



School of Engineering MSc Mechanical Engineering

M7X01384
Structural Integrity & Material Evaluation

Assessment 2

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1.0 Question 1

1a)

In table 1(Appendix), you have been provided with through wall thickness measurements in mm and basic error analysis results undertaken as part of a larger POD study used to assess the performance of a new ultrasonic thickness gauging procedure. These results are also presented in graphical form in figure 1(Appendix), where linear trend lines have been fitted to the data sets. There are 21 defect measurements in total, the dimensions of which are given in mm to 1 decimal place. 10 technicians have used the equipment and procedure to perform the measurements.

By analysing these results, comment on the relative sizing accuracy and general performance of each operator. How would you assess the performance of the procedure as a whole?

Analysis of operators

Relative sizing accuracy and general performance of each operator is considered against the mean average of the test group and detailed in the following table

Operator	1	2	3	4	5	6	7	8	9	10	Mean	σ
σ	0.429	0.676	0.514	0.531	0.461	0.382	0.551	0.254	0.411	0.258	0.447	0.131
$\pm 95\%$	0.841	1.325	1.007	1.041	0.903	0.749	1.081	0.498	0.805	0.506	0.876	0.256
R ²	0.956	0.915	0.942	0.944	0.948	0.965	0.938	0.984	0.966	0.993	0.955	0.023
Rank	5	10	7	8	6	3	9	2	4	1		

Operator 1

Within the test group operator 1 was 5th out of 10 where correlation R^2 , margin of error and standard deviation are considered across the group. There were 15 counts of over estimation of the measured values and 6 of underestimation. The liner trend would suggest that underestimation of size would increase with increased thickness.

Operator 2

Within the test group operator 2 was significantly below average and worst in the group, 10th out of 10 where correlation R^2 0.9149, margin of error 95% of measurements within 1.325% and standard deviation 0.429, are considered across the group. There were 15 counts of over estimation of the measured values and 6 of underestimation. However, it was noted that the liner trend would suggest that there is significant overestimation at both the lower and upper end of the test range.

Operator 3

Within the test group operator 3 was 7th out of 10 where correlation R^2 , margin of error and standard deviation are considered across the group. There were 13 counts of over estimation of the measured values and 6 of underestimation. The liner trend would suggest that underestimation of size would increase with increased thickness.

Operator 4

Within the test group operator 4 was 8th out of 10 where correlation R^2 , margin of error and standard deviation are considered across the group. There were 17 counts over estimation of the measured values and 4 of underestimation. The liner trend would suggest that underestimation of size would increase with increased thickness.

Operator 5

Within the test group operator 5 was 6th out of 10 where correlation R^2 , margin of error and standard deviation are considered across the group. There were 14 counts of over estimation of the measured values and 7 of underestimation. The liner trend would suggest that underestimation of size would increase with increased thickness.

Operator 6

Within the test group operator 6 was 3rd out of 10 where correlation R^2 , margin of error and standard deviation are considered across the group. There were 19 counts of over estimation of the measured values and 2 of underestimation. The liner trend would suggest there is a consistent overestimation in thickness irrespective of increase in thickness.

Operator 7

Within the test group operator 7 was below average, 9th out of 10 where correlation R^2 , margin of error and standard deviation, are considered across the group. There were 11 counts of over estimation of the measured values and 9 of underestimation. However, it was noted that liner trend would suggest that there is significant overestimation at both the lower and upper end of the test range.

Operator 8

Within the test group operator 8 was above average, 2nd out of 10 where correlation R^2 , margin of error and standard deviation, are considered across the group. There were 20 counts of over estimation of the measured values and 1 of underestimation. The liner trend would suggest there is a consistent overestimation in thickness irrespective of increase in thickness.

Operator 9

Within the test group operator 9 was 4th out of 10 where correlation R^2 , margin of error and standard deviation are considered across the group. There were 20 counts of over estimation of the measured values and 1 of underestimation. The liner trend would suggest that underestimation of size would increase with decrease with thickness, tending to become more accurate as thickness increased.

