

ULTRASONIC ATTENUATION
COEFFICIENT DETERMINATION AND
PROBABILITY OF SIZING ANALYSIS

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MSC. MOTORSPORT ENGINEERING

MODULE: STRUCTURAL INTEGRITY AND MATERIAL EVALUATION

MODULE CODE: ACEA7013

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PART 1: ULTRASONIC ATTENUATION COEFFICIENT DETERMINATION

1. ABSTRACT

The attenuation coefficient of two sample materials, a mild steel rectangular block and a brake disc, are determined using time of flight methods. This is done using an ultrasonic zero-degree 5MHz probe along with an ultrasonic flaw detector. The amplitudes of the ultrasonic waves used are determined using the ultrasonic flaw detector along with the thickness of the sample material and these are then put into the formula for attenuation coefficient. This process is repeated for multiple positions and the average of the attenuation coefficients achieved is considered to be the final value. The final attenuation coefficient achieved for the mild steel rectangular block was -0.10402 mm^{-1} and that of the brake disc was -0.47185 mm^{-1} .

2. APPARATUS

The apparatus used to complete this experiment were:

1. A mild steel rectangular block
2. A brake disc
3. An ultrasonic, zero-degree 5 MHz probe
4. An ultrasonic flaw detector
5. Vernier calliper

3. INTRODUCTION

The term attenuation coefficient can be defined as the measure of easiness of an incident energy beam, such as ultrasound or x-ray, by which it can penetrate through a material (Deng, 2019). It is the quantitative measure of how much the beam of energy is weakened upon passing through the material.

In this experiment, we aim to determine the material attenuation coefficients of two individual specimen. The first one is a rectangular block made of mild steel (Botvina et

al.,2016) and the other one is a brake disc. The attenuation coefficients are determined using time of flight method of ultrasonic flaw detection (Willcox and Downes, 2003). This is achieved using an ultrasonic zero-degree 5MHz probe (Rubbers and Pritchard, 2005) which is connected to an ultrasonic flaw detector, which can be seen in Fig.1.

4. PROCEDURE

Firstly, the specimens are measured for their thickness. This is done using a vernier calliper. The thickness of the rectangular mild steel block is measured to be 19.3 mm and that of the brake disc to be 12.6 mm. Then, both the specimen are wiped and cleaned to make sure that there are no unwanted impurities like dust on the surface of the specimen. Next, ultrasound gel is added to the surface of the specimen, which acts as a coupling medium between the probe and the specimen. This is done in order to allow the ultrasound waves to pass directly into the specimen without being intervened and reflecting off air.

The ultrasonic flaw detector is then turned on. The frequency is set to 5MHz as we are using a 5MHz probe.

Firstly, the mild steel rectangular block is taken. The gain used for this is 15. The probe is then placed onto the specimen with gel and the amplitudes of the waves shown in the ultrasonic flaw detector are noted. This is done again at different positions of the block to attain three sets of values. The values for the same are shown in Table 1. Similarly, the process is repeated for the brake disc. For the brake disc, the gain value is set to 28 and the amplitudes are measured at five different positions. The thickness of the specimen for each position was found to be same. The wave amplitudes for all the positions of the brake disc are shown in Table 2.

5. TABLES AND FIGURES

Table 1: Wave amplitudes for mild steel rectangular block

Amplitudes	A1	A2	A3
Position 1	92	49	32
Position 2	78	45	30
Position 3	60	40	28

Table 2: Wave amplitudes for brake disc

Amplitudes	A1	A2	A3
Position 1	97	24	7
Position 2	99	24	7
Position 3	90	19	5
Position 4	80	17	5
Position 5	93	23	6

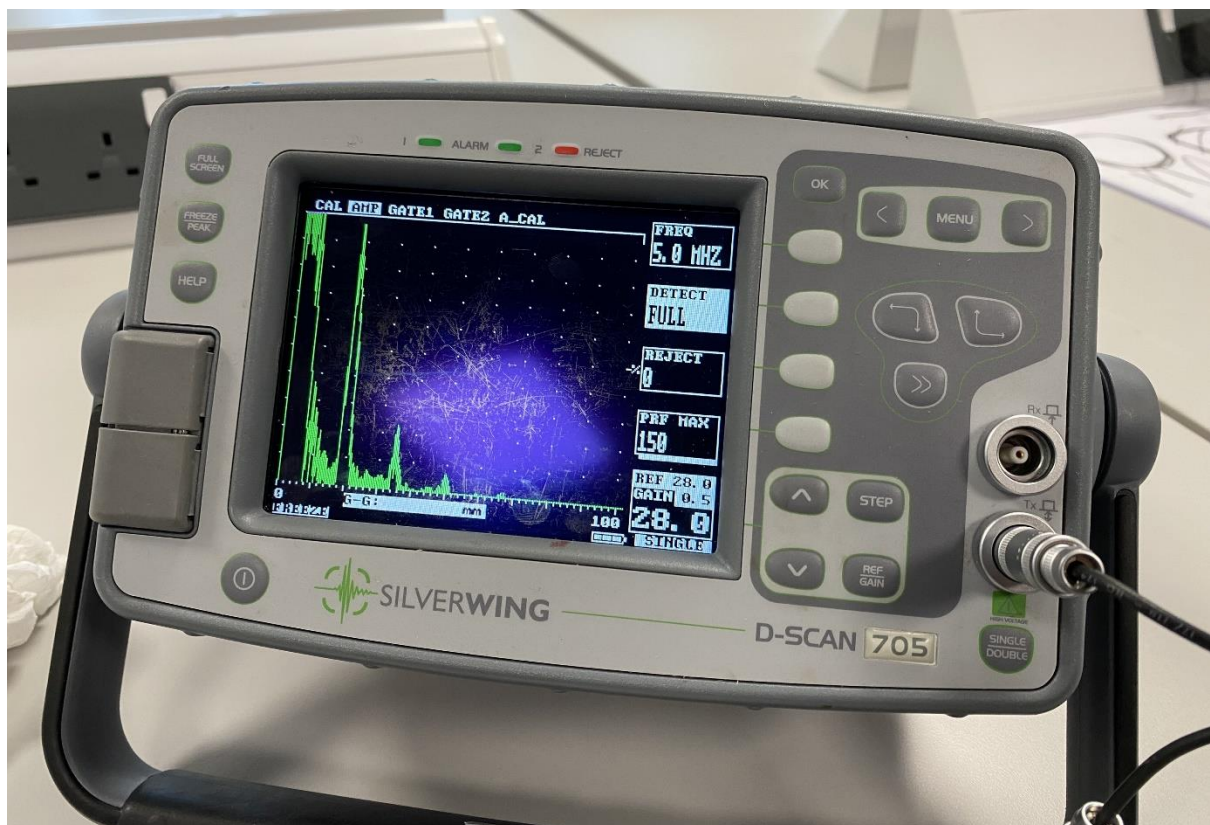


Fig. 1: Ultrasonic Flaw Detector

6. CALCULATIONS AND ERROR ESTIMATES

6.1 Calculations

Attenuation coefficient is given by-

$$\alpha_{dB/mm} = (20/t) * \log(A2/A1)$$

where, $t = 2 * \text{thickness}$ for consecutive wave amplitudes

and $t = 4 * \text{thickness}$ for alternate wave amplitudes.

