# APPLICATION OF THE "GUCHI" TECHNIQUE USED FOR FLAW SIZING ON PIPES BY RADIOGRAPHIC TESTING

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## Abstract

This paper presents the results of application of the "GUCHI" (Geometric Unravel for Crack Height Image) technique, to measure the size of flaw in stainless steel pipe by Radiographic Testing (RT). The pipes had been prepared by the AN[1)] committee in the JWES[2)]. The "GUCHI" technique has been developed in previous year and reported at FENDT 2002 and APCNDT 2003 with successful data applied on the steel plate test specimens including fatigue cracks and EDM slits. This paper reports the procedure of applied GUCHI technique and the flaw sizing results. The sizing performance was confirmed by accumulating the radiographic film data through a round robin test on 6 inches and 10 inches stainless steel pipes including circumferential semi-elliptical EDM slits with 0.2t, 0.4t and 0.6t depth at inside of the pipe. The RMS error of the flaw length measurements and the flaw depth measurements, as compared to the actual length and the depth, has been provided to satisfy the ASME Sec XI App. VIII, Flaw sizing requirements on Ultrasonic Testing (UT).

## 1. Introduction

When the flaw is detected during the in-service inspection of components, sizing should be performed to evaluate the flaw. Regarding flaw sizing techniques, several papers relating to ultrasonic testing (UT) are available [1],[2],[3]; however, it seems that radiographic testing (RT) has seldom been applied to flaw sizing. An improved RT technique for sizing called "GUCHI" (Geometric Unravel for Crack Height Image) has been developed by Hitachi. Feature of this technique on plate is that base line marker such as a small diameter copper wire shall be placed on the plate, and twice of exposures shall be performed for a crack. The sources are positioned in parallel to a film or an imaging device. The size of crack will be estimated by several theoretical calculations with geometrical arrangement of taking radiograph and dimensional data measured on each radiograph. Digitizing System is useful for flaw sizing. The application results compared with UT-TOFD, Phased Array and Crack Tip technique on the steel plate test specimens which include fatigue cracks and EDM slits has been reported at FENDT 2002 and APCNDT 2003. [4],[5] In case the flaw is detected at curved section such as circumferential welded seams of piping or pressure vessel, it seems that the GUCHI technique will also be applicable with circle analytic geometry. A round robin test was carried out on 6 inches and 10 inches stainless steel pipes including circumferential semi-elliptical EDM slits with 0.2t, 0.4t and 0.6t depth at inside of the pipe. The test pipes had been prepared by the AN[1)] committee in the JWES[2)] and the GUCHI technique has been applied to flaw sizing and five (5) separate teams were participated in the round robin test.

## 2. Procedures using of the GUCHI technique

The techniques to be applied are based on the formation of geometrical arrangement to taking radiographs. Baseline marker such as a small diameter copper wire being placed on pipe, and two X-Ray or $\gamma$-Ray exposures being taken.

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In accordance with the geometrical arrangement of taking radiograph as shown in Figure 1 to Figure 4, procedures using of fore (4) formations of GUCHI technique has been applied. The width and length of the flaw image that appear on each of the radiographs and the distances from baseline image to the tips and/or the maximum density point of the flaw image was measured by means of magnification