Operator 10

Within the test group operator 2 was significantly above average and best in the group, 1st out of 10 where correlation R^2 0.9925, margin of error 95% of measurements within 0.506% and standard deviation 0.258, are considered across the group. There were 18 counts of over estimation of the measured values and 3 of underestimation. However, it was noted that liner trend would suggest that there is overestimation at both the lower and upper end of the test range.

Performance of Procedure as a whole

The procedure is susceptible to overestimation at the lower, and underestimation at the upper end, of the test range, across the group the reading were the most consistent in the 1.5 – 3mm range. Overall, the equipment appears susceptible to calibration errors and possible further verification is required in this area as part of the test, as all operators tended to overestimate the actual thickness when error in readings is considered. Where calibration is considered it is likely that operator 8 would have taken first place from operator 10, as R^2 at 0.9925 was best in group, if nature of calibration and accuracy were determined.

The test description whilst clarifying that the 'technicians have used the equipment and procedure' does not describe calibration procedure, in that the technical was responsible for calibration or the equipment was independently calibrated. Or further does not describe the nature of probe contact, either an automated process, or the probe is manually placed for measurement. Both, method of calibration, and method of application would influence the outcome of reading taken as part of the test.

The test method suggests that there is a zero error with the equipment as in all cases the trend line indicates a positive value at the y intercept on all the operator result charts. This would further support argument for calibration method evaluation.

Overall, the procedure requires further clarification and improvement in calibration and it is likely that the procedure would not be valid over the full test range.

1b)

Table 2(Appendix) provides hit-miss data for complimentary NDT methods used to inspect an aircraft component. The technicians were required to report defects detected or not on a location-by-location basis. Carry out a full POD analysis using the ROC method.

Location	Defect	Method 1	Method 2	Method 3
1	Y	1	0	1
2	Y	1	1	1
3	N	0	0	0
4	Y	1	1	1
5	N	1	0	0
6	Y	0	0	1
7	Y	0	0	1
8	N	0	0	0
9	N	1	0	0
10	N	0	0	0
11	N	1	1	1
12	N	1	1	1
13	Y	0	1	1
14	N	0	0	0
15	N	0	0	0
16	Y	1	1	0
17	N	0	0	0
18	N	1	0	0
19	Y	1	0	1

True Positive (TP) – Flaw found, flaw present

False Positive (FP) – Flaw found, not flaw present

False Negative (FN) – No Flaw found, flaw present

True Negative (TN) – No Flaw found or present

Totals	Method 1	Method 2	Method 3
TP	5	4	7
FP	5	2	2
TN	6	9	9
FN	3	4	1

Probability of Detection (POD)

$$POD = \frac{\text{Total number of positive calls}}{\text{Total opportunities for rejection}} = \frac{TP}{TN + FN}$$