We need to use this formula for all the amplitudes at a position and calculate the average attenuation coefficient for the position and repeat the same for all positions of the specimen and take the average of all the averages.

For example, taking the case of the mild steel rectangular block, assuming $\alpha_{dB/mm1}$ as the average attenuation coefficient of position 1, where thickness = 19.3 mm, $A1 = 92$, $A2 = 49$, $A3 = 32$,

$$\alpha_{dB/mm11} = (20/2 * 19.3) * \log(49/92) = -0.14176 \text{ mm}^{-1}$$

$$\alpha_{dB/mm12} = (20/2 * 19.3) * \log(32/49) = -0.09585 \text{ mm}^{-1}$$

$$\alpha_{dB/mm13} = (20/4 * 19.3) * \log(32/92) = -0.11881 \text{ mm}^{-1}$$

Therefore, $\alpha_{dB/mm1} = -0.11881 \text{ mm}^{-1}$

Similarly, attenuation coefficients of position2 and position 3 were found to be $\alpha_{dB/mm2} = -0.1075 \text{ mm}^{-1}$ and $\alpha_{dB/mm3} = -0.08575 \text{ mm}^{-1}$ respectively.

Therefore, attenuation coefficient of the mild steel rectangular block is,

$$\alpha_{dB/mm1} = (\alpha_{dB/mm1} + \alpha_{dB/mm2} + \alpha_{dB/mm3})/3 = -0.10402 \text{ mm}^{-1}$$

Similarly, the attenuation coefficient for the brake disc is calculated as well.

6.2 Errors

While trying to determine the attenuation coefficient the sample materials, there are chances of error. These errors may be caused due to multiple reason. The most likely type of error is human error. In this experiment, there are possibilities of human error during the use of vernier callipers for measuring the thickness of the sample materials or even while trying the determine the amplitudes of the waves. It is also likely that the probe was not being held properly or enough gel was not added to the sample materials before taking the readings. It is very important to be precise during every step of the experiment in order to minimize or even completely remove human error.

The other possible source of error is the use of faulty equipment. It is important to ensure that all the equipments being used for the experiment function properly. We also need to keep in mind to calibrate the equipments properly in order to avoid getting faulty results.

7. RESULTS AND DISCUSSIONS

After making all the necessary calculations, the following results were achieved-

Attenuation coefficient of the mild steel rectangular block = -0.10402 mm^{-1}

Attenuation coefficient of the brake disc = -0.47185 mm^{-1}

8. CONCLUSIONS

In this experiment, we determined the attenuation coefficient of two sample materials, a mild steel rectangular block and a brake disc. Time of flight methods were used for the same. The attenuation coefficients were determined using an ultrasonic flaw detector and an ultrasonic zero-degree 5 MHz probe. This was done by measuring the amplitudes of the waves shown in the ultrasonic flaw detector along with the thickness of the sample materials and putting them into the formula for attenuation coefficient and taking averages of multiple readings. After following these steps, the attenuation coefficient of the steel rectangular block was determined to be -0.10402 mm^{-1} and that of the brake disc was determined to be -0.47185 mm^{-1} .

PART 2: THROUGH WALL SIZING ACCURACY ANALYSIS

1. ABSTRACT

With the use of probability of detection method, the performance of a new ultrasonic thickness gauging procedure was assessed. This was done on a specimen with twenty one defect measurements in total and was carried out by ten individual operators. The results obtained by each operator for each defect measured was tabulated and compared. Since the true sizes of the defects are known, the error in sizing by the operators are determined along with the mean and standard deviation of all the errors by each operator. The errors were then normalized and the normal distribution of the errors were represented in the form of histograms for each operator. Linear regression was used as well to visually assess the amount of deviation of the errors from the general trendline. In the end it was discovered that all the operators could be divided into four groups based on the amount of deviation in measuring the defects compared to their true sizes. The best group consisted of operator1 and operator9 with the least amount of deviation of 0.25mm and the worst group consisted of just one operator, i.e., operator2 with a deviation of 0.66mm. Operator4, operator5, operator8 and operator10 achieved deviation between 0.39mm and 0.45mm and operator3, operator6 and operator7 achieved deviation between 0.50mm to 0.54mm.

2. INTRODUCTION

Probability of detection (Wehling et al., 2011) is a statistical method which is used as a metric to describe the accuracy of a test. In non-destructive technique (NDT), it identifies how well defects can be detected. It is used to determine flaw size. Usually, there is a critical size. The critical size is the smallest size of flaw that can be detected. Any flaw which is smaller than the critical size may go undetected.

In this experiment, the performance of a new ultrasonic thickness gauging procedure was assessed. This was carried out by ten technicians using probability of detection method. The specimen had twenty one defects in total. Each of these defects were measured individually by every technician and then these were compared to the true size of the defect. The dimension in which all the measurements were taken was in millimeters.

In this paper, the terms technicians and operators are used interchangeably.

3. PROCEDURE

The method used in this paper is to use linear regression and statistical analysis. From the given excel datasheet, all the measurements are recorded individually for each operator along with the true sizes of the defects. This is done for all of the twenty one defects. Then for each defect, the error made in measuring the defects by the operator are noted down. For example, the true sizes of the defects are 0.25mm, 0.27mm, 0.28mm...and so on, the measurements taken by Operator1 were 0.50mm, 0.73mm, 0.76mm...etc. This gives errors of -0.25mm, -0.46, -0.48mm...and so on. This gives us the deviation of the measurements of the defects taken by the operator from its actual true size. Here, since we only need the amount of deviation from the true size and not its direction of deviation, absolute error of the measurement is considered. The mean of all the errors and the standard deviation are calculated as well.

Next, the errors are normalized and the normal distribution of the errors are represented in the form of histograms. This is done individually for each operator.

Linear regression was used as well, along with the use of histogram. In the linear regression, the true size of the defects is compared to that of the one calculated by the different operators. This is done individually for every operator to check the overall amount of deviation from the true size of each defect. Also, in the linear regression charts, the line of best fit or the trendline of the chart is drawn. In excel, the equation of this trendline can be easily obtained along with the value of the coefficient of determination (R^2). The value of the coefficient of determination gives the statistical measure of how much the variation of the dependent variables, the defects measured by the operators in this case, are explained the independent variables, the true sizes of the defects in this case, in a regression model.

Also, with the use of the equation of the trendline, the lines for the 95% confidence bands can be attained. This is done by adding and subtracting 95% of the standard deviation to the equation of the trendline. If all the data points remain inside the 95% confidence bands, the data is considered to be acceptable. Here, the trendlines are represented by blue dashed lines and the 95% confidence bands are represented using red and green dotted lines, orange for the upper limit and grey for the lower limit.

4. MEASUREMENTS AND GRAPHS

Below are the graphs obtained using spreadsheet. From Fig.1 to Fig.20, the normal distribution and the linear regression along with the trendline and 95% confidence bands are shown for each operator.

