DME-TR-11-001

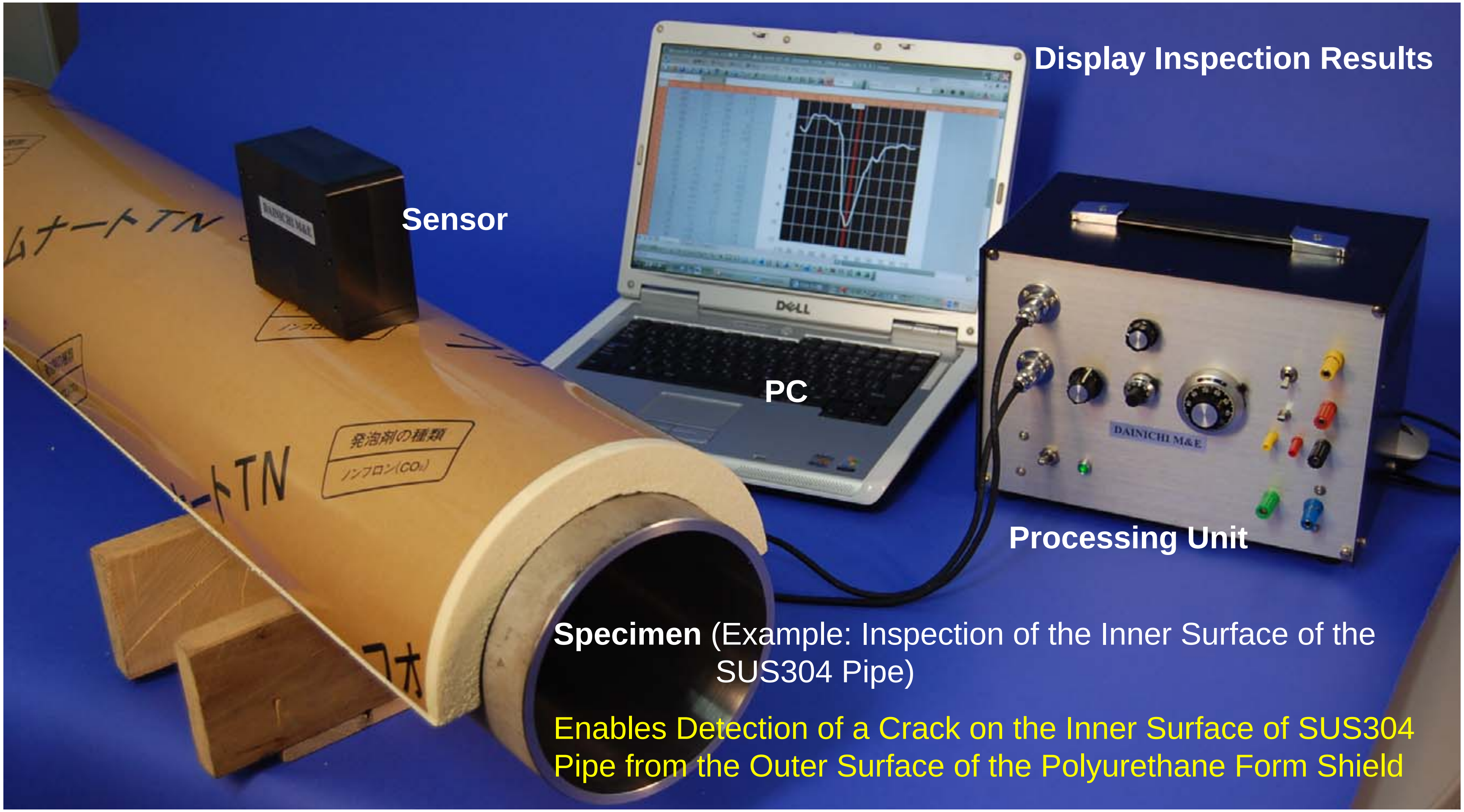
Electromagnetic Induction Nondestructive Inspection System

March 2011

DAINICHI

DAINICHI Machine & Engineering Co., Ltd.

Equipment Configuration



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Contents

Features

- Cover a Wide Range of Inspection
  - Defect Inspection of the Inner Surface of the Pipe from the Outer Surface (Contact/Lift-off) ; (Case 1, Case 3, and Case 5)
  - Corrosion Wastage Inspection from the Outer Pipe Surface (Contact/Lift-off); (Case 2, Case 8, and Case 9)
  - Defect Inspection of the Inner Wall Surface from the Outer Pipe Surface at Welded Zone; (Case 6)
  - Defect Inspection of the Inner Surface of Pipe in the Heat-affected Zone of the Stainless/Carbon Steel Welded Pipe; (Case 7)
  - Defect Inspection of the Inner Surface of the Inner Pipe from the Outer Pipe Surface of the Double Layered Pipe ; (Case 4)
  - Corrosion Wastage Inspection of the Inner Pipe from the Outer Pipe Surface of a Double Layered Pipe; (Case 10)
  - Defect & Corrosion Wastage Inspection of Piping from the Outer Surface of the Dew Condensation Prevention Shield; (Case 11)
- Small & Lightweight, Space-Saving
- Maintenance-Free

Application and Effects

- Application to Plant
  - Enables to Build Up Long Term Monitoring & Automatic Measuring System
  - Application to Centralized Remote Monitoring System at Control Room by Wired/Wireless Data Transmission
- Expected Effects
  - Significant Cost Saving by Maintenance and Inspection Automation
  - Eradication of Human Error by Automated Data Acquisition and Digitized Data Management

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Breakthrough Technique in Maintenance Engineering

Application to Plant (Image)