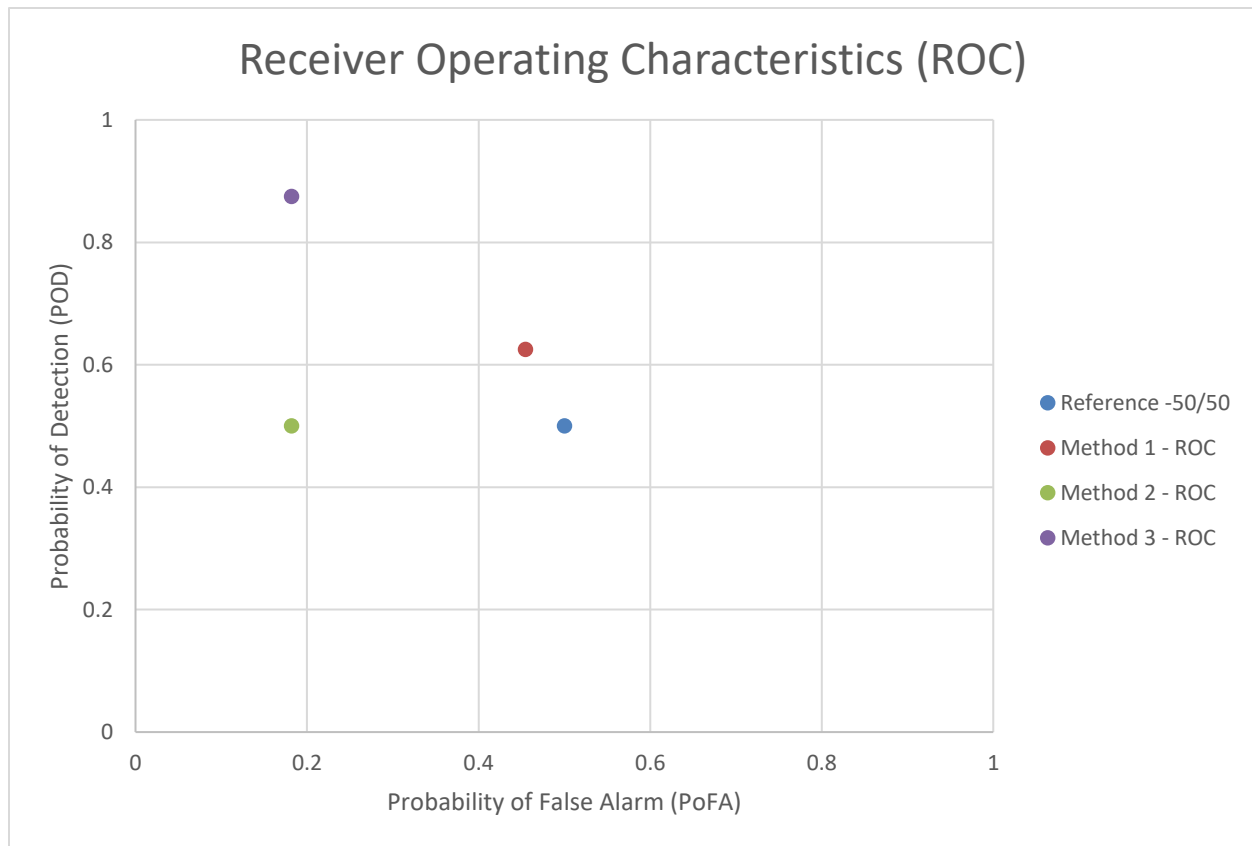
Probability of False Alarm (PoFA)

$$PoFA = \frac{\text{Total number of false positives}}{\text{Total opportunities for acceptance}} = \frac{FP}{TN + FP}$$

	Method 1	Method 2	Method 3
POD	0.625	0.5	0.875
PoFA	0.454545	0.181818	0.181818

Receiver Operating Characteristics (ROC)

POD and PoFA analysis plotted on a ROC diagram



The ROC diagram is a measure of reliability of an NDT method. An ideal test method would be represented as a step curve with a $POD = 1$, and $PoFA = 0$. A reference 50/50 test is added as a reference describing a method with a reliability of 50% and is considered as pure chance. The closer the method point is plotted to the ideal point demonstrates the chosen methods reliability.

Method 3, has the greatest reliability of the methods analysed, with the point plot on the ROC diagram closest to the ideal point. The values for POD and PoFA being 0.875 and 0.181818 respectively.

Methods 1 and 2 are not considered reliable.

2.0 Question 2

2a)

A micro-focus 2D x-ray inspection is to be undertaken on a rectangular (4mm x 6mm) CFRP plate of thickness 2mm. The source to detector distance is fixed at 0.25m and the digital detector is a 2D CCD array 4096 x 4096 pixels and dimensions 0.8mm x 0.8mm. The focal spot size of the x-ray tube is 30µm. A geometric unsharpness value (U_g) of better than 0.025mm is required. Calculate

CFRP plate 4mm x 6mm (rectangle) - 2mm (depth)

Detector 2D CCD 4096 x 4096 pixels (0.8m x 0.8m)

Focal spot size of x-ray tube 30µm.