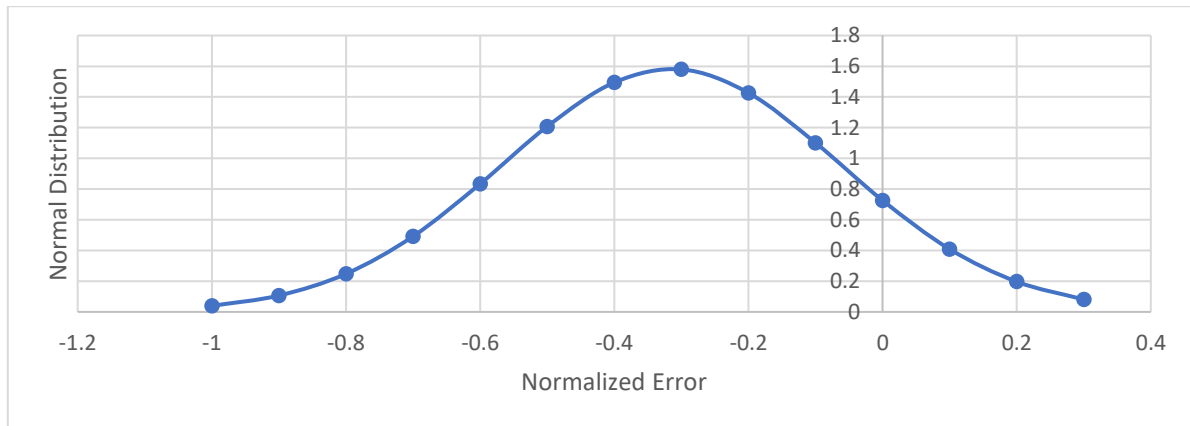


Fig.1: Normal Distribution of Errors by Operator1

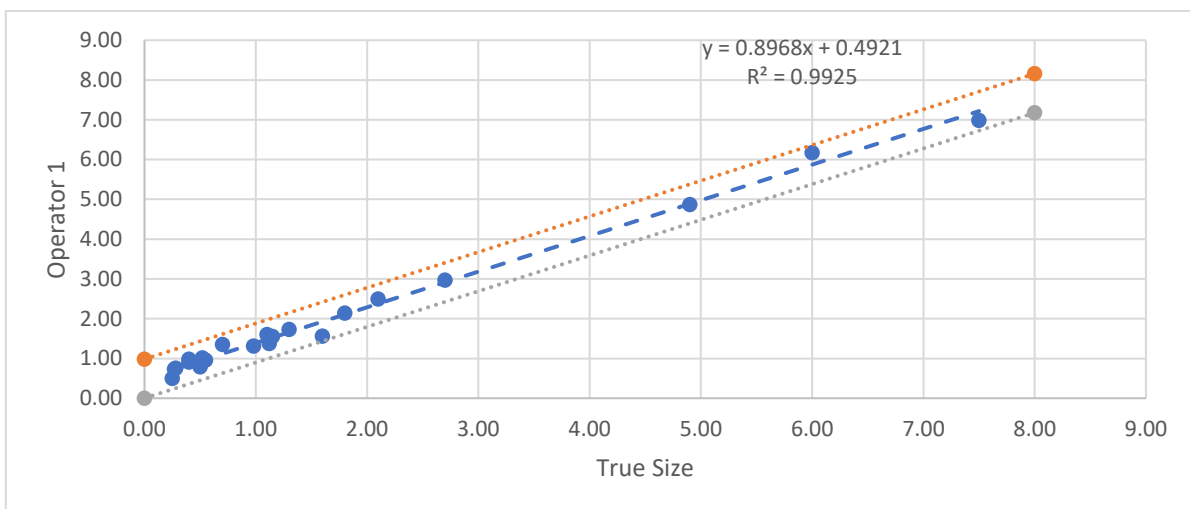


Fig.2: Linear Regression of Errors by Operator1

Here, it can be seen that for Operator1, the mean error is about -0.31mm and standard deviation is about 0.2mm. Also, all the errors were within the confidence bands of 95%.

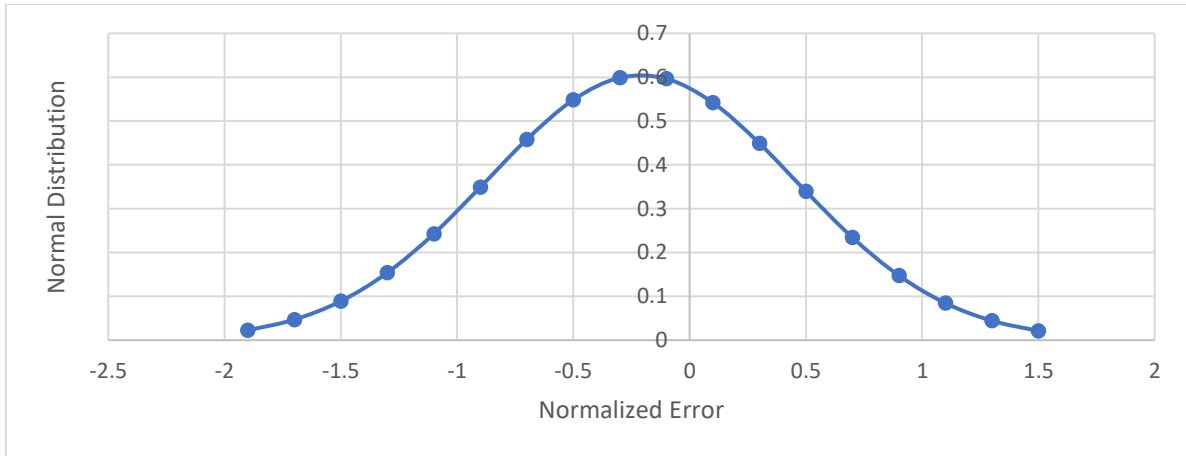


Fig.3: Normal Distribution of Errors by Operator2

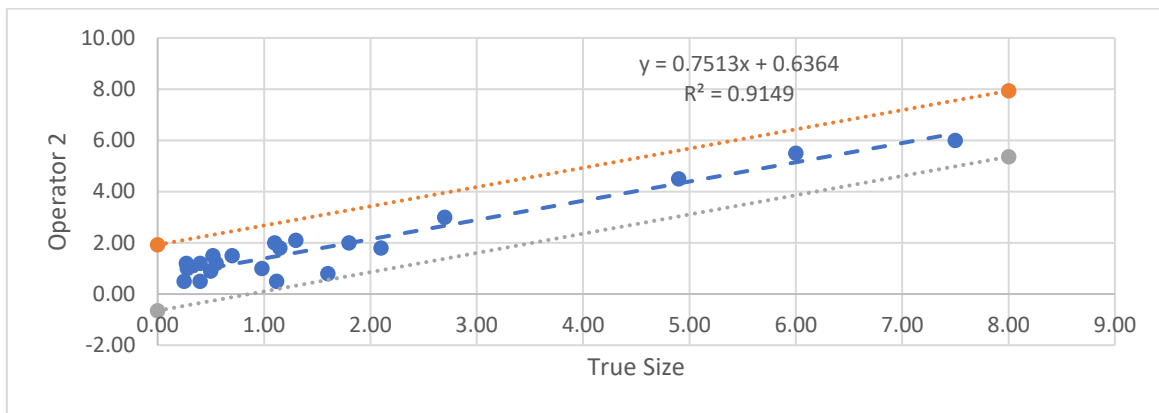


Fig.4: Linear Regression of Errors by Operator2

For Operator2, the mean error is about -0.21mm and standard deviation is about 0.66mm. Also, all the errors were within the confidence bands of 95%.