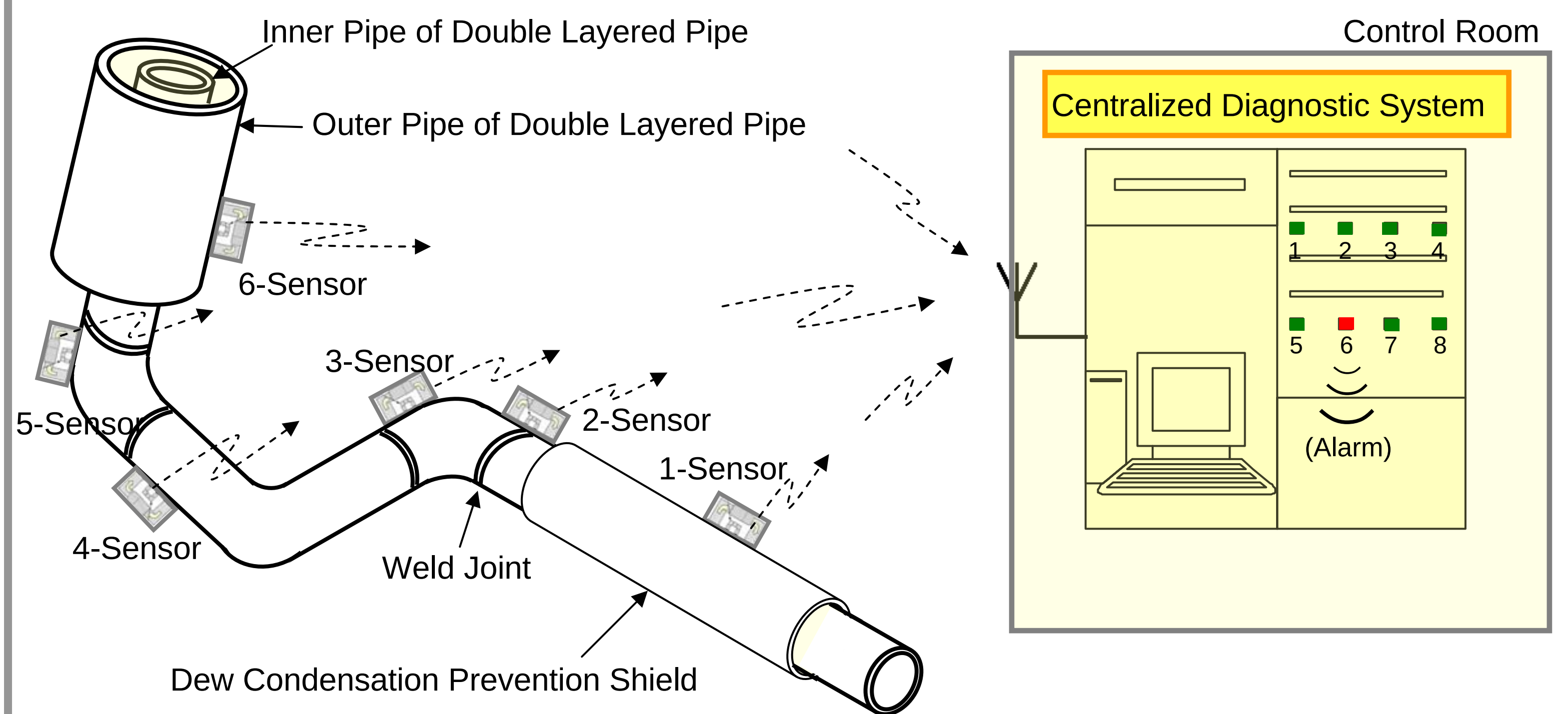


Fig. 1 Automated Diagnostic System for Integrity of Piping

Principle

Basic Principle of Eddy Current Testing Method

- When alternating magnetic flux is applied to the specimen (conductor), eddy currents are induced in the specimen by electromagnetic induction.
- Eddy current density decreases exponentially with depth of penetration and its phase lag increases in proportion to depth of penetration. The depth of penetration of magnetic flux increases with lower frequency of the excitation current and lower electrical conductivity and magnetic permeability of the specimen. As a consequence, eddy current can be induced at a deeper part when the excitation frequency and the values of these factors are lower.
- Eddy currents produce a secondary magnetic flux to oppose the applied alternating magnetic flux.
- The Eddy current is distorted by the presence of the defect and varies the secondary magnetic flux.
- This variation of the secondary flux is detected as variation of voltage induced in the detection coil.

Our Unique Technology (Patent Pending)

- Technology to pick up the faint signal from the eddy current distorted by the defect at a deep layer by eliminating the effect of surface eddy current
- Signal processing technology which may detect a very small change of the signal

⇨ Enables Inspection of Piping even from the Outer Surface of the Insulation or Coating

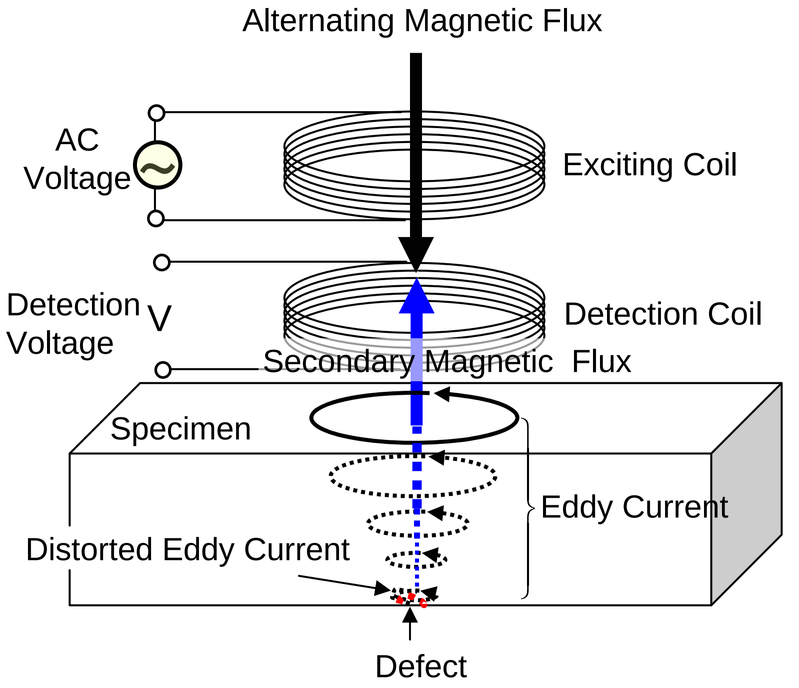


Fig. 2 Basic Principle of Eddy Current Testing

Depth of Magnetic Field Penetration (Calculation)

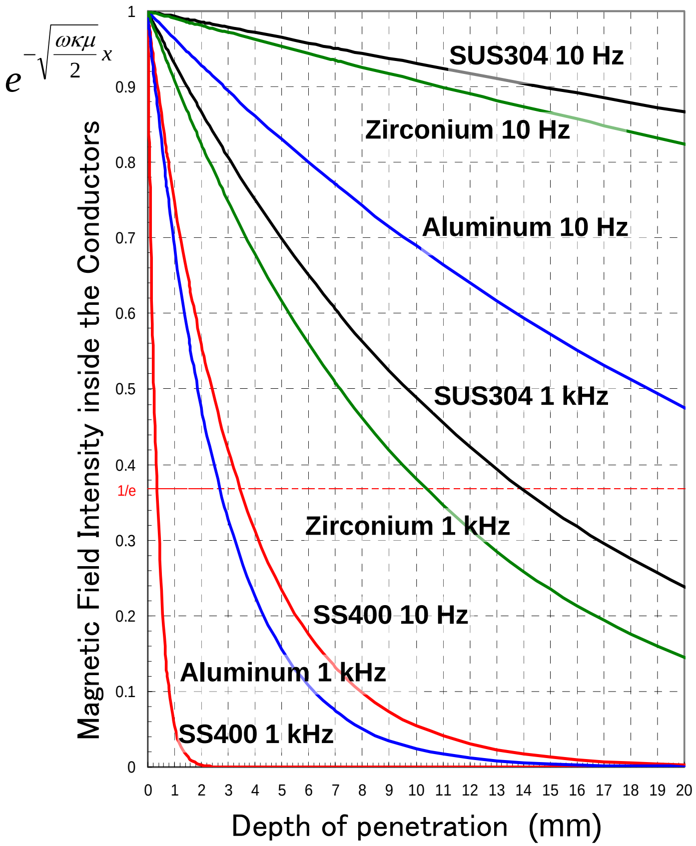


Fig. 3 Magnetic Field Intensity Inside the Conductors

Equation

Magnetic flux distribution

$$B = \mu H e^{-\sqrt{\frac{\omega\kappa\mu}{2}}x} \cos\left(\omega t - \sqrt{\frac{\omega\kappa\mu}{2}}x\right)$$

ω : Angular frequency
κ : Electrical conductivity
μ : Magnetic permeability
x : Depth of penetration

Materials properties

Material	Conductivity κ (MS/m)	Relative Magnetic permeability μ_s
SS400	6.25*	341**
SUS304	1.3*	1.0*
Aluminum	35.0*	1.0*
Zirconium	2.36***	1.0****

* Physical Constants, http://www.mogami.com/paper/physical-constants.html
** Takahashi, FEM-Based Magnetic Field Optimization, Morikita Publishing (2001), pp.196
*** Wikipedia, http://en.wikipedia.org/wiki/Zirconium
**** No Published Data Available (Hypothetical Value)

Depth of Magnetic Field Penetration increases with Lower Excitation Frequency. It also varies considerably by Materials; SS400 < Aluminum < Zirconium < SUS304.