Geometric sharpness (U_g) better than 0.025mm

f_1 ? (source to object distance)

f_2 0.25m (source to detector distance)

2a)i

The required source to object distance f_1

$$\frac{U_g}{U_f} = \frac{f_2 - f_1}{f_1}$$

$$f_1 = \frac{U_f (f_2 - f_1)}{U_g}$$

$$f_1 = f_2 \left(\frac{U_f}{U_g + U_f} \right)$$

$$f_1 = 0.25 \left(\frac{30 \times 10^{-6}}{25 \times 10^{-6} + 30 \times 10^{-6}} \right)$$

$$f_1 = 0.1364m$$

2a)ii

The dimensions of the imaged object in detector pixels

For magnification

$$\begin{aligned} \text{Magnification} &= \frac{f_1}{f_2} \\ &= \frac{0.25}{0.1364} \\ &= 1.8333 \end{aligned}$$

For object image size on detector

4mm dimension

$$\begin{aligned} \text{Image (4mm dimension)} &= 4 \times 1.8333 \\ &= 7.3333\text{mm} \end{aligned}$$

6mm dimension

$$\begin{aligned} \text{Image (6mm dimension)} &= 6 \times 1.8333 \\ &= 11\text{mm} \end{aligned}$$

Pixel density

$$\frac{800}{4096} = 0.1953 \text{ mm/pixel}$$

Object pixels at 7.33mm on detector (4mm dimension)

$$\text{pixels} = \frac{7.3333}{0.1953}$$

$$pixels = 37.55px$$

Object pixels at 11mm on detector (6mm dimension)

$$pixels = \frac{11}{0.1953}$$

$$pixels = 56.32px$$

Dimension of imaged object in detector pixels

$$37.55 \times 56.32 \text{ pixels}$$

2a)iii

The system measurement accuracy in pixels

$$\text{Measurement accuracy} = \frac{\text{Object size}}{\text{Number of pixels}}$$

For 4mm dimension

$$\text{measurement accuracy} = \frac{4}{37.55}$$

$$= 0.1065\text{mm}$$

For 6mm dimension

$$\text{measurement accuracy} = \frac{6}{56.32}$$

$$= 0.1065\text{mm}$$

The system measurement accuracy is >0.1mm per pixel

2b)

The intensity of an unshielded I-131 source is 140mR/hr. Determine the thickness of lead that is required to reduce this radiation down to 92nR/hr. Assume your distance from the source has not changed. The HVL of lead for I-131 is 0.178cm.

Intensity of unshielded I-131 source – 140mR/hr

Required intensity after shielding – 92nR/hr

HVL of lead for I-131 – 0.178cm

Distance to source does not change

Determine thickness of lead (x)

$$HVL = \frac{-\ln 0.5}{\mu}$$

$$\mu = \frac{-\ln 0.5}{HVL}$$

$$= \frac{-\ln 0.5}{0.178}$$

$$\mu = 3.894 \text{ cm}^{-1}$$

$$I_x = I_o e^{-\mu x}$$

$$\ln \frac{I_x}{I_o} = -\mu x$$

$$x = \frac{\ln \left(\frac{I_x}{I_o} \right)}{-\mu}$$

$$= \frac{\ln \left(\frac{92 \times 10^{-9}}{140 \times 10^{-3}} \right)}{-3.894}$$

$$x = 3.656 \text{ cm}$$

2c)

A technician is in an area for 35 minutes and the reading on an exposure meter is 0.75mR/hr. Determine the actual radiation dose received by the technician.

Duration – 35 minutes

Exposure – 0.75mR/hr

$$Dose(R) = \frac{0.75 \times 10^{-3}}{60} \times 35$$

$$= 4.375 \times 10^{-4} R$$

$$= 0.4375 \text{ mR}$$

2d)

The technician should not receive a radiation dose greater than 1.5mR. Based upon the conditions in c) determine the maximum time the technician can stay in the area.