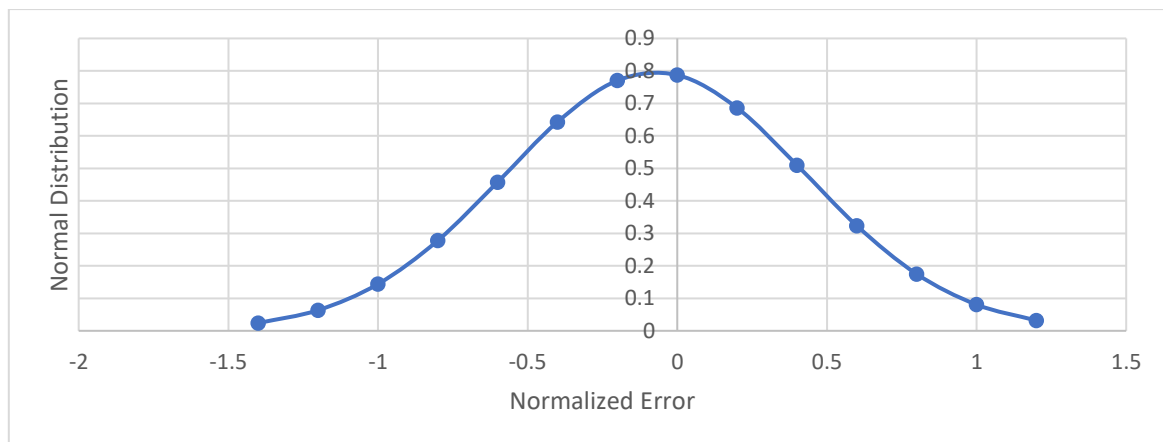


Fig.5: Normal Distribution of Errors by Operator3

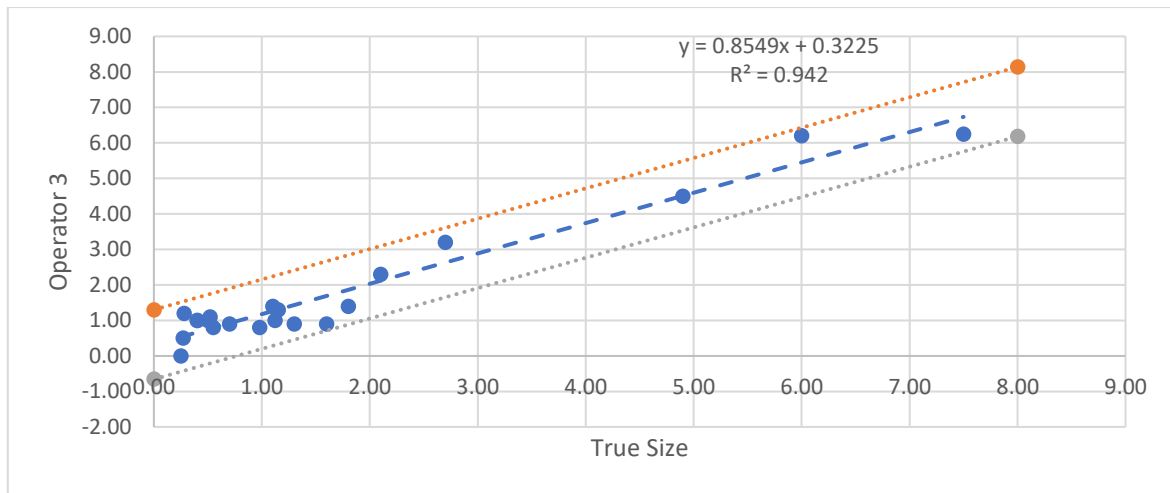


Fig.6: Linear Regression of Errors by Operator3

For Operator3, the mean error is about -0.07mm and standard deviation is about 0.50mm. Also, all the errors were within the confidence bands of 95%.

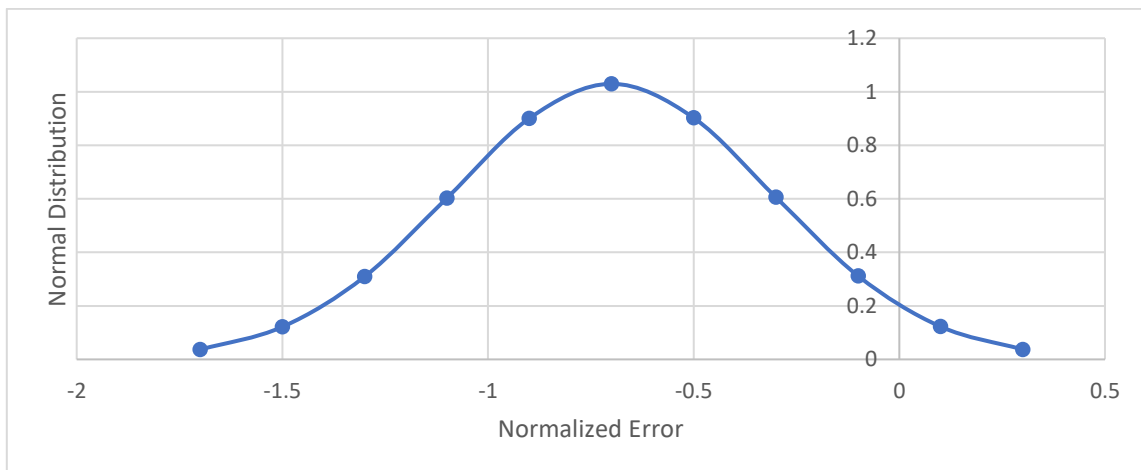


Fig.7: Normal Distribution of Errors by Operator4

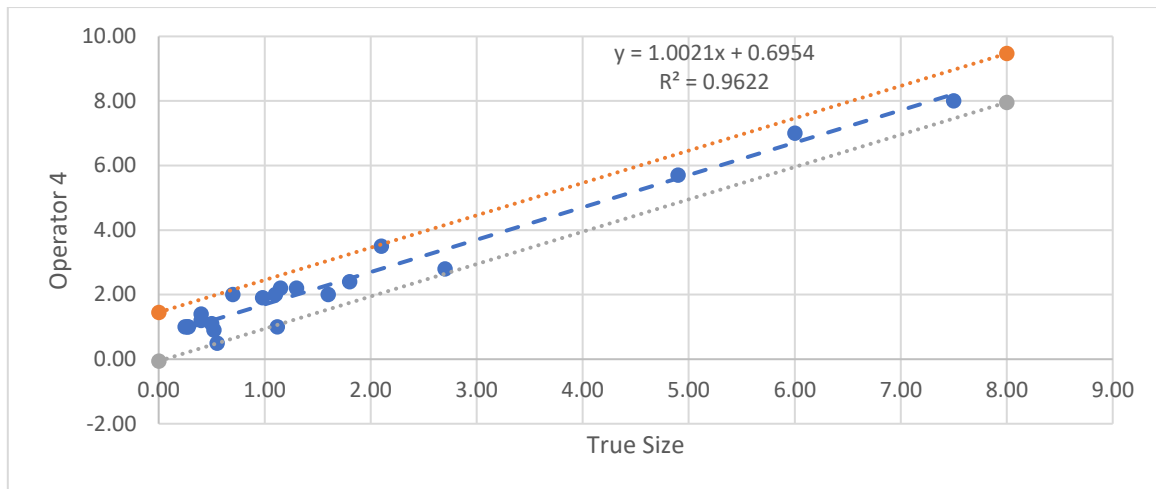


Fig.8: Linear Regression of Errors by Operator4

For Operator4, the mean error is about -0.70mm and standard deviation is about 0.93mm. Also, multiple errors were on the cusp of crossing the confidence bands of 95%.