(Case 1) Detection of Groove Machined on the Back of Carbon Steel Plate

A groove machined on the back of a carbon steel plate at 7 mm deep can be detected with lift-off height of 5 mm.

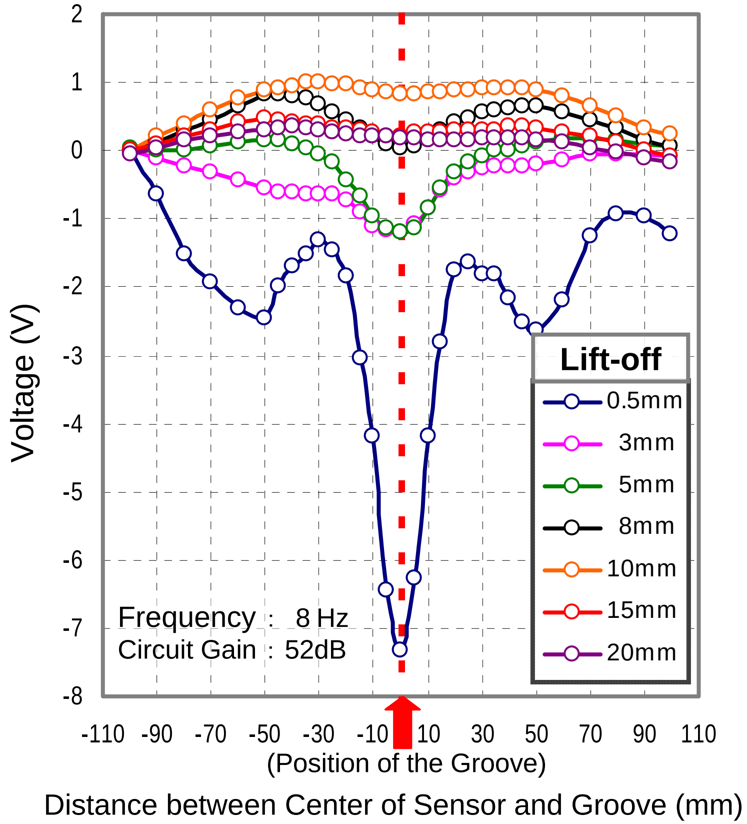


Fig. 4 Experiments to Detect the Groove on the Back of Carbon Steel Plate

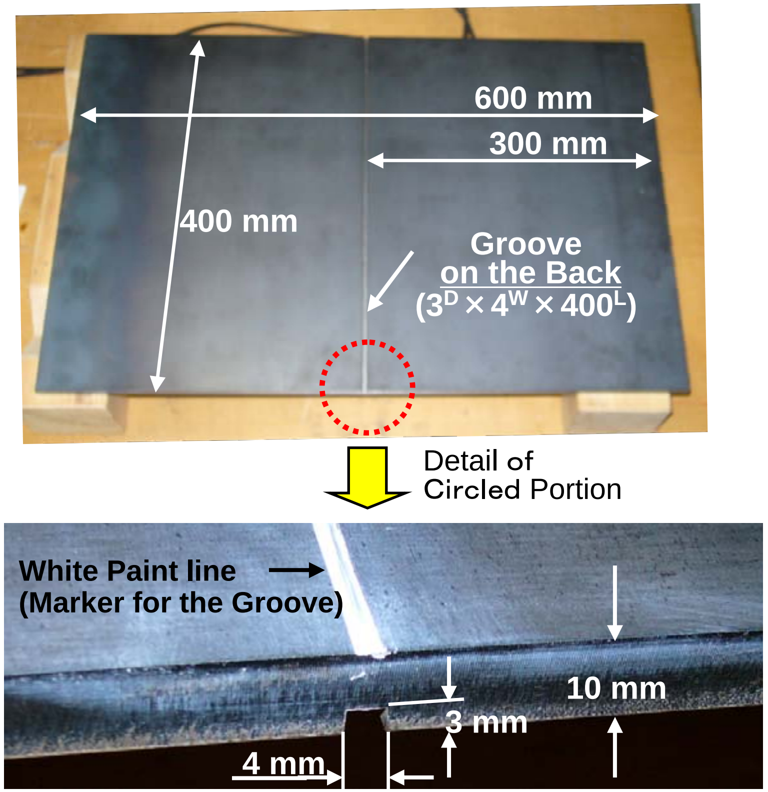


Fig. 5 Photo of Test Piece

(Case 2) Measurement of Wall Thickness of Carbon Steel Pipe

Remarkable linear relationship between pipe wall thickness and the output signal is observed.

⇨ **Enables Detection of Corrosion Wastage with High Accuracy**

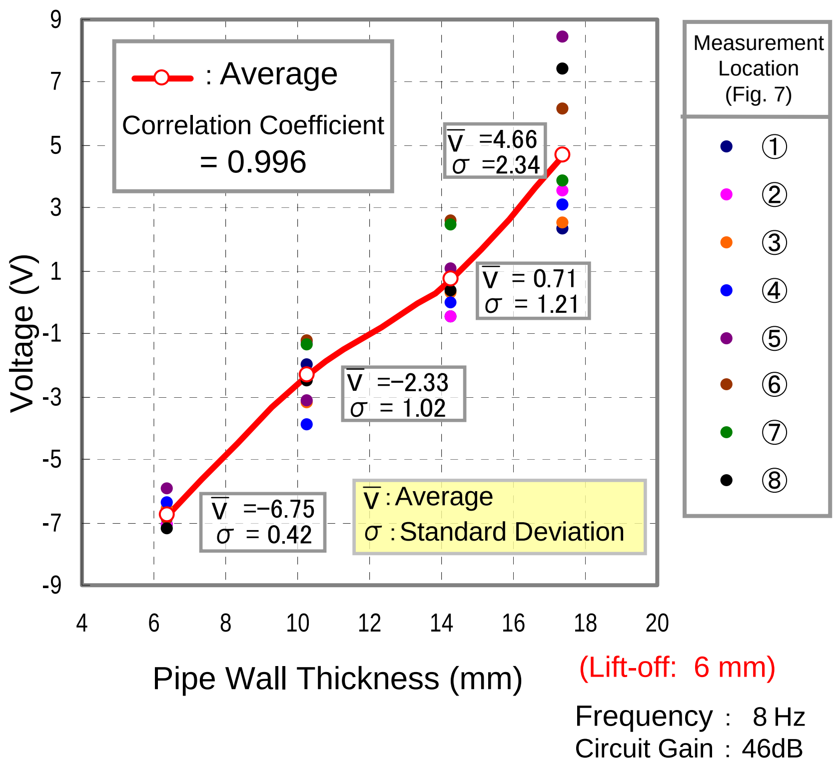
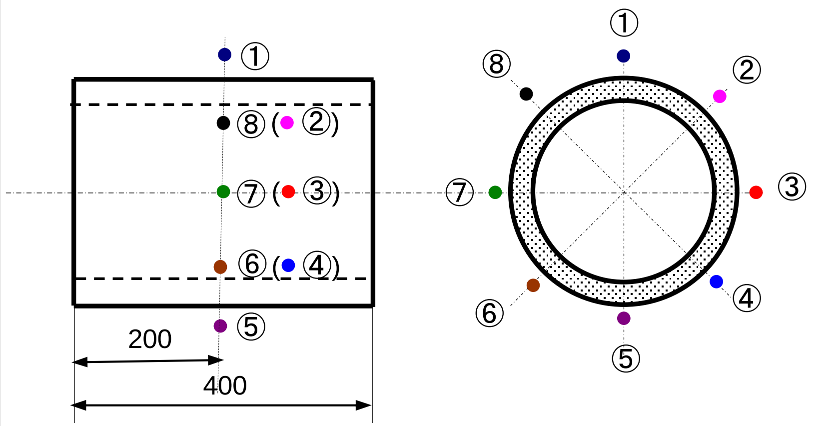