Maximum dose – 1.5mR

$$time \text{ (minutes)} = \frac{1.5}{0.75} \times 60$$

$$= 120 \text{ minutes}$$

2e)

For an x-ray tube voltage of 90kV determine

2e)i

The maximum electron kinetic energy

Electron charge – $q_e = 1.6 \times 10^{-19} \text{C}$

$$U = q_e V_t$$
$$= 1.6 \times 10^{-19} \times 90 \times 10^3$$

$$= 1.44 \times 10^{-14} \text{J}$$

2e)ii

λ_{swl} (short wavelength limit) value for the breaking radiation process

Planck constant – $h = 6.63 \times 10^{-34} \text{J.s}$

Speed of light – $c = 3 \times 10^8 \text{m/s}$

$$\lambda_{swl} = \frac{hc}{q_e V_t}$$

$$= \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{1.6 \times 10^{-19} \times 90 \times 10^3}$$

$$\lambda_{swl} = 1.381 \times 10^{-11} \text{m}$$
$$= 13.81 \text{ pm}$$

2f)

An X-Ray tube has a copper anode with K, L and M electron shell binding energy levels of 8.98, 0.93 and 0.07 KeV respectively. Determine the wavelengths at which the K_α and K_β characteristic radiation lines would occur.

K – 8.98 KeV

L – 0.93 KeV

M – 0.07 KeV

For K_α

$$L \rightarrow M = k_\alpha = 8.05 K_e V$$

$$\begin{aligned}\lambda &= \frac{hc}{q_e V} \\ &= \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{1.6 \times 10^{-19} \times 8.05 \times 10^3}\end{aligned}$$

$$\begin{aligned}\lambda &= 1.544 \times 10^{-10} m \\ &= 154.43 pm\end{aligned}$$

For K_β

$$M \rightarrow K = k_\beta = 8.91 K_e V$$

$$\begin{aligned}\lambda &= \frac{hc}{q_e V} \\ &= \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{1.6 \times 10^{-19} \times 8.91 \times 10^3}\end{aligned}$$

$$\begin{aligned}\lambda &= 1.395 \times 10^{-10} m \\ &= 139.52 pm\end{aligned}$$

3.0 Question 3

3a)

With reference to induced eddy currents in a conductor, explain the skin effect and effective depth of penetration.

Skin effect – Eddy currents traveling parallel into an object under test from the winding of a coil probe concentrate near the material surface, the eddy current density decreased exponentially with depth and is known as the skin effect. The skin effect is caused by magnetic fields which are generated within the material by the eddy current, which oppose the primary field, this causes a decrease in current flow as the net magnetic flux decreases with an increase in depth.

Effective depth of penetration – This is considered as the depth within a material beyond which the effects of eddy currents can no longer be utilised for testing by a given system. For flaw detection a frequency should be used which places the defect within the depth known as 'one standard depth of penetration'. The standard depth of penetration is described as the depth where the eddy current density has diminished to $1/e$, or approximately 37% of that at the surface. The eddy current penetrates deeper into the material than one standard depth of penetration, however the density decreased rapidly with increasing depth. The frequency of the eddy current has a direct effect on conductivity and permeability within the material. High frequencies resulting in high conductivity and permeability, conversely, low frequencies result in low conductivity and permeability. Eddy current frequencies in the range of three times the standard depth of penetration are used when assessing material conductivity as changes in the material thickness at the far side will not effect the eddy current measurement due to the diminished eddy current.

3b)

Explain the effects of shielding on an eddy current coil

Shielding of the probe coil in eddy current testing is used to prevent or reduce the interaction of the probes magnetic field with non-relevant features near the probe. The shielding methods commonly utilised are eddy current shielding or magnetic shielding.

Eddy current shielding – A ring of non-magnetic highly conductive material, typically copper, surrounds the coil. Where the magnetic fields generated by the coil pass through the shielding material, eddy currents are generated in the shielding material and not in the non-relevant features outside of the shielding area. The shielding is more effective when a higher frequency is used due to the skin effect of the shielding material.