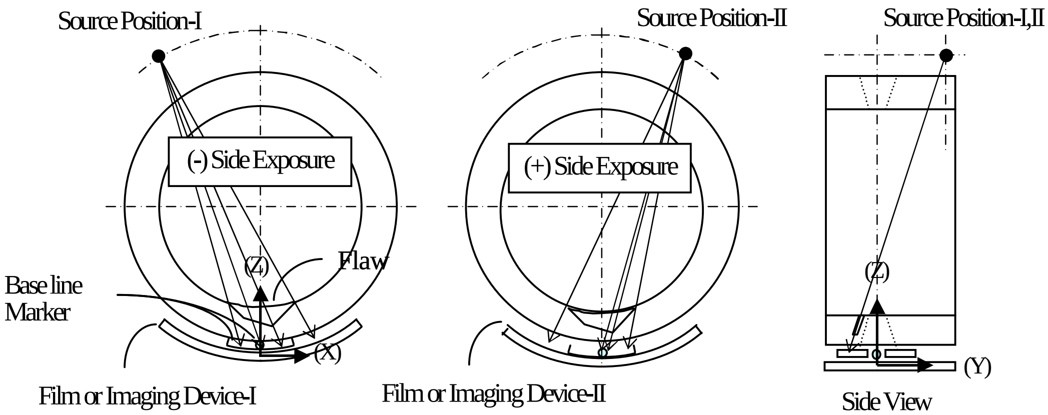



Figure 1: *Double-wall technique, single image viewing, XC-axis formation*

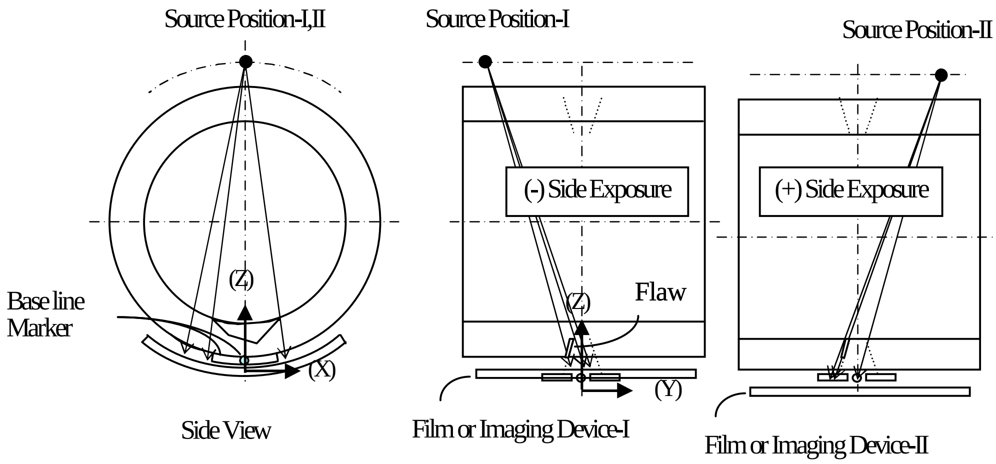



Figure 2: *Double-wall technique, single image viewing, Y-axis formation*

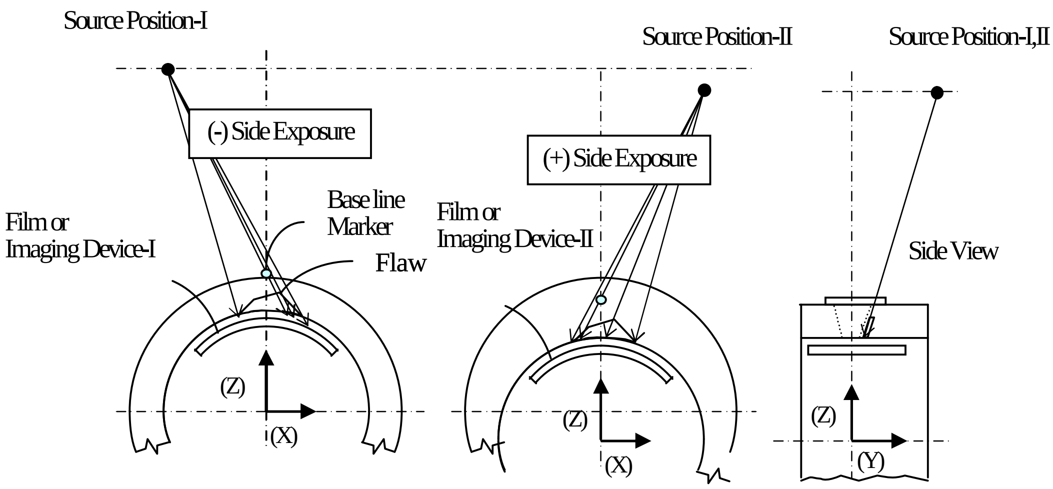



Figure 3: *Single-wall technique, X-axis formation*

Figure 5: *Configuration and size*

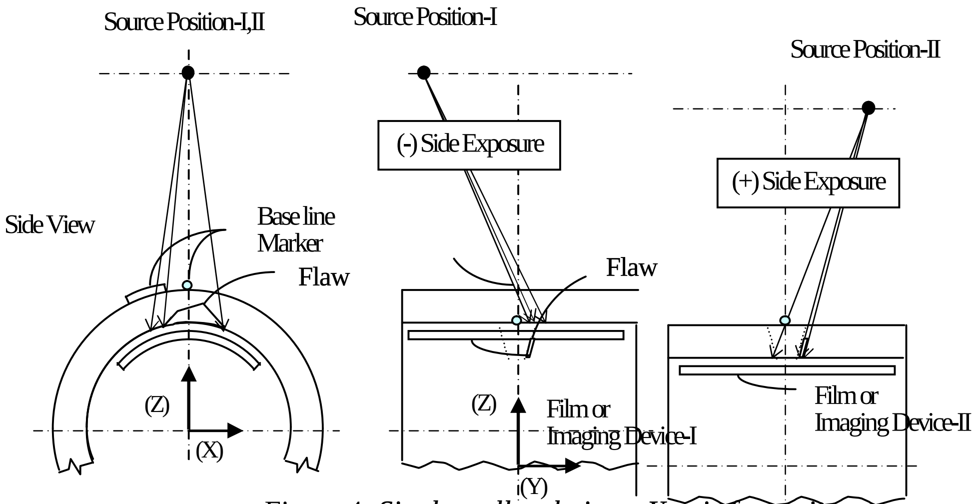



Figure 4: *Single-wall technique, Y-axis formation*

A digitizing system was used to characterize the flaw image and to obtain its dimensions. The size of the flaw was estimated by theoretical calculations, utilizing the dimensional data on the arrangement of taking radiographs and the dimensional data measured on each of the radiographs.

## 3. Test Pipes and Round Robin Test

6 inches and 10 inches stainless steel pipes including circumferential semi-elliptical EDM slits with 0.2t, 0.4t and 0.6t depth at inside of the pipes, as shown in Figure 5, had been prepared by the AN committee in the JWES

A round robin test was carried out on the test pipes. Five (5) different company teams of the AN Committee members participated in the round robin test. Conventional X-Ray or γ-Ray equipments were used for radiation source and 3 types of X-Ray films (IX50, IX80, and IX100) and a type of imaging plate (ST-VI) was used as imaging devices.

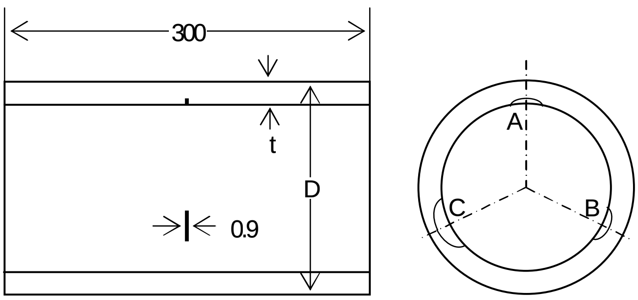
Four (4) formations of the GUCHI technique, as shown in Figure 1 to Figure 4 were employed for the geometrical arrangement of taking radiograph. All radiographic films were digitized at Hitachi using the Hitachi Radiographic Film Digitizer. Table 1 shows the round robin radiographic test parameters.

## 4. Interpretation and Measuring of Radiographic Image

The digital images of slit and baseline that were indicated on each radiograph had been interpreted and several specific dimensions had been measured by means of magnification.

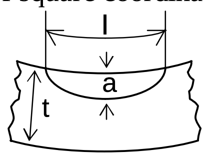
Figure 6 shows a typical slit and baseline images, of which source positions are different.

The distances from X-, Y-baseline image to slit image-tips are different respectively. In case of Y-axis formation, the maximum width of slit image is also different. A basic scale of 10x10 mm square line has drawn up on each digital display, where a corner of square coordinate




Unit : mm

| No. | D | t |
|---|---|---|
| 1 | 165.2 | 11.0 |




| EDM Slit | a/t (%) | a/l |
|---|---|---|
| A | 20 | 0.25 |
| B | 40 | 0.25 |
| C | 60 | 0.25 |

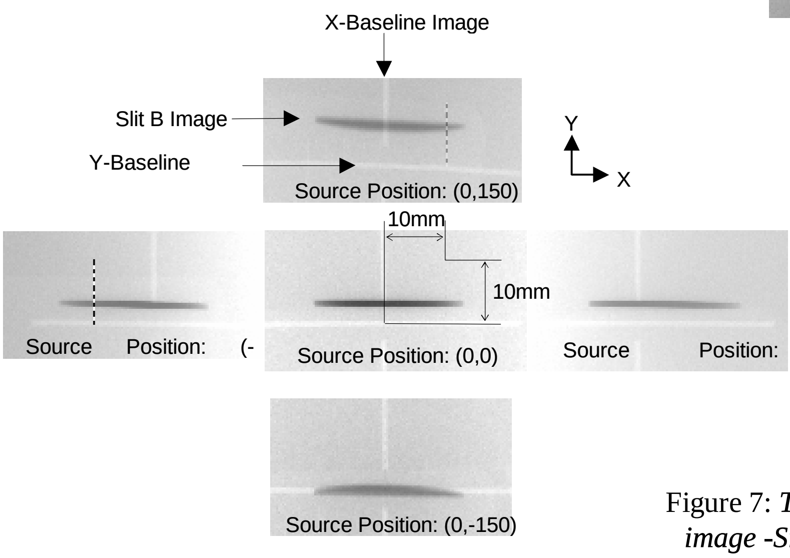
Figure 6: *Typical radiographs with slit and baseline image Single-wall, X&Y-axis formation technique for TP No.2 Sl*