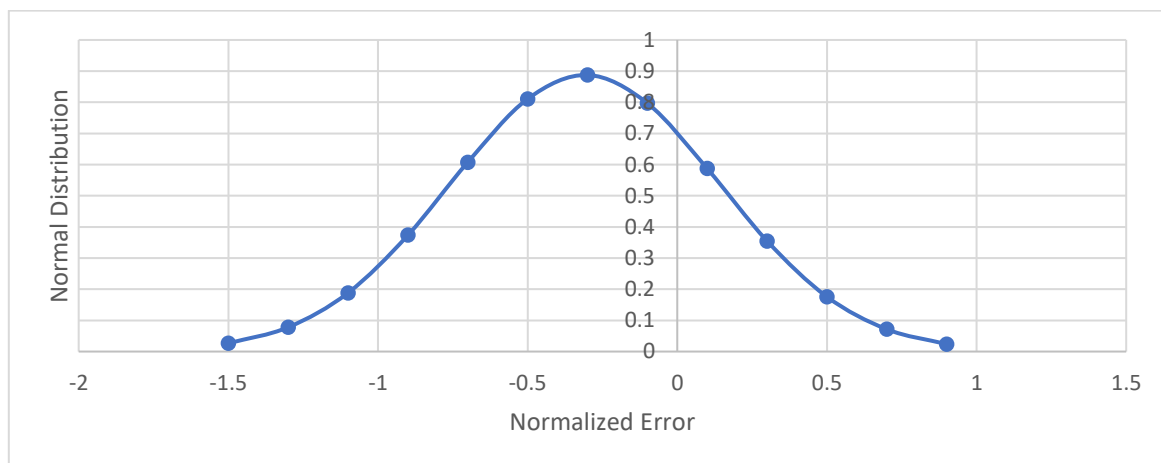


Fig.9: Normal Distribution of Errors by Operator5

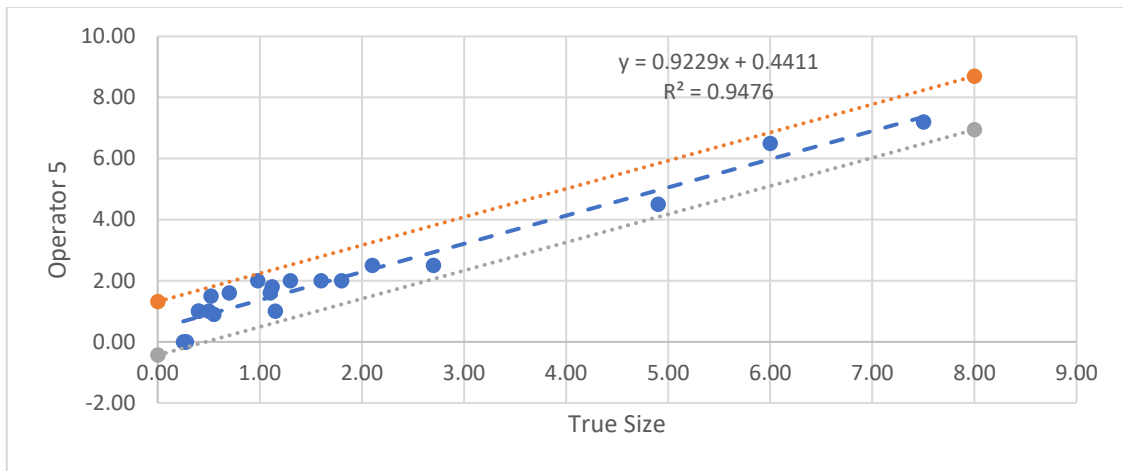


Fig.10: Linear Regression of Errors by Operator5

For Operator5, the mean error is about -0.31mm and standard deviation is about 0.45mm. Also, all the errors were within the confidence bands of 95%.

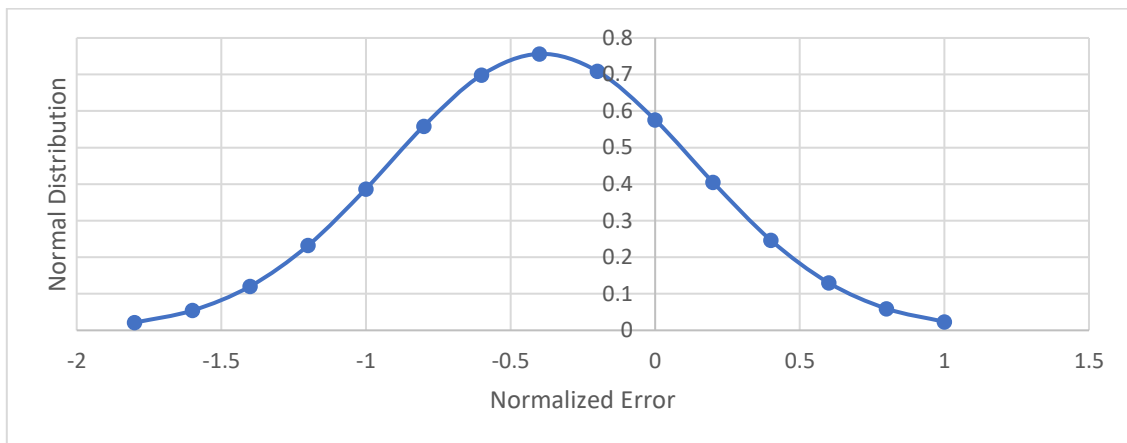


Fig.11: Normal Distribution of Errors by Operator6

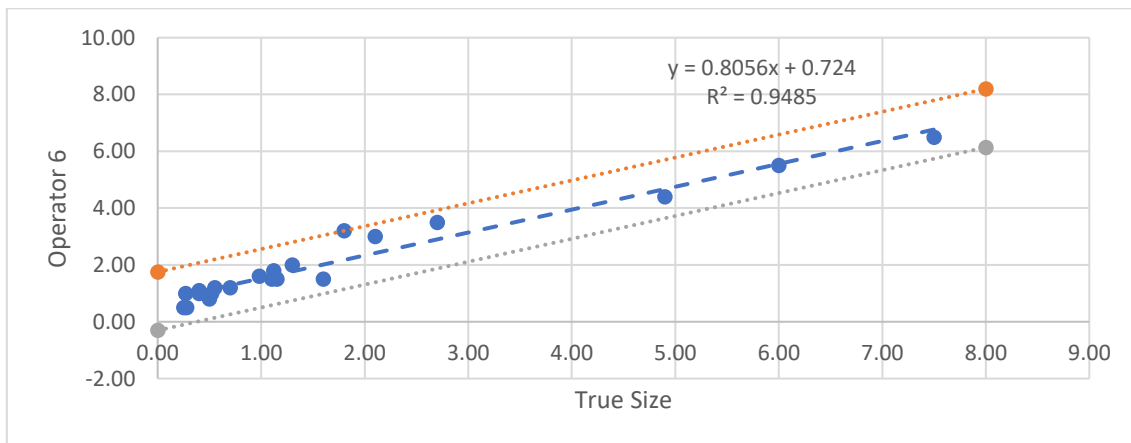


Fig.12: Linear Regression of Errors by Operator6

For Operator6, the mean error is about -0.39mm and standard deviation is about 0.53mm. Also, most defects measured were found to be close to the trendline but one of the measurements was over the confidence bands of 95%.