Magnetic shielding – A ring of ferrite or other material with high permeability and low conductivity surrounds the coil. An area of low magnetic reluctance is created by the ferrite surrounding the coil, this concentrates the probes magnetic field about the coil, thereby stopping the field from generating eddy currents in the non-relevant features.

3c)

A test coil is used to inspect an aluminum component 0.5mm in thickness. Assuming 0.15mm as the standard depth of penetration required and that the conductivity of aluminum is 64.94 %IACS:

3c)i

Calculate the required test frequency.

$$\delta_{mm} \approx \frac{661}{\sqrt{f\mu_r\sigma}}$$

$$f \approx \left(\frac{661}{\delta_{mm}}\right)^2 \times \frac{1}{\mu_r\sigma}$$

$$f \approx \left(\frac{661}{0.15}\right)^2 \times \frac{1}{1 \times 64.94}$$

$$f \approx 299025.43Hz$$

$$\approx 299.025KHz$$

3c)ii

What would be the maximum phase difference between the induced near and far-surface eddy currents?

$$\theta = \frac{x}{\delta} \times 57.3$$

Induced far surface

$$\theta = \frac{0.5}{0.15} \times 57.3$$

$$\theta = 191^\circ$$

Maximum phase difference

$$\theta = 191^\circ$$

3c)iii

If we were to increase the test frequency by an order of 2, what would the effects be regarding the depth of penetration and near and far surface phase differences?

Depth of penetration

$$\delta_{mm} \approx \frac{661}{\sqrt{f\mu_r\sigma}}$$

$$\delta_{mm} \approx \frac{661}{\sqrt{2 \times 299.025 \times 10^3 \times 1 \times 64.94}}$$

$$\delta_{mm} \approx 0.106mm$$

The increase in frequency results in a reduction in the depth of penetration.

Near and far surface phase difference

Induced far surface

$$\theta = \frac{0.5}{0.106} \times 57.3$$

$$\theta = 270.11^\circ$$

Maximum phase difference

$$\theta = 270.11^\circ$$

The increase in frequency results in an increase in the phase difference between the near and far surfaces.