*Table 1: Round Robin Test Parameters*

| TP No. | Dia. Thik. (mm) | Test Team | Technique | Radiation Source | Source Size (mm) | Type of Film/ Device | Radiographic Arraignment (*) (mm) J | X | Y | k/G | GBq/ kVp /mA | Exposure Time | Density at Base | Visible Wire (mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 165.2 11.0 | A | Double Wall | $^{192}$Ir γ -Ray | 2.8 | IX100 | 5 | -45 0 45 | -50 0 50 | 0.8/5.7 | 370 | 1'40" | 2.71～2.89 | 0.32 |
| | | | Single Wall | | | | | -50 0 50 | -50 0 50 | 0.9/5.2 | 140/5 110/5 | 0.4' 0.3' | 2.2～2.6 0.9～2.1 | |
| | | B | Single Wall | X-Ray | 2.8 | FCR IX50 ST-VI /AC-5 | 250 | | | | 85/5 | 0.3' | 0.9～1.6 | 0.16～0.2 0.2 |
| | | | | | | | 160 | -60 0 60 | -50 0 50 | | 120/3 | | 1.29～2.43 | |
| 2 | 267.4 15.1 | C | Single Wall | X-Ray | 1.3 | | 450 | -150 0 150 | -150 0 150 | 0.9/6.9 1.1/5 | 160/5 | 2'～3' 2.4' | 2.5～3.0 | |
| | | D | Double Wall | X-Ray | 2.8 | FCR ST-VI /AC-5 IX80 | 600 | -35 0 35 | -70 0 70 | | 225/3 | | | 0.16 |

(*) J : Distance from Source to Object X : Offset of Source Position for X-Direction Y : Offset of Source Position for Y-Direction
k : Diameter of Base Maker G : Distance from Object to Film (Imaging Device)

with X-, Y-line crosses point. That takes advantage of measuring at proper magnification. Figure 7 shows typical specific dimensioning for a slit image. It will be accommodated with the density distribution curve of the flaw indication. The curve can be processed and displayed from the digital data at any interested region and direction of the radiographs. The length of the flaw image and the distances from baseline image to the tips and/or even high-density point of the flaw image can be measured by proportional distribution scale.
In case of the Y-axis formation, maximum width of the flaw indication shall be additionally measured.



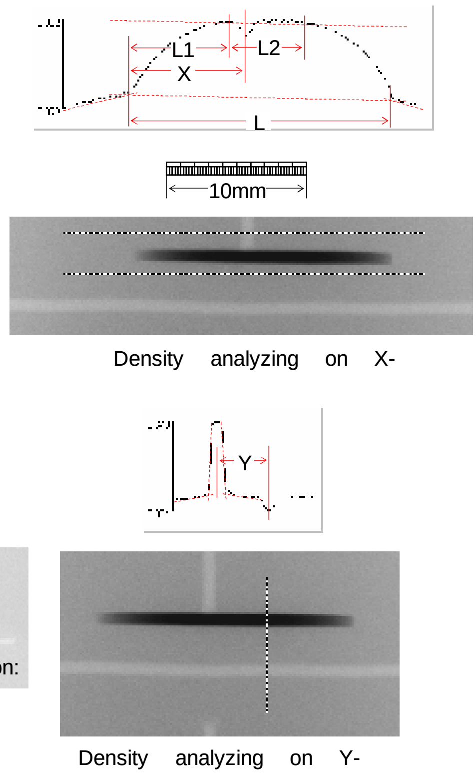




Figure 7: *Typical specific dimensioning for a slit image -Single-wall, X-axis formation GUCHI technique for TP No.1 Slit A-*

## 5. Test Results and Discussion

Figure 8 illustrates one of the GUCHI real-time output dimensions for a circumferential semi-elliptical flaw on inner surface of piping, one hundred (100) set of input data has been well analyzed and sized through the round robin test

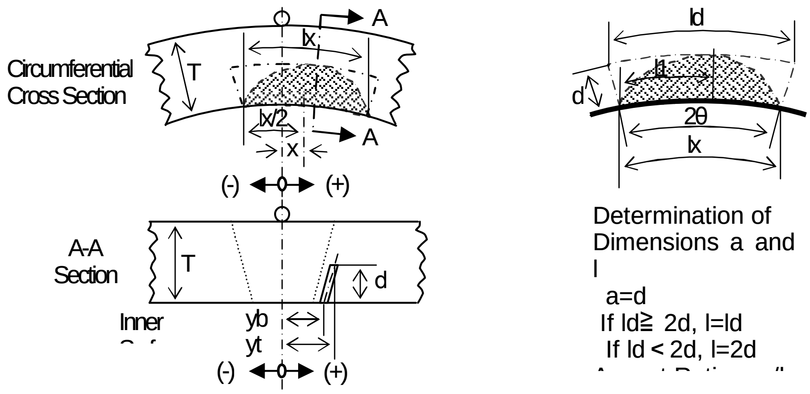



Figure 8: *Typical computer output dimensions for a flaw on inner surface of piping*