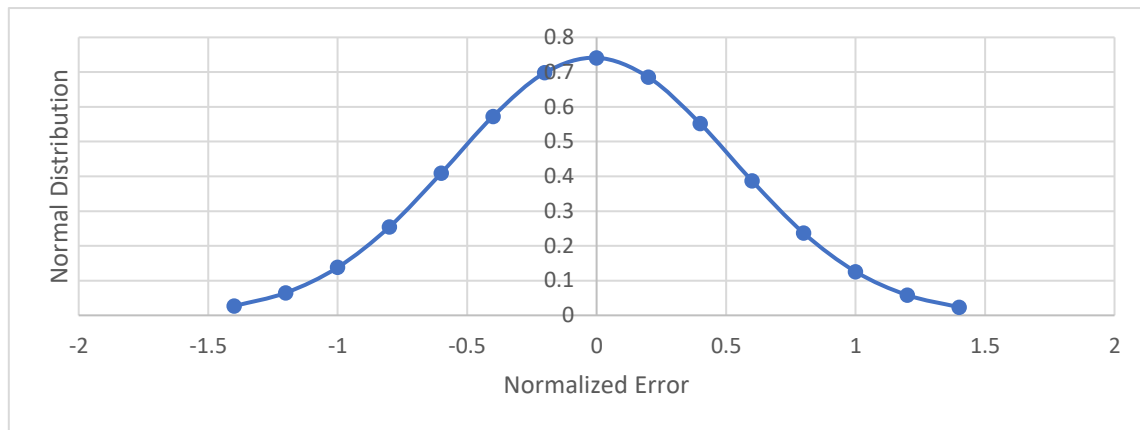


Fig.13: Normal Distribution of Errors by Operator

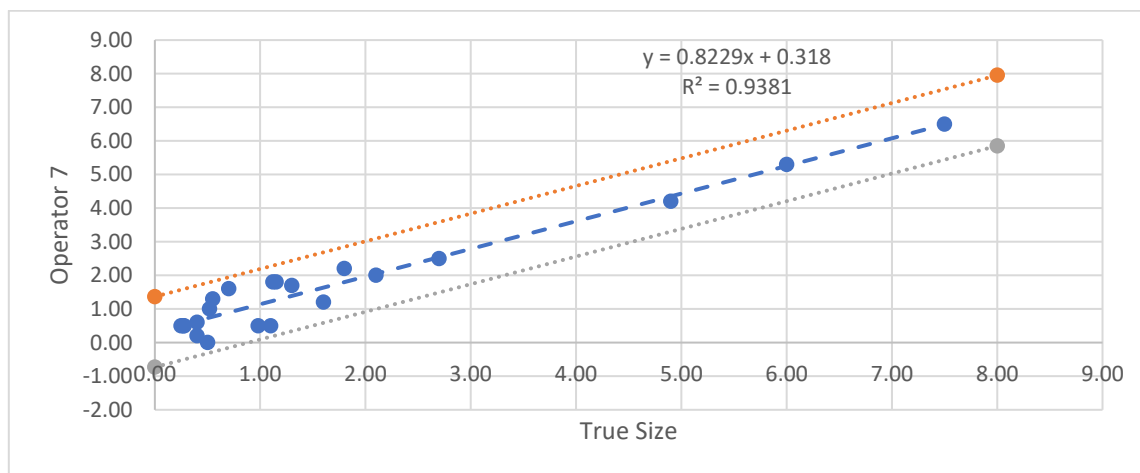


Fig.14: Linear Regression of Errors by Operator7

For Operator7, the mean error is about -0.01mm and standard deviation is about 0.54mm. Also, all the errors were within the confidence bands of 95%.