Appendix

Table 1. For use with Question 1

		Operator 1		Operator 2		Operator 3		Operator 4		Operator 5		Operator 6		Operator 7		Operator 8		Operator 9		Operator 10	
Defect	true size	Estimate	Error	Estimate	Error	Estimate	Error	Estimate	Error	Estimate	Error	Estimate	Error	Estimate	Error	Estimate	Error	Estimate	Error	Estimate	Error
1	0.250	0.400	-0.150	0.500	-0.250	0.000	0.250	0.500	-0.250	0.000	0.250	1.000	-0.750	0.500	-0.250	1.000	-0.750	0.800	-0.550	0.495	-0.245
2	0.270	1.000	-0.730	1.200	-0.930	0.500	-0.230	1.000	-0.730	0.000	0.270	1.000	-0.730	0.500	-0.230	1.000	-0.730	0.800	-0.530	0.727	-0.457
3	0.280	0.800	-0.520	1.000	-0.720	1.200	-0.920	0.500	-0.220	0.000	0.280	1.000	-0.720	0.500	-0.220	1.000	-0.720	1.300	-1.020	0.758	-0.478
4	0.400	0.900	-0.500	0.500	-0.100	1.000	-0.600	1.000	-0.600	1.000	-0.600	1.200	-0.800	0.600	-0.200	1.000	-0.600	1.500	-1.100	0.910	-0.510
5	0.400	0.800	-0.400	1.200	-0.800	1.000	-0.600	1.200	-0.800	1.000	-0.600	1.400	-1.000	0.200	0.200	1.000	-0.600	1.600	-1.200	0.980	-0.580
6	0.500	0.400	0.100	0.900	-0.400	1.000	-0.500	0.800	-0.300	1.000	-0.500	1.100	-0.600	0.000	0.500	1.200	-0.700	1.000	-0.500	0.790	-0.290
7	0.520	0.700	-0.180	1.500	-0.980	1.100	-0.580	1.000	-0.480	1.500	-0.980	0.900	-0.380	1.000	-0.480	1.000	-0.480	0.900	-0.380	1.012	-0.492
8	0.550	0.500	0.050	1.200	-0.650	0.800	-0.250	1.200	-0.650	0.900	-0.350	0.500	0.050	1.300	-0.750	1.000	-0.450	1.600	-1.050	0.955	-0.405
9	0.700	1.200	-0.500	1.500	-0.800	0.900	-0.200	1.000	-0.300	1.600	-0.900	2.000	-1.300	1.600	-0.900	1.000	-0.300	2.000	-1.300	1.350	-0.650
10	0.980	1.500	-0.520	1.000	-0.020	0.800	0.180	1.600	-0.620	2.000	-1.020	1.900	-0.920	0.500	0.480	1.000	-0.020	1.800	-0.820	1.308	-0.328
11	1.120	1.200	-0.080	0.500	0.620	1.000	0.120	1.800	-0.680	1.800	-0.680	1.000	0.120	1.800	-0.680	1.500	-0.380	2.000	-0.880	1.372	-0.252
12	1.150	1.500	-0.350	1.800	-0.650	1.300	-0.150	1.500	-0.350	1.000	0.150	2.000	-0.850	1.800	-0.650	1.500	-0.350	2.000	-0.850	1.555	-0.405
13	1.100	1.700	-0.600	2.000	-0.900	1.400	-0.300	1.500	-0.400	1.600	-0.500	2.000	-0.900	0.500	0.500	2.000	-0.900	2.200	-1.100	1.600	-0.500
14	1.300	1.800	-0.500	2.100	-0.800	0.900	0.400	2.000	-0.700	2.000	-0.700	2.000	-0.700	1.700	-0.400	1.500	-0.200	2.000	-0.700	1.730	-0.430
15	1.600	1.400	0.200	0.800	0.800	0.900	0.700	1.500	0.100	2.000	-0.400	2.200	-0.600	1.200	0.400	2.000	-0.400	2.000	-0.400	1.560	0.040
16	1.800	1.300	0.500	2.000	-0.200	1.400	0.400	3.200	-1.400	2.000	-0.200	2.500	-0.700	2.200	-0.400	2.500	-0.700	2.500	-0.700	2.140	-0.340
17	2.100	2.500	-0.400	1.800	0.300	2.300	-0.200	3.000	-0.900	2.500	-0.400	3.500	-1.400	2.000	0.100	2.000	0.100	3.200	-1.100	2.490	-0.390
18	2.700	2.500	0.200	3.000	-0.300	3.200	-0.500	3.500	-0.800	2.500	0.200	2.800	-0.100	2.500	0.200	3.500	-0.800	3.500	-0.800	2.970	-0.270
19	4.900	5.500	-0.600	4.500	0.400	4.500	0.400	4.000	0.900	4.500	0.400	5.700	-0.800	4.200	0.700	5.500	-0.600	5.400	-0.500	4.870	0.030
20	6.000	6.500	-0.500	5.500	0.500	6.200	-0.200	5.500	0.500	6.500	-0.500	7.000	-1.000	5.300	0.700	6.500	-0.500	6.700	-0.700	6.170	-0.170
21	7.500	6.500	1.000	6.000	1.500	6.250	1.250	7.000	0.500	7.200	0.300	8.000	-0.500	6.500	1.000	8.000	-0.500	6.900	0.600	6.985	0.515
		σ	0.429	σ	0.676	σ	0.514	σ	0.531	σ	0.461	σ	0.382	σ	0.551	σ	0.254	σ	0.411	σ	0.258
		$\pm 95\%$	0.841	$\pm 95\%$	1.325	$\pm 95\%$	1.007	$\pm 95\%$	1.041	$\pm 95\%$	0.903	$\pm 95\%$	0.749	$\pm 95\%$	1.081	$\pm 95\%$	0.498	$\pm 95\%$	0.805	$\pm 95\%$	0.506

Figure 1 – For use with Question 1.

