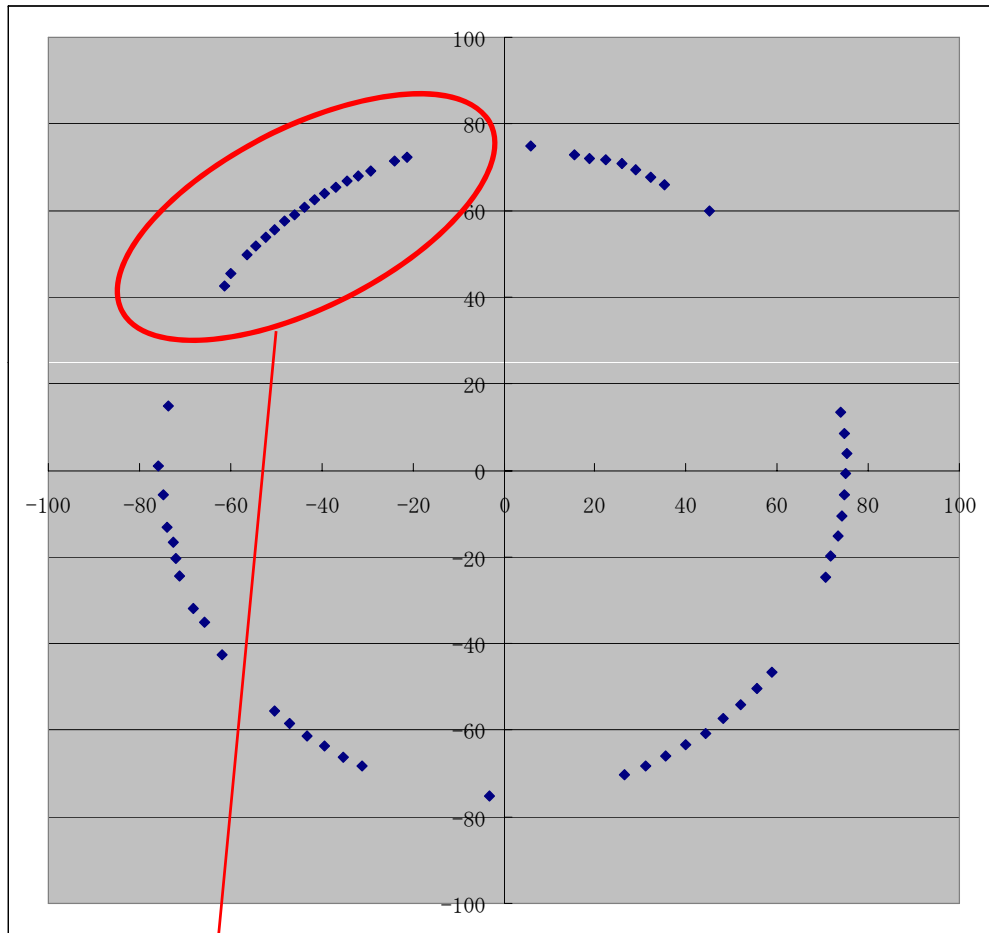


Saturation or Vanish of Laser Image



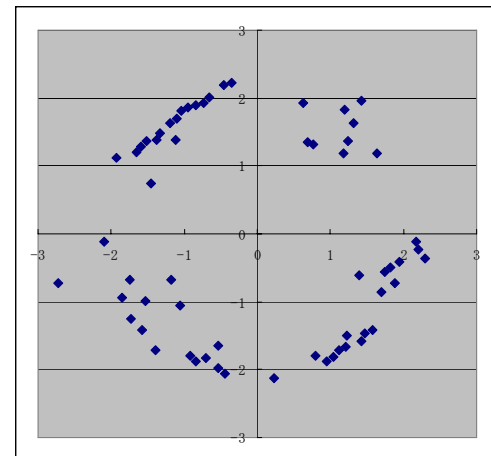
To Identify Parameters which fits these data to Circle Data of $\phi 150\text{mm}$