Fig. 6 Measurement of Wall Thickness of Carbon Steel Pipe



- Specimen: Four 300A Carbon Steel Pipes with different wall thickness
- Wall Thickness: 6.4mm, 10.3mm, 14.3mm and 17.4mm
- Measuring Position: Eight Points around each pipe (shown in the above figure)
- Data Processing:- Calculate the average and the standard deviation of the output signal for each pipe wall thickness, and calculate the correlation coefficient between the output signal and the wall thickness

Fig.7 Specimen and Method of Measurement

(Case 3) Detection of Groove Machined on the Back of Stainless Steel Plate

A groove machined on the back of a stainless steel plate at 7 mm deep can be detected with lift-off height of 25mm.

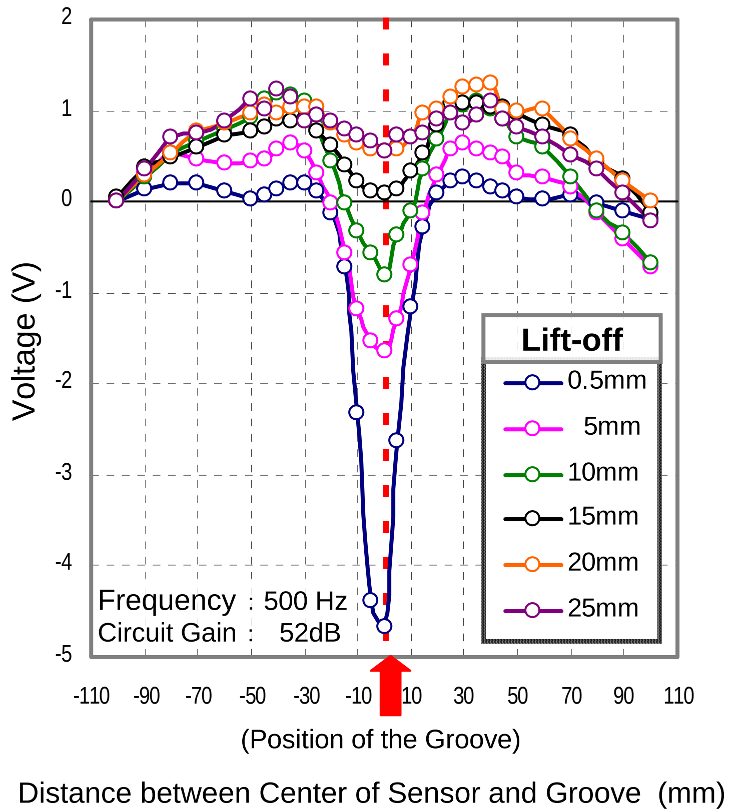
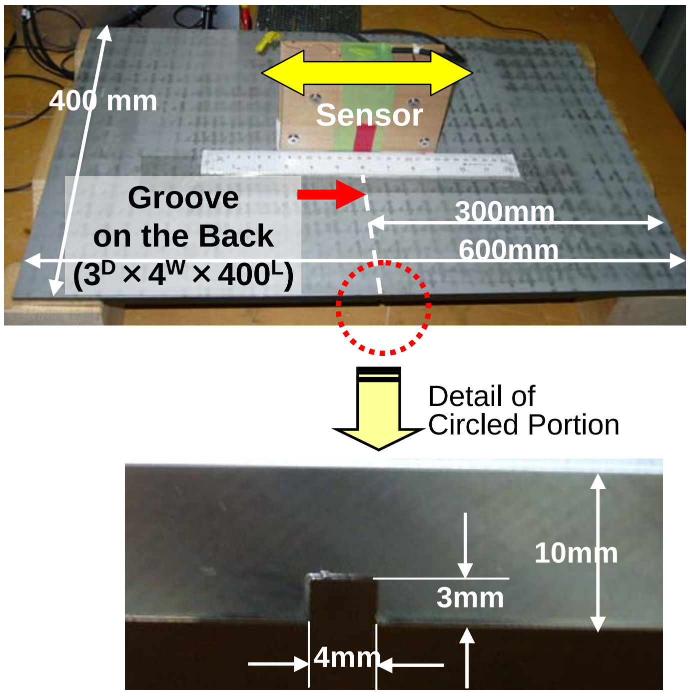


Fig. 8 Experiments to Detect the Groove on the Back of Stainless Steel Plate



Machined Groove on the Back of Stainless Steel Plate

Fig. 9 Photo of Test Piece

(Case 4) Detection of Groove Machined on the Back of the Underside Plate from the Top Surface of Double Layered Stainless Steel Plates

⇨ Enables Detection of Defects on Inner Wall Surface of Inner Pipe from Outer Pipe Surface of Double Layered Stainless Steel Pipe

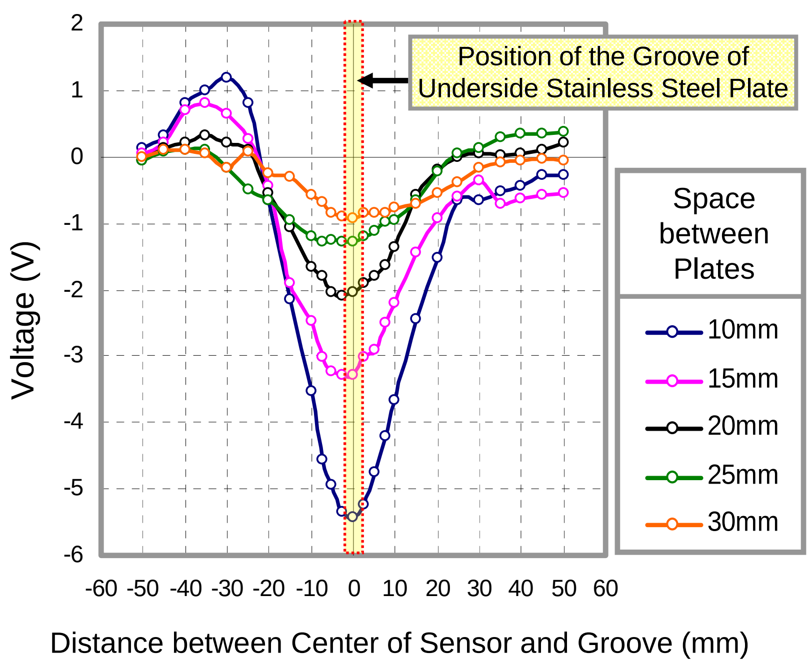


Fig.10 Experiments to Detect the Groove on the Back of the Lower Plate from the Top of the Upper Plate of SUS 304 Double Layered Plates