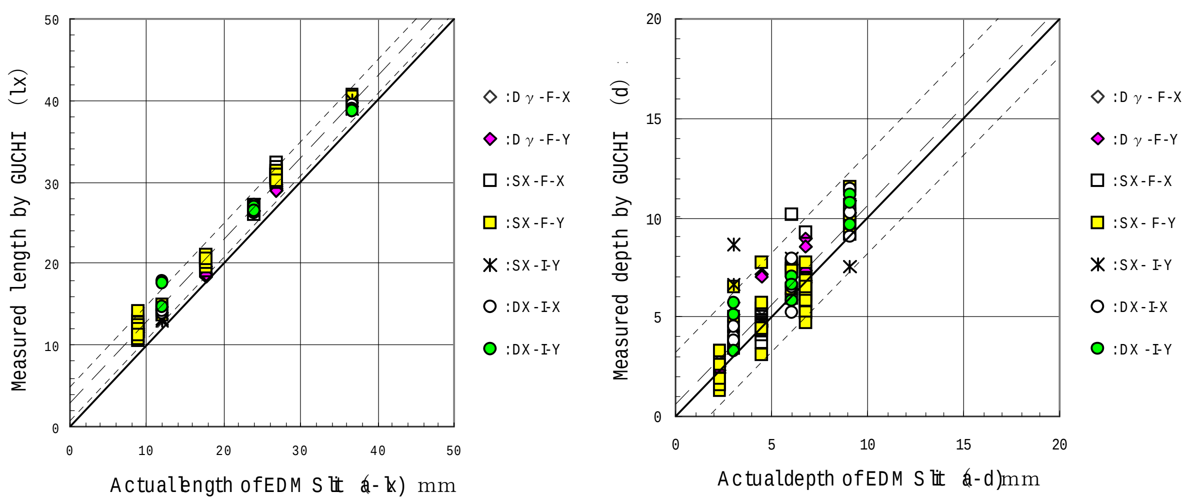



Figure 9: *Summary of the RT-GUCHI sizing results (Case 1)*

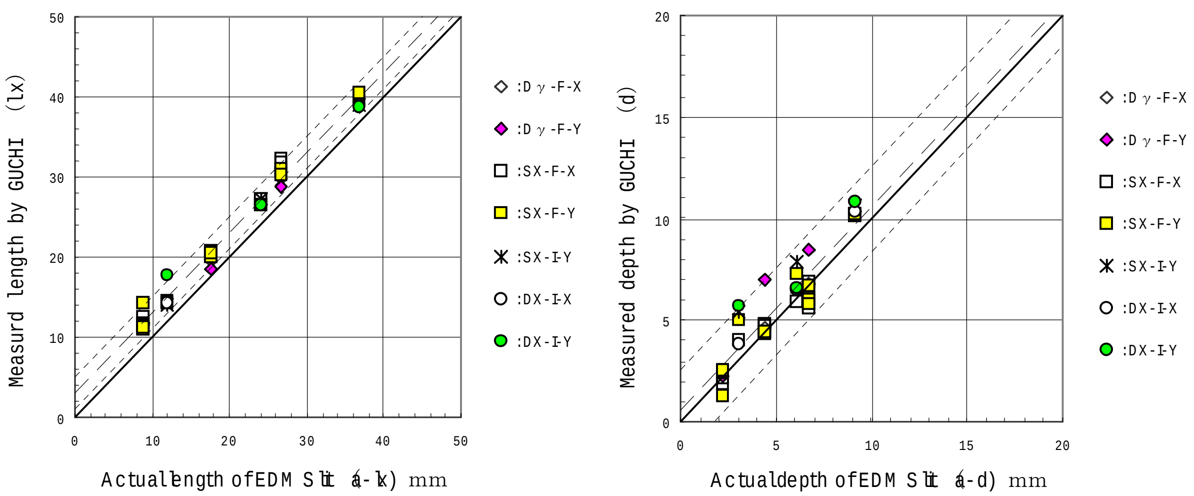



Figure 10: *Summary of the RT-GUCHI*

The data were segregated and characterized by the geometrical arrangement of taking radiographs of which radiation source position [-X,0],[0,X],[-X,X] and [-Y,0],[0,Y],[-Y,Y] formations for each team signified in Table 1.

Figure 9 and 10 shows summary of the GUCHI sizing results for length (lx) and depth (d) of the EDM slits. They were compared with the actual length (a-lx) and the depth (a-d) of the EDM slits. Figure 9 shows summary of the sizing results "Case 1" for every case of full set of characterized input data. Figure 10 shows the significant sizing results "Case 2" for set of input data characterized by the geometrical arrangement of taking radiographs of which radiation source position in ordinary [-X,X],[-Y,Y] conditions for each team. In those figures, following symbol letters are used to identify the test procedure parameters.

D: Double-wall technique,
S: Single-wall technique,
γ: γ-Ray source, X:X-Ray source
F: Film, I: Imaging Plate
X: X-axis formation technique
Y: Y-axis formation technique

The digital deviations of the flaw length and the depth, as compared to the actual flaw length and the depth are summarized on Table 2.

length measurements and the flaw depth measurements, as compared with the actual length and the depth, has been provided to satisfy the ASME Sec XI App. VIII, Flaw sizing requirements on Ultrasonic Testing (UT).

It is considered that the EDM slit will make flaw image easy and sharp. Thus, the mean deviation fell into small value and slightly plus side. This round robin test is to determine whether or not the RT-GUCHI technique may apply to the curved section, and to determine the sizing capability is comparable to UT sizing. For this purpose, the results are exactly showing a good correspondence. As further noted, this suggests possibility that the RT-GUCHI technique will available for sizing of natural cracks propagated at the components which complicate the application of UT, especially due to the surface configuration or inherently coarse-grained metallurgical structures.

## 6. Conclusions

The RT-GUCHI technique has been applied to a round robin test for measuring the size of flaws in stainless steel pipes which were 6 in. and 10 in. in diameter, 11.0 mm and 15.1 mm in thickness and included circumferential semi-elliptical EDM slits with 0.2t, 0.4t and 0.6t depth at inside of the pipe. 5 separate teams conducted the test and 4 forms of the GUCHI geometrical arrangement of taking radiograph, conventional X-Ray or γ-Ray source, 4 types of imaging devices has been applied to the round robin test. The RMS errors of the flaw length measurements were 0.98-1.04 mm and the flaw depth measurements were 0.98-1.28 mm, as compared with the actual length and the depth. It has been provided to satisfy the ASME Sec XI Art. VIII, Flaw sizing requirements on UT.

*Table 2: Deviations of the RT-GUCHI sizing results (Unit: mm)*

| Case | Dimension | Mean Deviation | Standard Deviation 2σ | RMS Error (See Note) |
|---|---|---|---|---|
| Case 1 | Flaw Length | +2.87 | 2.10 | 0.98 |
| | Depth of Flaw | +0.63 | 2.56 | 1.28 |
| Case 2 | Flaw Length | +2.99 | 2.10 | 1.04 |
| | Depth of Flaw | +0.55 | 1.98 | 0.98 |

Note; ASME Sec XI App. VIII, Flaw sizing requirements on Ultrasonic Testing (UT) specify RMS error of 0.75 in. (19 mm) for length, 0.125 in. (3 mm) for depth. [6]

From these results, RT-GUCHI technique with conventional radiation source, imaging devices, shooting arrangement of X-axis or Y-axis formation as round robin test parameters can be substantively applicable for sizing of slit-type flaws on piping. The RMS error of the flaw

Finally, authors would like to appreciate the members of AN committee for their useful discussions and comments.