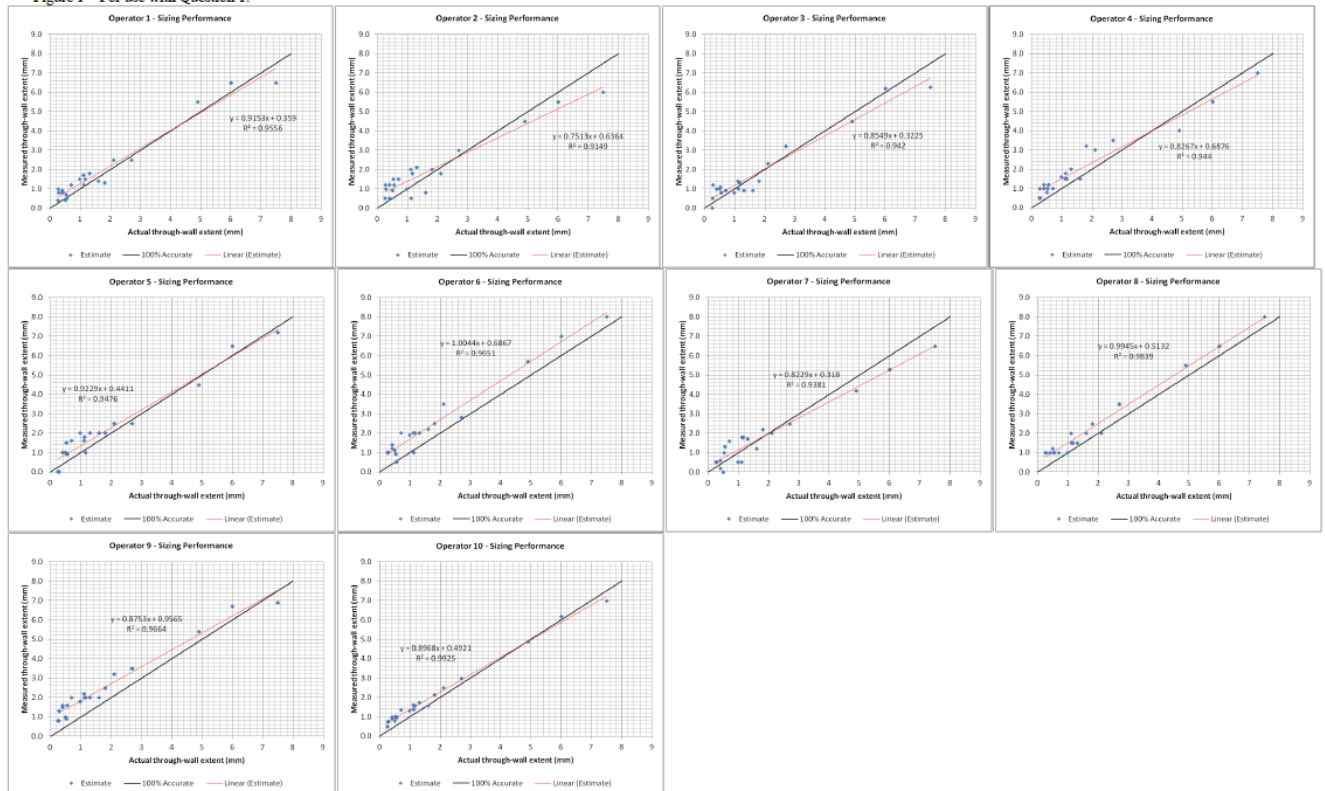


Table 2. For use with Question 2.

Location	Defect	Method 1	Method 2	Method 3
1	Y	1	0	1
2	Y	1	1	1
3	N	0	0	0
4	Y	1	1	1
5	N	1	0	0
6	Y	0	0	1
7	Y	0	0	1
8	N	0	0	0
9	N	1	0	0
10	N	0	0	0
11	N	1	1	1
12	N	1	1	1
13	Y	0	1	1
14	N	0	0	0
15	N	0	0	0
16	Y	1	1	0
17	N	0	0	0
18	N	1	0	0
19	Y	1	0	1