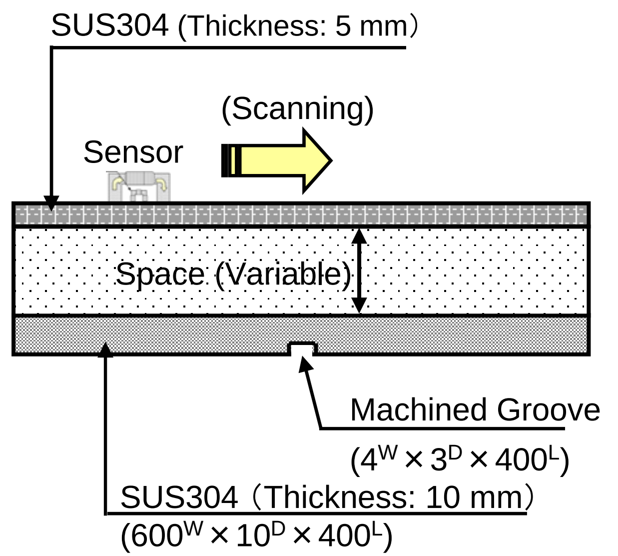


Fig.11 Schematic View of Testing

(Case 5) Detection of Artificial Surface Crack on the Inner Surface from the Outer Surface of the Stainless Steel Pipe

➡ Enables Detection of Cracks on the Inner Surface of Stainless Steel Pipe from the Outer Surface

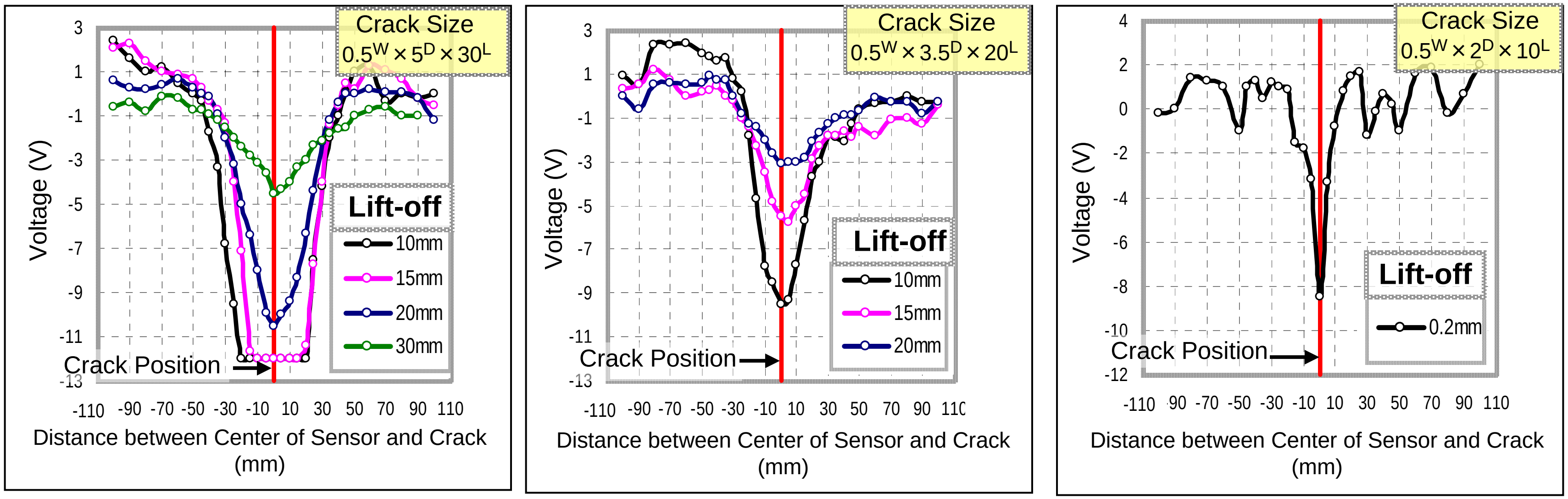


Fig.12 Experiments on an Artificial Slit-like Defect at the Inner Surface of 150A Stainless Steel Pipe

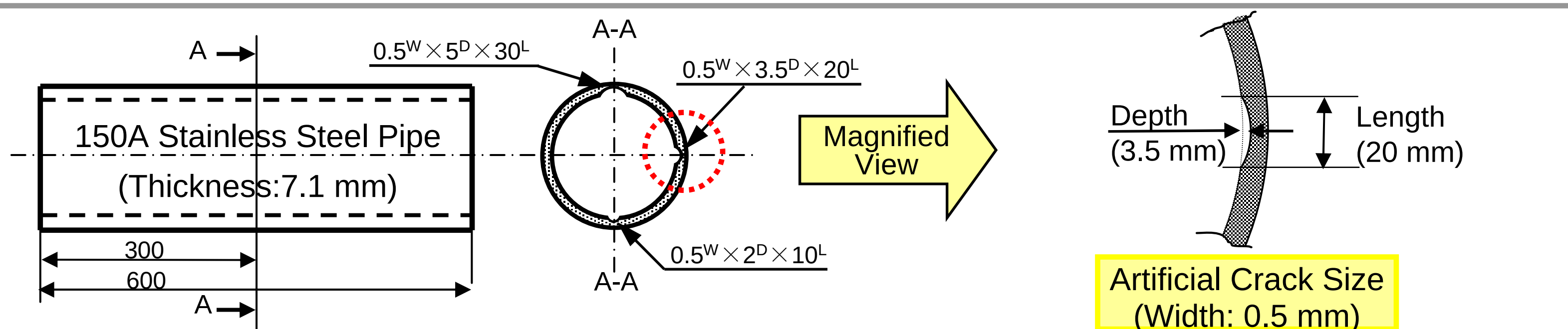


Fig.13 Test Piece

(Crack: Machined by Electrical Discharge Machining)

(Case 6) Detection of Artificial Surface Crack on the Inner Surface of a Weld Joint from the Outer Surface of Stainless Steel Pipe