## 7. References

[1] NDIS 2418(1996) "Measurement Technique of Defect Height using Tip Echo Method" and NDIS 2423(2001) "Method of Measuring Defect Height by using TOFD Technique" published by JSNDI.

[2] M. Koshirae, "Ultrasonic Testing using Digital Phased Array and TOFD Inspection System", *Plant Engineer*, March 2002, Vol.34, 3, p.26-29.

[3] H. Wustenberg, A. Erhard, G. Schenk "Scanning Modes at the Application of Ultrasonic Phased Array Inspection Systems" 15th WCNDT, Rome, Italy, October 2000.

[4] S. Higuchi, M. Okudaira, Z. Makihara, N. Ooka "Flaw Sizing for Fatigue Crack by Radiographic Testing -Application of the "GUCHI" Technique-" 6th FENDT, Tokyo, Japan, October 2002.

[5] S. Higuchi, Z. Makihara, Y. Nonaka, N. Ooka "Development of Flaw Sizing Technique by Radiographic Testing -Application of the "GUCHI" Technique-", *Key Engineering Materials Vols. 270-273(2004) pp.1316-1323*, Proceeding of the 11th APCNDT, Jeju Island, Korea, 3-7 Nov. 2003.

[6] ASME Code 2004 Sec. XI, Division I, Appendix VIII, Sup. 2 Performance Demonstrations for Ultrasonic Examination Systems.

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## 1. Introduction

When the flaw is detected during the in-service inspection of components, sizing should be performed to evaluate the flaw. Regarding flaw sizing techniques, several papers relating to ultrasonic testing (UT) are available [1],[2],[3]; however, it seems that radiographic testing (RT) has seldom been applied to flaw sizing. An improved RT technique for sizing called "GUCHI" (Geometric Unravel for Crack Height Image) has been developed by Hitachi. Feature of this technique on plate is that base line marker such as a small diameter copper wire shall be placed on the plate, and twice of exposures shall be performed for a crack. The sources are positioned in parallel to a film or an imaging device. The size of crack will be estimated by several theoretical calculations with geometrical arrangement of taking radiograph and dimensional data measured on each radiograph. Digitizing System is useful for flaw sizing. The application results compared with UT-TOFD, Phased Array and Crack Tip technique on the steel plate test specimens which include fatigue cracks and EDM slits has been reported at FENDT 2002 and APCNDT 2003. [4],[5] In case the flaw is detected at curved section such as circumferential welded seams of piping or pressure vessel, it seems that the GUCHI technique will also be applicable with circle analytic geometry. A round robin test was carried out on 6 inches and 10 inches stainless steel pipes including circumferential semi-elliptical EDM slits with 0.2t, 0.4t and 0.6t depth at inside of the pipe. The test pipes had been prepared by the AN[1)] committee in the JWES[2)] and the GUCHI technique has been applied to flaw sizing and five (5) separate teams were participated in the round robin test.

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The techniques to be applied are based on the formation of geometrical arrangement to taking radiographs. Baseline marker such as a small diameter copper wire being placed on pipe, and two X-Ray or $\gamma$-Ray exposures being taken.

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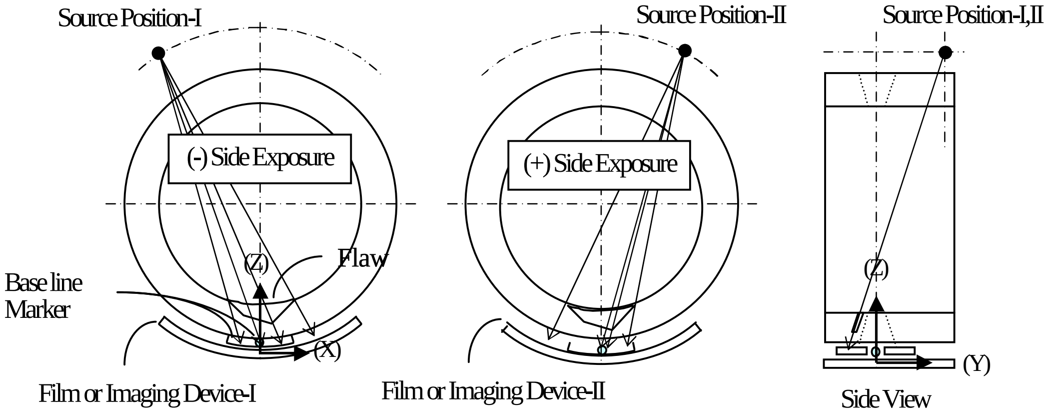