Reconstruction of shape



- Circle Shape $\Phi 150\text{mm}$

errors

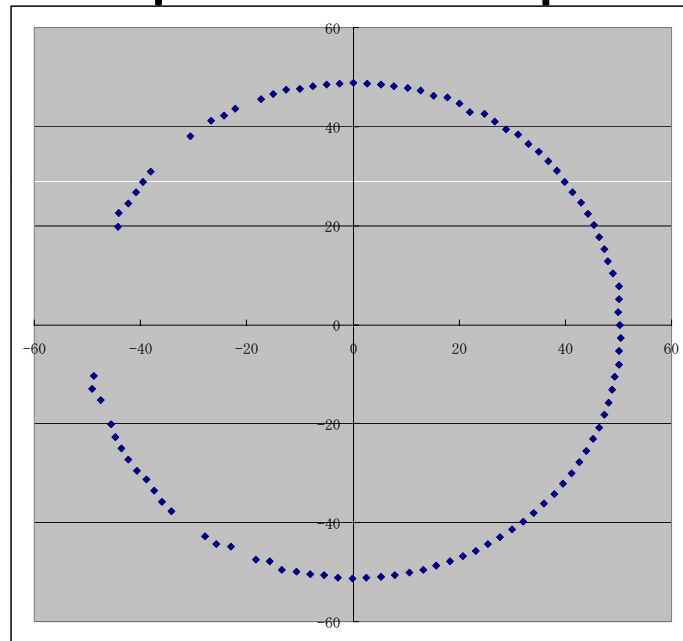


Deformation of Raw Data are Correctly reconstructed!

Measurement of $\phi 100\text{mm}$ Pipe

- Measurement of $\phi 100\text{mm}$ Pipe

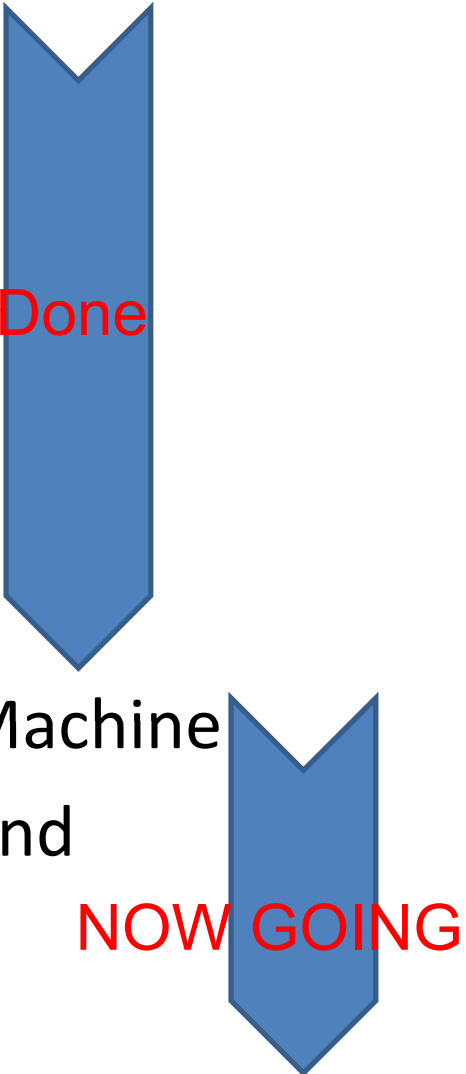
Elimination of Uncertain
Data By Software



Result :Radius 49.9mm.Center is (0.3mm,-1.2mm)

**Successfully Shape Measurement
without setting in high accuracy**

Conclusion

- 1D Measurement
 - High Resolution higher than 0.1mm
 - Image Processing
 - Error Canceling
 - 2D Measurement
 - Calibration using Pipe Object
 - 3D Measurement
 - Design and Production of Measuring Machine
 - Detection of 3-Dimensional Position and Orientation of a Measuring Header
- 
- Done
- NOW GOING