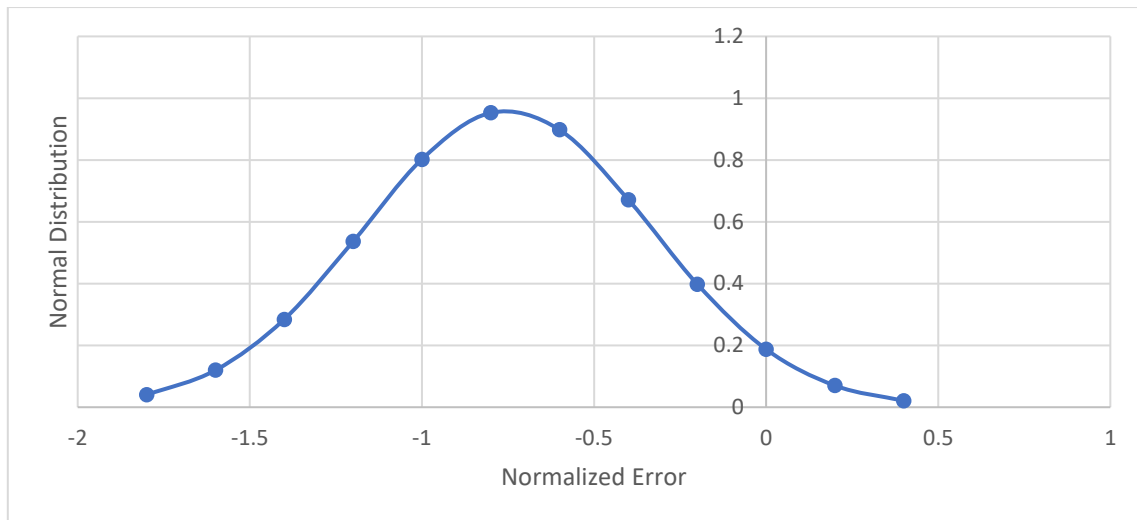


Fig.15: Normal Distribution of Errors by Operator8

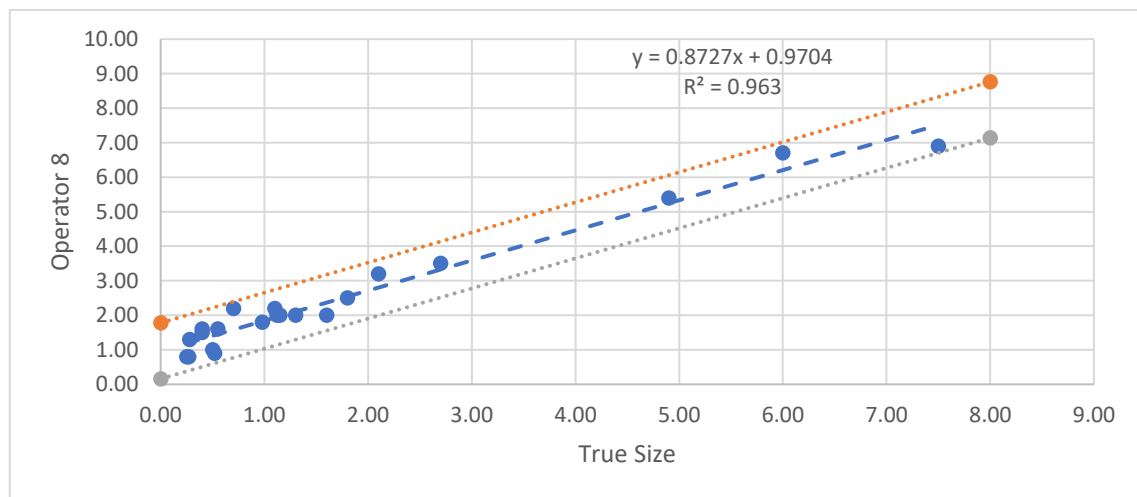


Fig.16: Linear Regression of Errors by Operator8

For Operator8, the mean error is about -0.75mm and standard deviation is about 0.42mm. Also, all the errors were within the confidence bands of 95%.

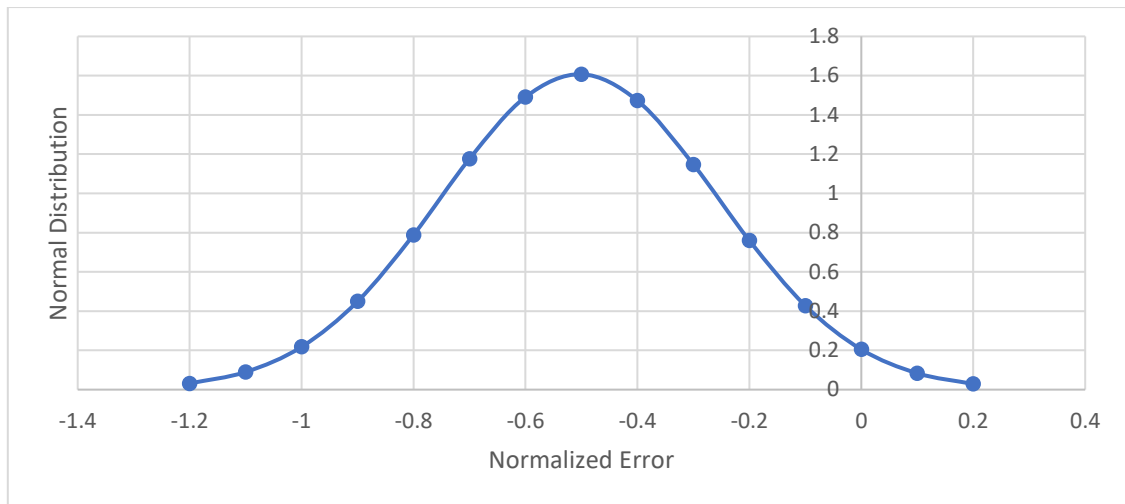


Fig.17: Normal Distribution of Errors by Operator9

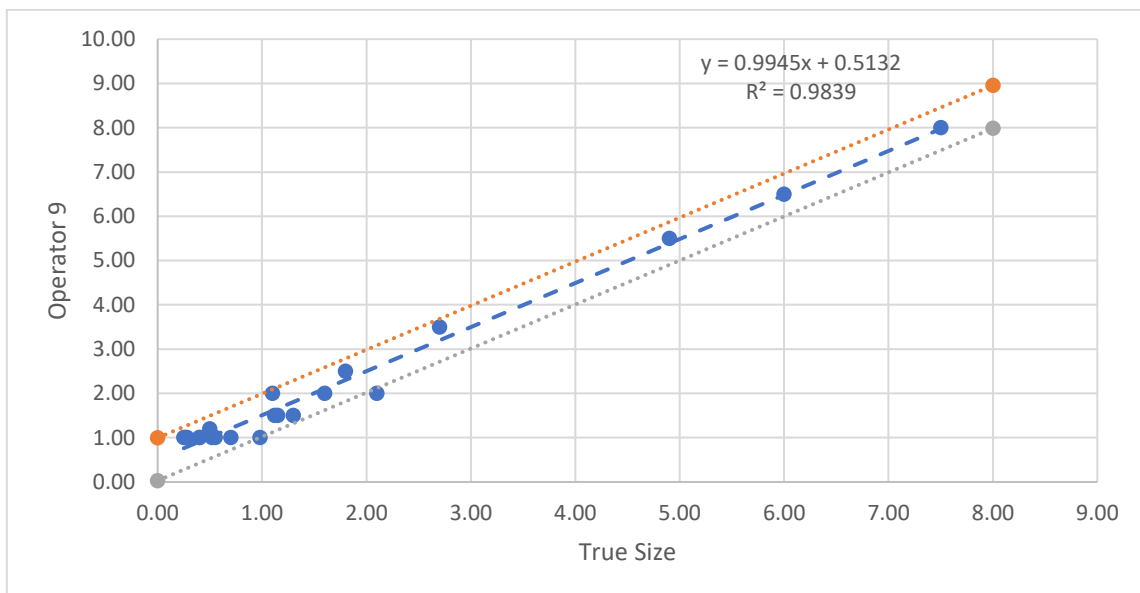


Fig.18: Linear Regression of Errors by Operator9

For Operator9, the mean error is about -0.50mm and standard deviation is about 0.25mm. Also, multiple errors were on the cusp of crossing the confidence bands of 95%.