Figure 1: *Double-wall technique, single image viewing, XC-axis formation*

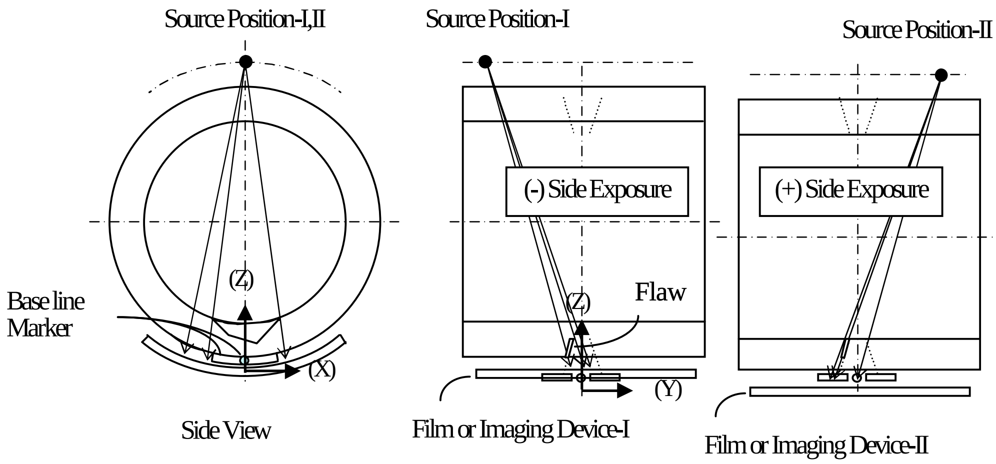


Figure 2: *Double-wall technique, single image viewing, Y-axis formation*

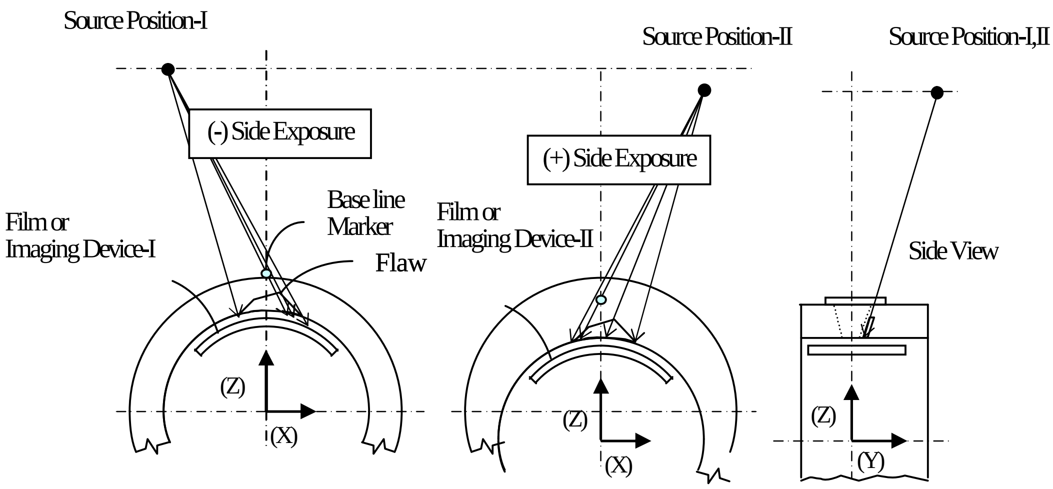


Figure 3: *Single-wall technique, X-axis formation*

Figure 5: *Configuration and size*

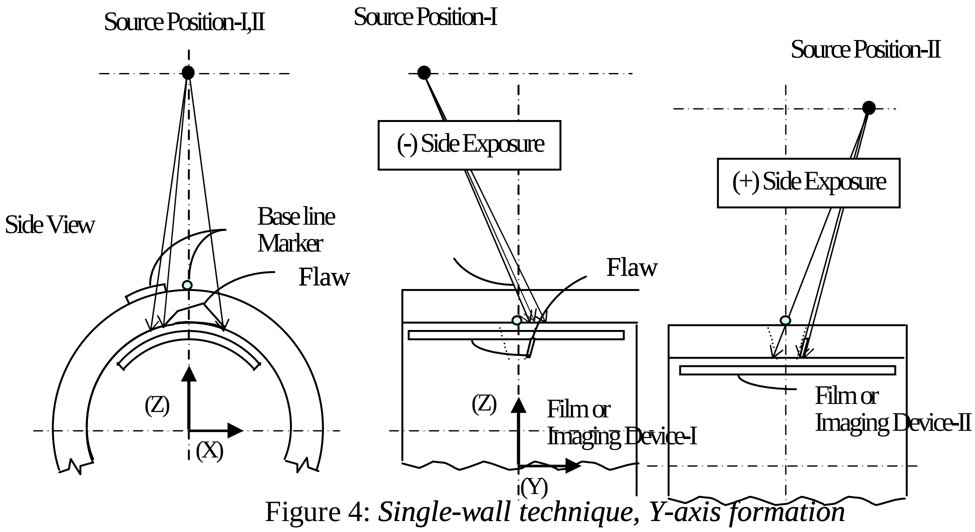


Figure 4: *Single-wall technique, Y-axis formation*

A digitizing system was used to characterize the flaw image and to obtain its dimensions. The size of the flaw was estimated by theoretical calculations, utilizing the dimensional data on the arrangement of taking radiographs and the dimensional data measured on each of the radiographs.

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6 inches and 10 inches stainless steel pipes including circumferential semi-elliptical EDM slits with 0.2t, 0.4t and 0.6t depth at inside of the pipes, as shown in Figure 5, had been prepared by the AN committee in the JWES

A round robin test was carried out on the test pipes. Five (5) different company teams of the AN Committee members participated in the round robin test. Conventional X-Ray or γ-Ray equipments were used for radiation source and 3 types of X-Ray films (IX50, IX80, and IX100) and a type of imaging plate (ST-VI) was used as imaging devices.

Four (4) formations of the GUCHI technique, as shown in Figure 1 to Figure 4 were employed for the geometrical arrangement of taking radiograph. All radiographic films were digitized at Hitachi using the Hitachi Radiographic Film Digitizer. Table 1 shows the round robin radiographic test parameters.

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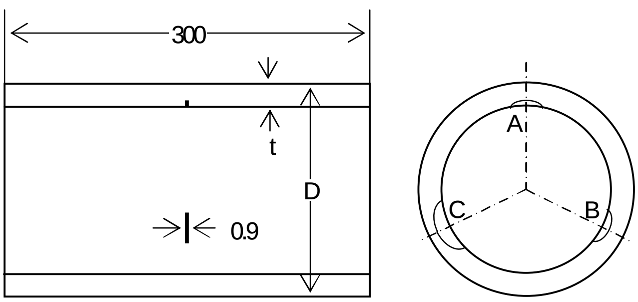
The digital images of slit and baseline that were indicated on each radiograph had been interpreted and several specific dimensions had been measured by means of magnification.

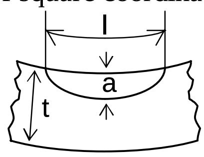
Figure 6 shows a typical slit and baseline images, of which source positions are different.

The distances from X-, Y-baseline image to slit image-tips are different respectively. In case of Y-axis formation, the maximum width of slit image is also different. A basic scale of 10x10 mm square line has drawn up on each digital display, where a corner of square coordinate




Unit : mm

| No. | D | t |
|---|---|---|
| 1 | 165.2 | 11.0 |




| EDM Slit | a/t (%) | a/l |
|---|---|---|
| A | 20 | 0.25 |
| B | 40 | 0.25 |
| C | 60 | 0.25 |

Figure 6: *Typical radiographs with slit and baseline image -Single-wall, X&Y-axis formation technique for TP No.2 Sl*