⇨ Enables Detection of Inside Cracks at the Weld Joint from the Outer Surface

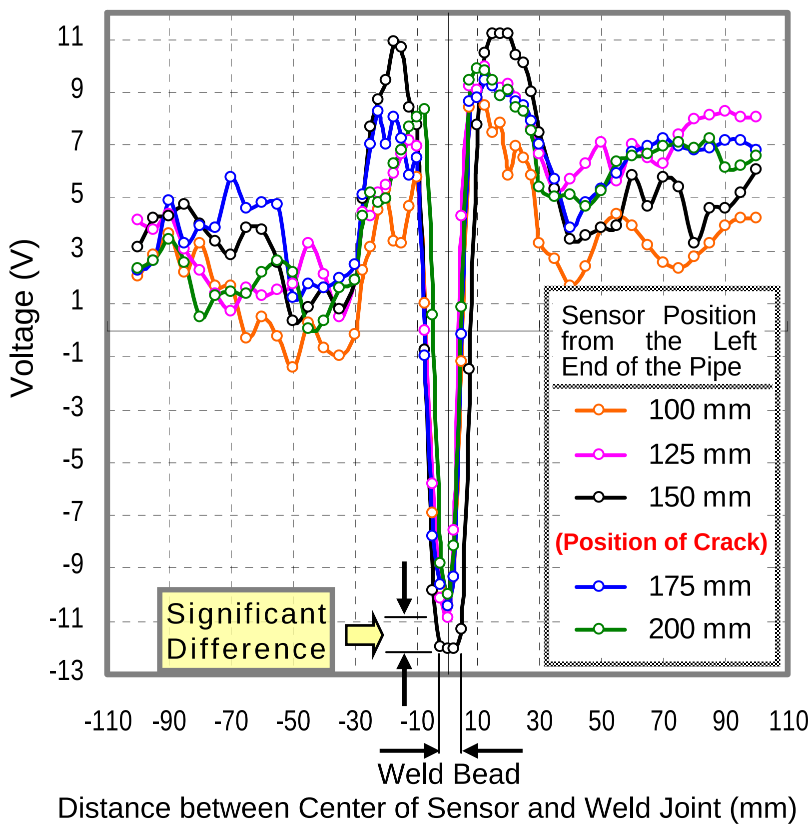


Fig.14 Experiment on Artificial Crack by Circumferential Scanning

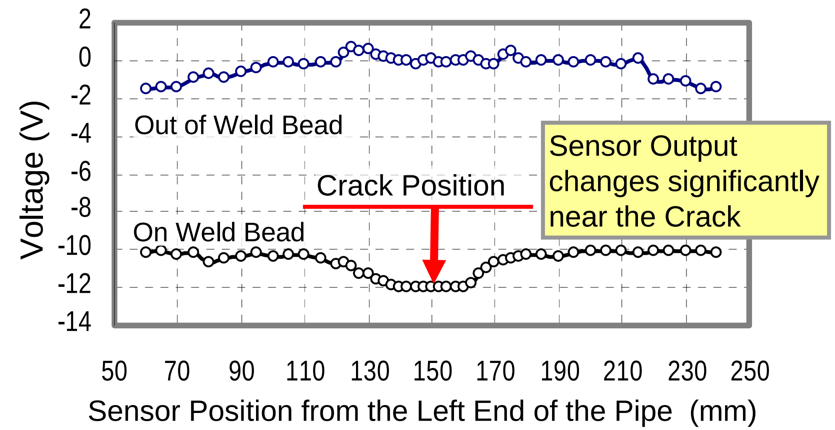


Fig.15 Experiment on Artificial Crack by Axial Scanning

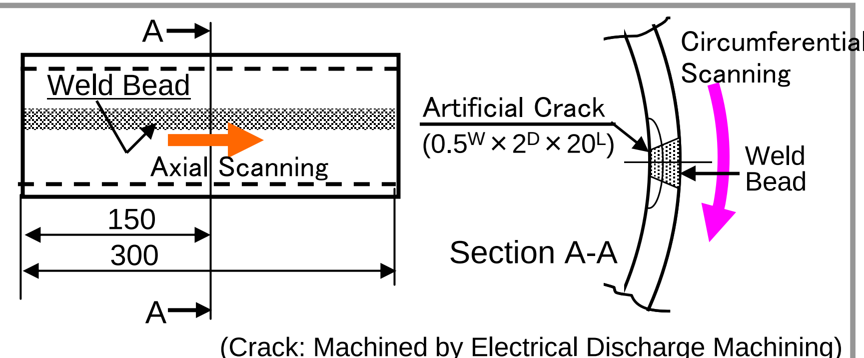


Fig 16 Test Piece (SUS304 Pipe: Φ162.5, 4.5t)

(Case 7) Detection of Artificial Crack at the Heat-affected Zone of Stainless/Carbon Steel Weld Joint

⇨ Enables Defect Inspection of Inner Surface of Pipe in the Heat-affected Zone of Stainless/Carbon Steel Weld Joint

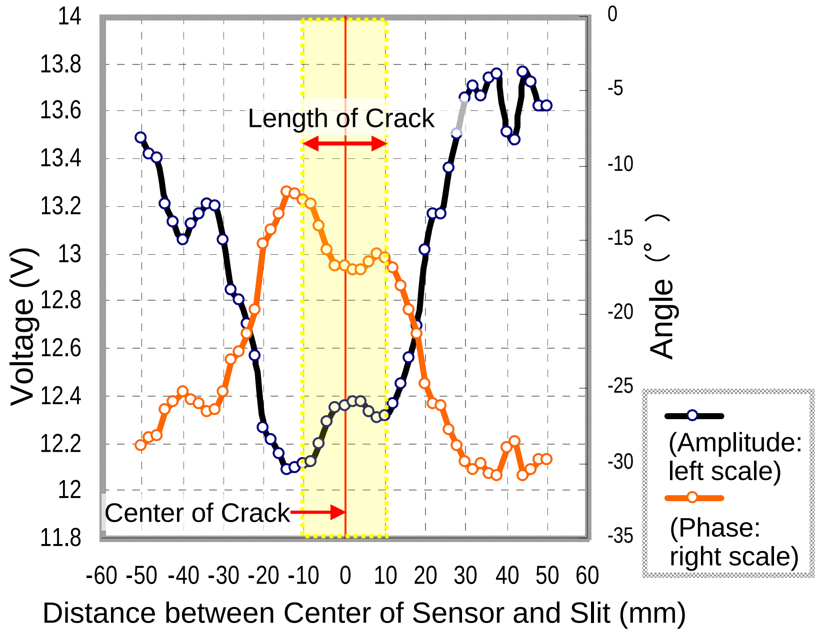


Fig.17 Experiment on the artificial crack at the heat-affected zone of the stainless / carbon steel welded pipe

Output signal changes significantly at the crack.

⇨ Detect the Crack in the Heat-affected-zone of SUS/CS Weld Joint from the Pipe Surface

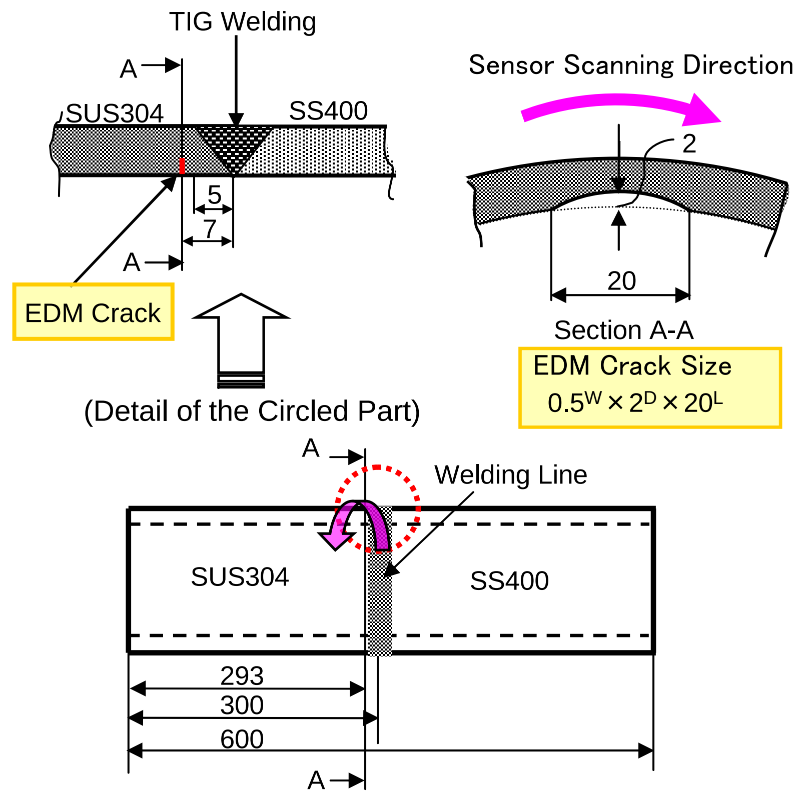


Fig. 18 Test Piece (150A SUS/CS Welded Pipe)

EDM : Electrical Discharge Machining

(Case 8) Measurement of Wall Thickness of Stainless Steel Pipe (1)