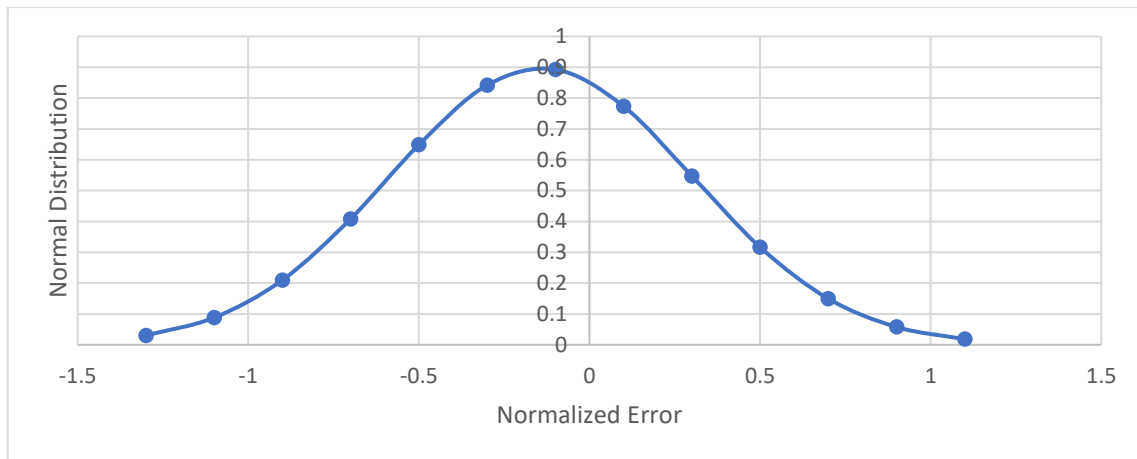


Fig.19: Normal Distribution of Errors by Operator10

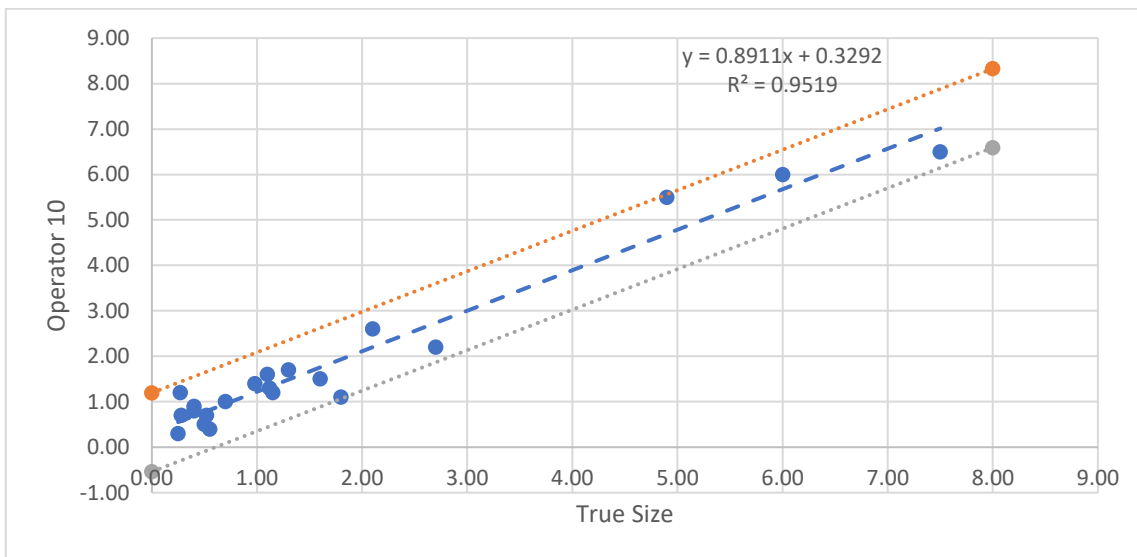


Fig.20: Linear Regression of Errors by Operator10

For Operator10, the mean error is about -0.14mm and standard deviation is about 0.44mm. Also, two measurements were on the cusp of crossing the confidence bands of 95%.

5. CALCULATIONS AND ERROR ESTIMATES

5.1 Calculating error

As we know the true sizes of the defects and the measurements of the defects by each of the operators, the difference between the true size and the measured value gives us the error in detecting the size of the defect.

For example, true size of defect 'A' is 0.25mm and the size measured by Operator1 was 0.50mm. So, the error in this case is $0.25 - 0.50 = -0.25\text{mm}$.

Also, we calculate the absolute error. This gives a defect size of 0.25mm.

5.2 Mean

Mean is the ratio of sum of all the terms and the total number of terms.

Mean = Sum of terms / Number of terms

For example, in this case we calculate the mean of the errors in measurement done by Operator 1.

Mean Op1 = $(-0.25 - 0.46 - 0.48 - 0.51 - 0.58 - 0.29 - 0.49 - 0.41 - 0.65 - 0.33 - 0.25 - 0.41 - 0.50 - 0.43 + 0.04 - 0.34 - 0.39 - 0.27 + 0.03 - 0.17 + 0.51) / 21 = -0.31\text{mm}$

5.3 Standard deviation

Standard deviation gives the amount of variation in a set of data. It is given by the formula:

$$\sigma = \sqrt{\frac{\sum (x_i - \mu)^2}{N}}$$

where, σ = Standard deviation

N = Number of terms

x_i = Each value of population (errors in this case)

μ = Mean

Here, we use this formula to calculate the standard deviation in the errors in measurement.

For example, $\sigma = \sqrt{[(1/21) * [(-0.25 - 0.31)^2 + (-0.46 - 0.31)^2 + (-0.48 - 0.31)^2 + (-0.51 - 0.31)^2 + (-0.58 - 0.31)^2 + (-0.29 - 0.31)^2 + (-0.49 - 0.31)^2 + (-0.41 - 0.31)^2 + (-0.65 - 0.31)^2 + (-0.33 - 0.31)^2 + (-0.25 - 0.31)^2 + (-0.41 - 0.31)^2 + (-0.50 - 0.31)^2 + (-0.43 - 0.31)^2 + (0.04 - 0.31)^2 + (-0.34 - 0.31)^2 + (-0.39 - 0.31)^2 + (-0.27 - 0.31)^2 + (0.03 - 0.31)^2 + (-0.17 - 0.31)^2 + (-0.51 - 0.31)^2]]}$
= 0.25mm

5.4 Errors

While performing the experiment and during calculations, there are chances of errors to occur. These errors may be caused due to multiple reasons. Firstly, it is necessary to ensure that all the equipment and apparatus used to carry out the experiment were functioning properly. If they functioned properly as expected, there is also the possibility of the apparatus not being calibrated correctly. Then, there is also the factor of human errors. It is important to be very precise and careful while measuring the defects in order to minimise or completely remove any chance of human errors.

There might be errors during the ultrasonic thickness gauging procedure as well. This could be due to various factors such as change in the ambient temperature or sources of electronic and structural noises (Honarvar et al., 2014)

6. RESULTS AND DISCUSSIONS

After completing all the calculations and making the graphs, it showed that there were huge variations in the number of errors and deviations of the defects measured by all the operators when compared to the true sizes of the defects. The best way to detect the operators who measured the defects more accurately or with less errors is to check for the amount of deviation from its true size.

The standard deviation achieved by each operator are as follows:

Operator1 = 0.25mm

Operator2 = 0.66mm

Operator3 = 0.50mm

Operator4 = 0.39mm

Operator5 = 0.45mm

Operator6 = 0.53mm

Operator7 = 0.54mm

Operator8 = 0.42mm

Operator9 = 0.25mm

Operator10 = 0.44mm

Operator1 and operator9 have shown the least amount of overall deviation at 0.25mm.

Operator4, operator5, operator8 and operator10 achieved very similar overall deviation, between 0.39mm and 0.45mm.

The next range of operator achieved deviation which only differed by 0.04mm. These were operator3, operator6 and operator7, ranging from 0.50mm to 0.54mm.

The worst results were achieved by operator2, who got an overall deviation of 0.66mm.

7. CONCLUSIONS

This experiment used probability of detection method to perform out a new ultrasonic thickness gauging procedure. Upon the experiment being carried out by ten operators, the defects measured by the operators were compared. This was done for twenty one different defects in the specimen. In the end, it was discovered that the measurements taken by operator1 and operator9 showed the least amount of deviation at 0.25mm when compared to the true sizes of the defects. The highest deviation was observed by operator2 at 0.66mm. the rest of the operators can be divided into two groups. Operator4, operator5, operator8 and operator10 achieved deviation between 0.39mm and 0.45mm and operator3, operator6 and operator7 achieved deviation between 0.50mm to 0.54mm.

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