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| TP No. | Dia. Thik. (mm) | Test Team | Technique | Radiation Source | Source Size (mm) | Type of Film/ Device | Radiographic Arraignment (*) (mm) J | X | Y | k/G | GBq/ kVp /mA | Exposure Time | Density at Base | Visible Wire (mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 165.2 11.0 | A | Double Wall | $^{192}$Ir γ -Ray | 2.8 | IX100 | 5 | -45 0 45 | -50 0 50 | 0.8/5.7 | 370 | 1'40" | 2.71 ~ 2.89 | 0.32 |
| | | | Single Wall | | | | | -50 0 50 | -50 0 50 | 0.9/5.2 | 140/5 110/5 | 0.4' 0.3' | 2.2 ~ 2.6 0.9 ~ 2.1 | |
| | | B | | | | | 250 | | | | 85/5 | 0.3' | 0.9 ~ 1.6 | |
| | | | Single Wall | X-Ray | 2.8 | FCR IX50 ST-VI /AC-5 | 160 | -60 0 60 | -50 0 50 | | 120/3 | | 1.29 ~ 2.43 | 0.16 ~ 0.2 0.2 |
| 2 | 267.4 15.1 | C | Single Wall | X-Ray | 1.3 | | 450 | -150 0 150 | -150 0 150 | 0.9/6.9 1.1/5 | 160/5 | 2' ~ 3' 2.4' | 2.5 ~ 3.0 | |
| | | D | Double Wall | X-Ray | 2.8 | FCR ST-VI /AC-5 IX80 | 600 | -35 0 35 | -70 0 70 | | 225/3 | | | 0.16 |

(*) J : Distance from Source to Object X : Offset of Source Position for X-Direction Y : Offset of Source Position for Y-Direction
k : Diameter of Base Maker G : Distance from Object to Film (Imaging Device)

with X-, Y-line crosses point. That takes advantage of measuring at proper magnification. Figure 7 shows typical specific dimensioning for a slit image. It will be accommodated with the density distribution curve of the flaw indication. The curve can be processed and displayed from the digital data at any interested region and direction of the radiographs. The length of the flaw image and the distances from baseline image to the tips and/or even high-density point of the flaw image can be measured by proportional distribution scale.

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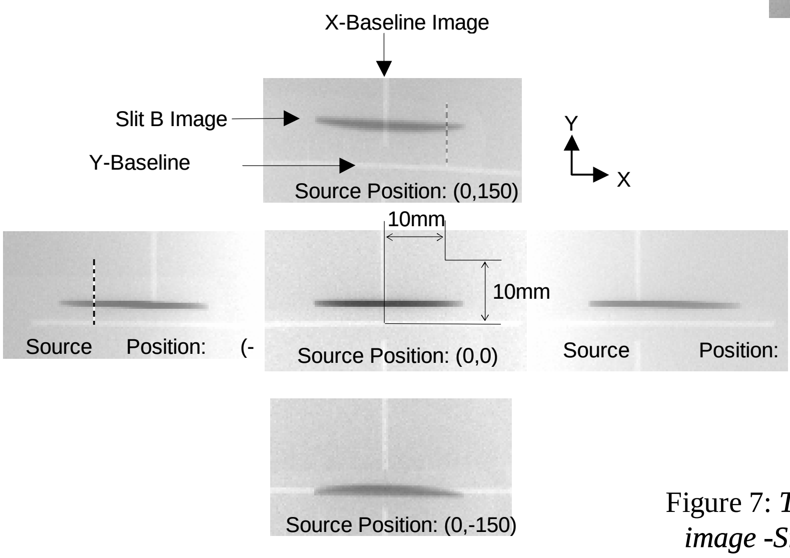


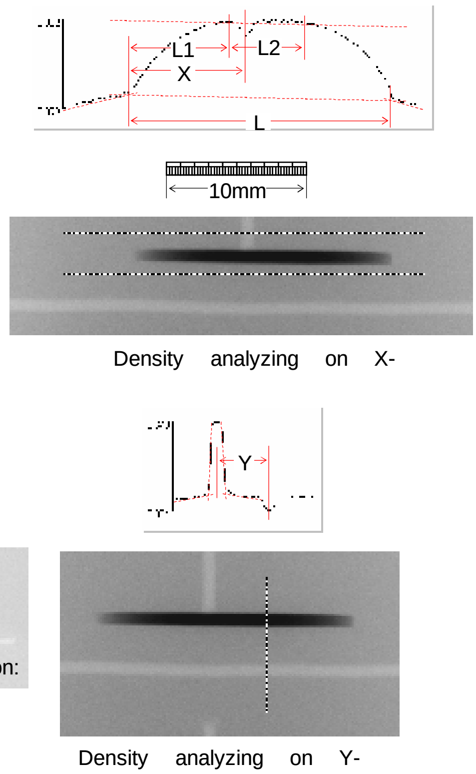


Figure 7: *Typical specific dimensioning for a slit image -Single-wall, X-axis formation GUCHI technique for TP No.1 Slit A-*

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Figure 10: *Summary of the RT-GUCHI*

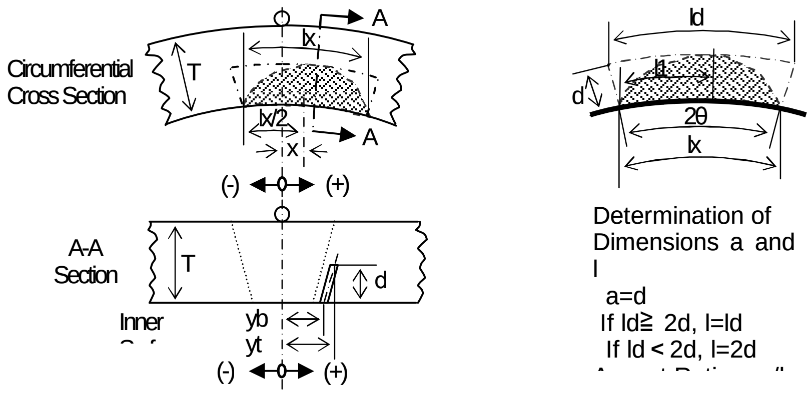



Figure 8: *Typical computer output dimensions for a flaw on inner surface of piping*