⇨ Enables Detection of Corrosion Wastage with High Accuracy

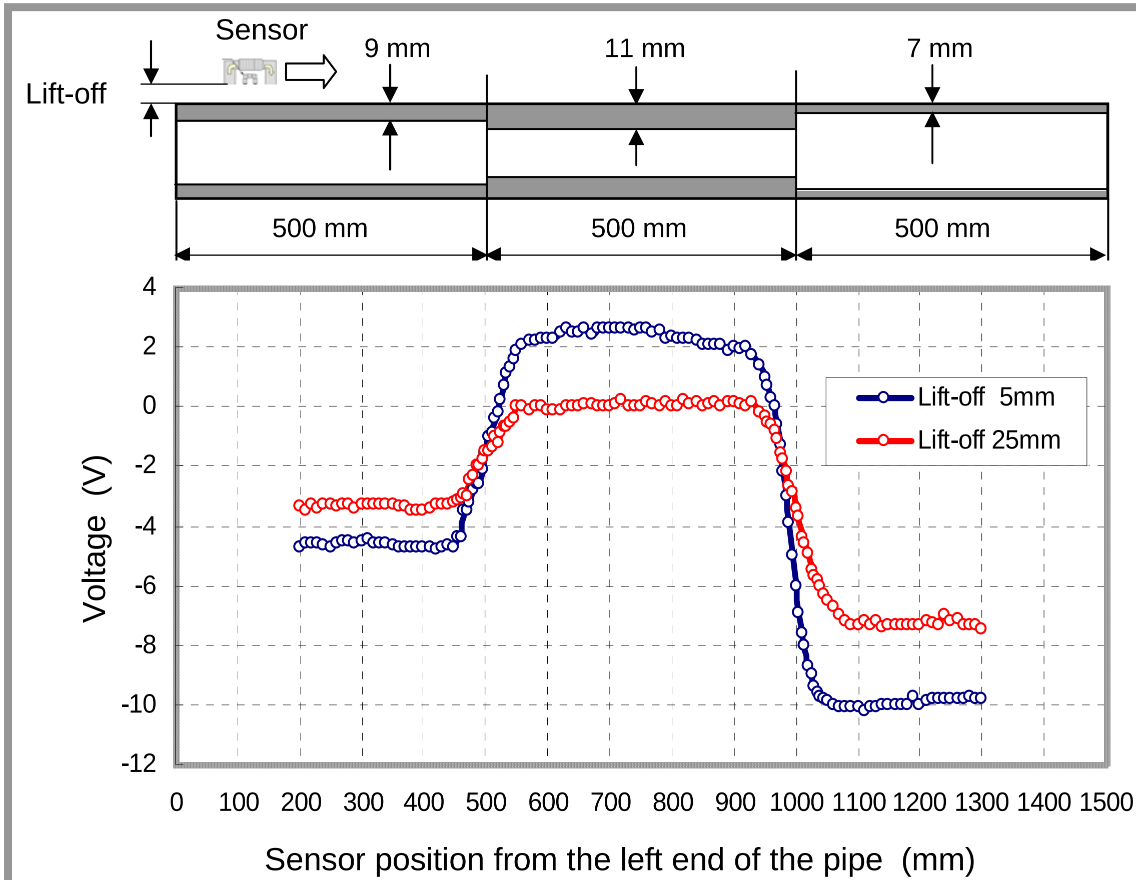


Fig. 19 Measurement of Wall Thickness of Stainless Steel (SUS304) Pipe

■ Specimen: 150A Sch80 SUS Pipe shown in Fig. 19
Wall Thickness: 7 mm, 9 mm, and 11 mm

Lift-off	Rate of voltage change vs. scanning distance at the boundary of wall thickness	
	9 mm to 11 mm	11 mm to 7mm
5 mm	70 mV/mm	-128 mV/mm
25 mm	21 mV/mm	-58 mV/mm

■ Measurement: The pipe is scanned in axial direction with lift-off.

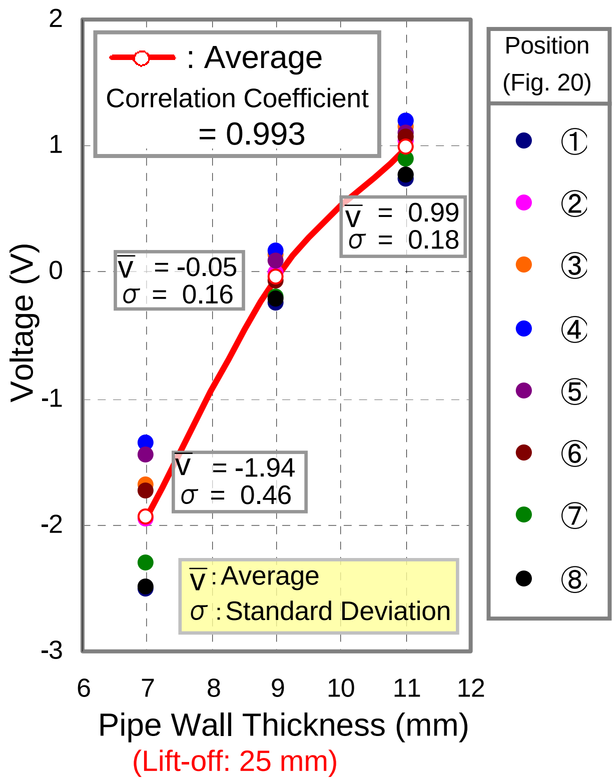
■ Results:–

The change of the thickness of pipe wall by 2 mm is detected with high accuracy even with large lift-off.

The output signal changes suddenly at the boundary of the different pipe wall thickness.

(Case 9) Measurement of Wall Thickness of Stainless Steel Pipe (2)

⇨ Enables Detection of Corrosion Wastage of Stainless Steel Pipe with Large Lift-off



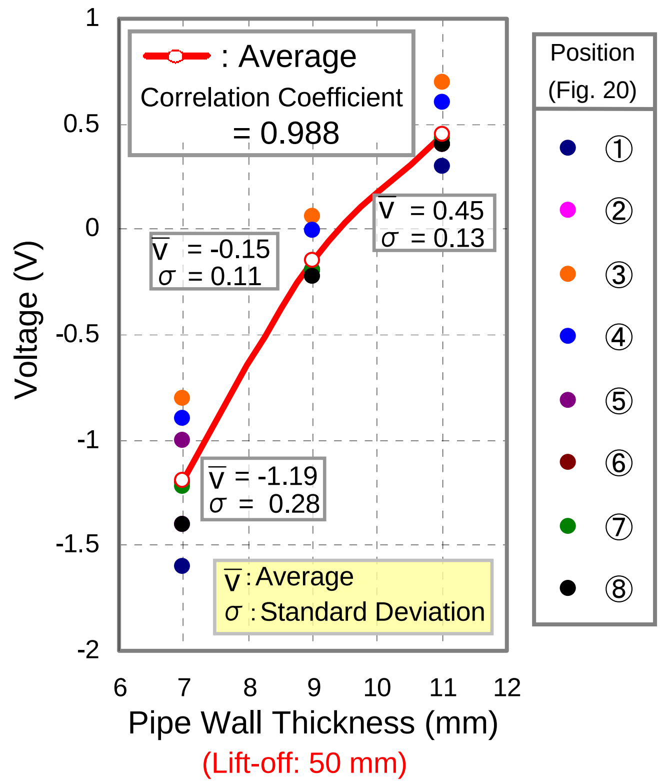
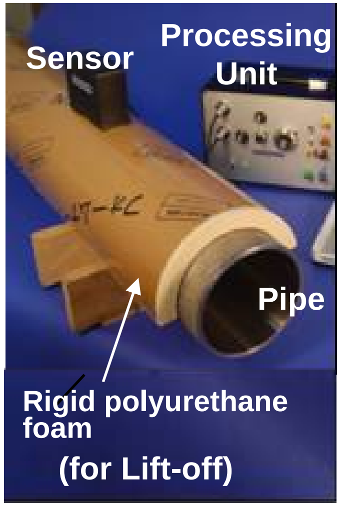


Fig. 20 Measurement of Wall Thickness of Stainless Steel (SUS304) Pipe

Wastage rate of 20 % is detected with more than 98.7 % probability at 50 mm lift-off.