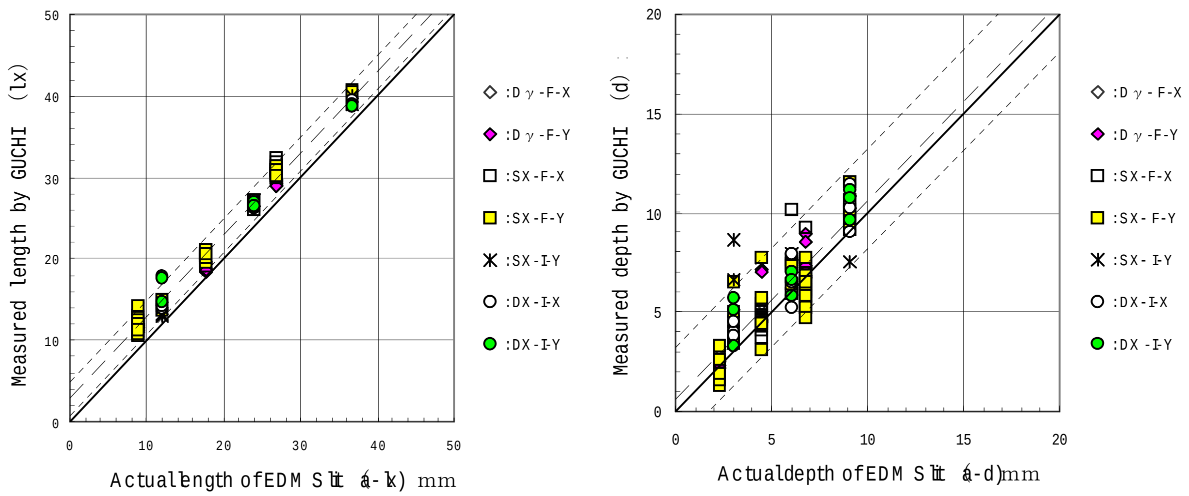
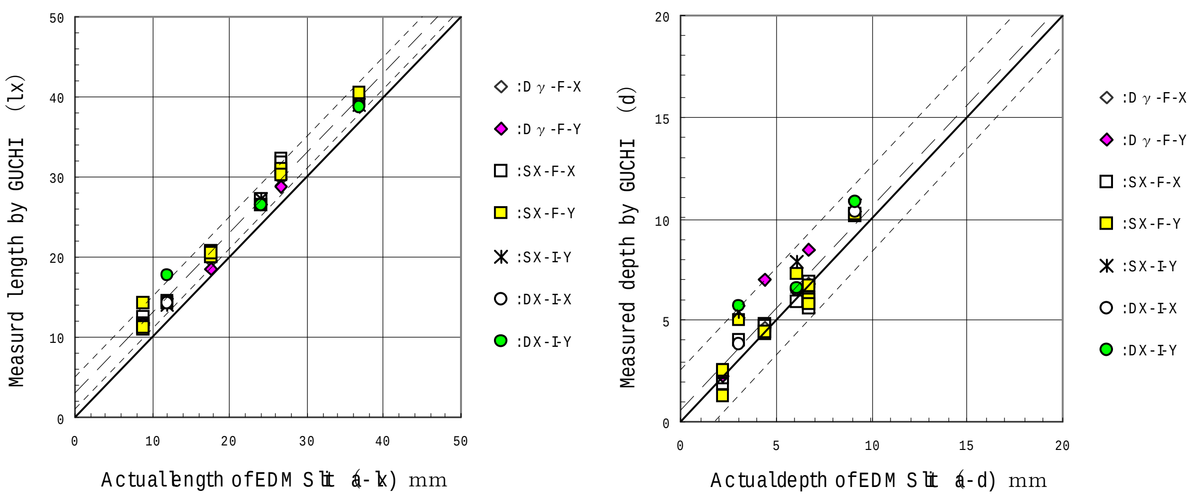



Figure 9: *Summary of the RT-GUCHI sizing results (Case 1)*



The data were segregated and characterized by the geometrical arrangement of taking radiographs of which radiation source position [-X,0],[0,X],[-X,X] and [-Y,0],[0,Y],[-Y,Y] formations for each team signified in Table 1.

Figure 9 and 10 shows summary of the GUCHI sizing results for length (lx) and depth (d) of the EDM slits. They were compared with the actual length (a-lx) and the depth (a-d) of the EDM slits. Figure 9 shows summary of the sizing results “Case 1” for every case of full set of characterized input data. Figure 10 shows the significant sizing results “Case 2” for set of input data characterized by the geometrical arrangement of taking radiographs of which radiation source position in ordinary [-X,X],[-Y,Y] conditions for each team. In those figures, following symbol letters are used to identify the test procedure parameters.

D: Double-wall technique,
S: Single-wall technique,
γ: γ-Ray source, X:X-Ray source
F: Film, I: Imaging Plate
X: X-axis formation technique
Y: Y-axis formation technique

The digital deviations of the flaw length and the depth, as compared to the actual flaw length and the depth are summarized on Table 2.

length measurements and the flaw depth measurements, as compared with the actual length and the depth, has been provided to satisfy the ASME Sec XI App. VIII, Flaw sizing requirements on Ultrasonic Testing (UT).

It is considered that the EDM slit will make flaw image easy and sharp. Thus, the mean deviation fell into small value and slightly plus side. This round robin test is to determine whether or not the RT-GUCHI technique may apply to the curved section, and to determine the sizing capability is comparable to UT sizing. For this purpose, the results are exactly showing a good correspondence. As further noted, this suggests possibility that the RT-GUCHI technique will available for sizing of natural cracks propagated at the components which complicate the application of UT, especially due to the surface configuration or inherently coarse-grained metallurgical structures.

## 6. Conclusions

The RT-GUCHI technique has been applied to a round robin test for measuring the size of flaws in stainless steel pipes which were 6 in. and 10 in. in diameter, 11.0 mm and 15.1 mm in thickness and included circumferential semi-elliptical EDM slits with 0.2t, 0.4t and 0.6t depth at inside of the pipe. 5 separate teams conducted the test and 4 forms of the GUCHI geometrical arrangement of taking radiograph, conventional X-Ray or γ-Ray source, 4 types of imaging devices has been applied to the round

*Table 2*: *Deviations of the RT-GUCHI sizing results (Unit: mm)*

| Case | Dimension | Mean Deviation | Standard Deviation 2σ | RMS Error (See Note) |
|---|---|---|---|---|
| Case 1 | Flaw Length | +2.87 | 2.10 | 0.98 |
| | Depth of Flaw | +0.63 | 2.56 | 1.28 |
| Case 2 | Flaw Length | +2.99 | 2.10 | 1.04 |
| | Depth of Flaw | +0.55 | 1.98 | 0.98 |

Note; ASME Sec XI App. VIII, Flaw sizing requirements on Ultrasonic Testing (UT) specify RMS error of 0.75 in. (19 mm) for length, 0.125 in. (3 mm) for depth. [6]

From these results, RT-GUCHI technique with conventional radiation source, imaging devices, shooting arrangement of X-axis or Y-axis formation as round robin test parameters can be substantively applicable for sizing of slit-type flaws on piping. The RMS error of the flaw

robin test. The RMS errors of the flaw length measurements were 0.98-1.04 mm and the flaw depth measurements were 0.98-1.28 mm, as compared with the actual length and the depth. It has been provided to satisfy the ASME Sec XI Art. VIII, Flaw sizing requirements on UT.

Finally, authors would like to appreciate the members of AN committee for their useful discussions and comments.

## 7. References

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[6] ASME Code 2004 Sec. XI, Division I, Appendix VIII, Sup. 2 Performance Demonstrations for Ultrasonic Examination Systems.