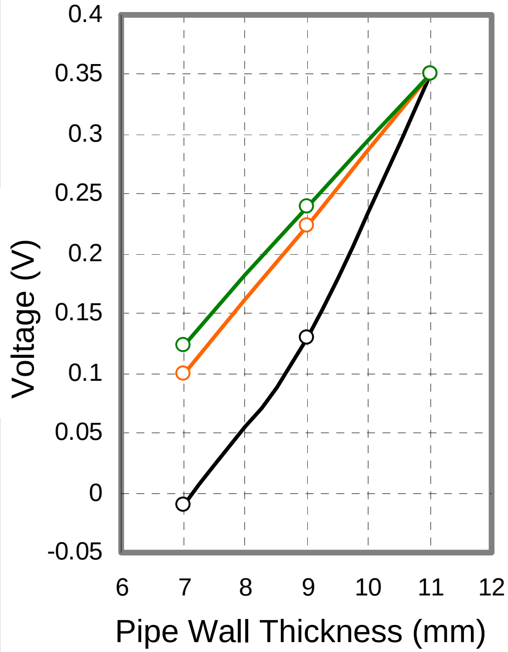


Lift-off is adjusted by varying the thickness of the polyurethane foam (25 mm lift-off in the above photo)

Fig. 21 Measurement of Pipe Wall Thickness

(Case 10) Measurement of Wall Thickness of Stainless Steel Pipe from the Top Surface of the Stainless Steel Plate placed apart above the Pipe

⇨ Enables Detection of Corrosion Wastage of Inner Pipe from Outer Pipe Surface of Double Layered Stainless Steel Pipe

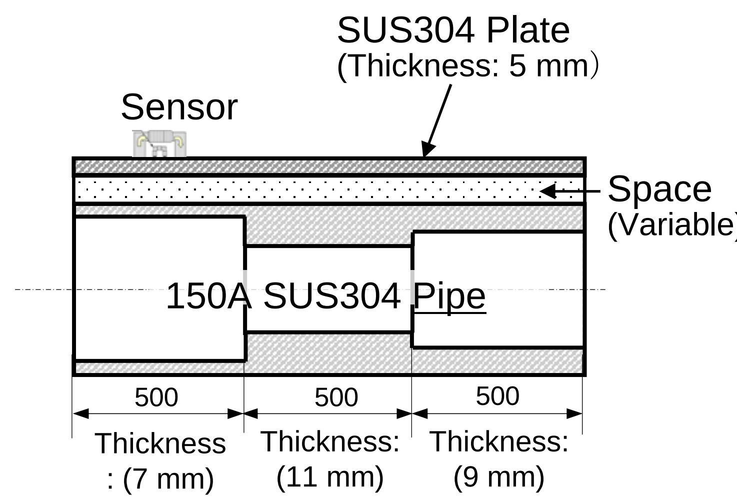


Space between Plate & Pipe	Correlation Coefficient of Thickness & Output Signal
25mm	r = 0.992
30mm	r = 1
35mm	r = 1

Frequency	: 500 Hz
Circuit Gain	: 98 dB
Lift-off	: 0.2 mm

Fig. 22 Measurement of Wall Thickness of SUS304 Pipe from the Surface of SUS304 Plate placed apart above the Pipe

The change of pipe wall thickness by 2 mm is detected from the surface of SUS304 plate (thickness of 5 mm) located 35 mm above the pipe.

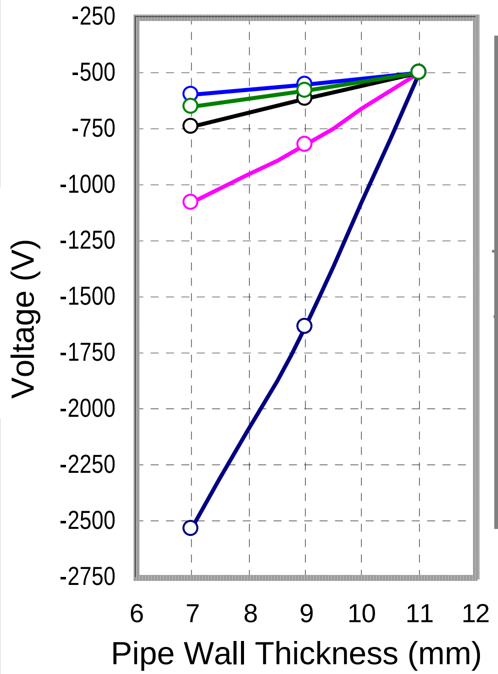


- Specimen: 150A Sch80 SUS304 Pipe (1.5 m in length)
- Wall Thickness: 7 mm, 9 mm, and 11 mm
- Spacer Material: NR Sponge rubber
- Data Processing:-
  Calculate the correlation coefficient of pipe wall thickness and output signal

Fig. 23 Schematic View of Testing

(Case 11) Measurement of Wall Thickness of Stainless Steel Pipe from the Top Surface of the Stainless Steel Plate placed apart above the Pipe

⇨ Enables Detection of Corrosion Wastage of Pipe from Dew Condensation Prevention Shield

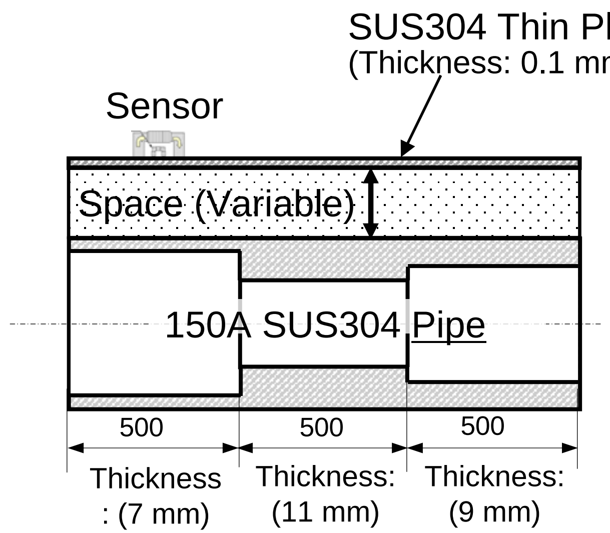


Space between Plate & Pipe	Correlation Coefficient of Pipe Wall Thickness and Sensor output	Circuit Gain
25mm	r = 0.998	66 dB
45mm	r = 0.998	66 dB
65mm	r = 1	66 dB
85mm	r = 0.996	78 dB
105mm	r = 0.999	84 dB

Frequency : 500 Hz
Lift-off : 0.2 mm

Fig. 24 Measurement of Wall Thickness of SUS304 Pipe from the Surface of Thin SUS304 Plate placed apart above the Pipe

The change of pipe wall thickness by 2 mm is detected from the surface of SUS304 plate (thickness of 0.1 mm) located 105 mm above the pipe.



- Specimen: 150A Sch80 SUS304 Pipe (1.5 m in length)
- Wall Thickness: 7 mm, 9 mm, and 11 mm
- Spacer Material: NR Sponge rubber
- Data Processing:- Calculate the correlation coefficient of pipe wall thickness and output signal

Fig. 25 Schematic View of Testing

Inquiries

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