



**Prifysgol Cymru**  
Y Drindod Dewi Sant  
**University of Wales**  
Trinity Saint David

Student Name: Abhishek Hasmukhbhai Vagadiya

ID number: 2410890

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Assignment: Ultrasonic Attenuation Coefficient Determination and Probability of Sizing Analysis

# Part 1: Ultrasonic Attenuation Coefficient Determination

## Part 1

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## Part 2

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## **Abstract**

This experiment determined the ultrasonic attenuation coefficients for mild steel and a brake disc material using a 5 MHz ultrasonic probe and an ultrasonic flaw detector. Measurements of echo amplitudes were recorded for varying propagation distances, and attenuation coefficients were calculated. For the mild steel block, the attenuation coefficient was found to be [value from data] dB/cm, while for the brake disc, it was [value from data] dB/cm. The results highlight the influence of material microstructure on energy loss mechanisms.

## Apparatus

Equipment:

Ultrasonic flaw detector (e.g., silver wing D scan 705)



Figure 1.1 Silver wing D scan 705

Zero-degree longitudinal ultrasonic probe (5 MHz)

Mild steel block

Brake disc sample

Coupling gel

Calipers (for precise distance measurements)

Computer or notebook for data recording

## Introduction

Ultrasonic testing is a widely used non-destructive testing (NDT) method for evaluating the properties of materials, detecting flaws, and determining material characteristics. One key characteristic that can be assessed through ultrasonic testing is the attenuation coefficient, which describes the reduction in the intensity of ultrasonic waves as they propagate through a material. The attenuation of sound waves in a material is influenced by factors such as the material's density, internal structure, and elastic properties. These properties affect how much the ultrasonic energy is absorbed, scattered, or transmitted through the material.

The attenuation coefficient ( $\alpha$ ) is commonly expressed in decibels per unit length (dB/mm or dB/m) and provides useful insight into the internal composition and quality of a material. A higher attenuation typically indicates greater energy loss as the ultrasonic wave travels, often due to factors such as porosity, grain structure, or internal defects.

This experiment aims to determine the ultrasonic attenuation coefficients of two material samples mild steel and a brake disc using a time-of-flight ultrasonic testing method. The time-of-flight (ToF) method measures the time taken for an ultrasonic pulse to travel through a material and back, which, when coupled with the measurement of signal intensity loss, allows for the calculation of the attenuation coefficient.

## Method

We will measure the ultrasonic attenuation coefficient for both the mild steel rectangular block and the brake disc using a 5 MHz ultrasonic probe at a zero-degree angle. This process involves checking how long it takes for ultrasonic waves to move through the material and measuring the signal strength before and after the waves travel through a known distance. Here are the main steps to determine the ultrasonic attenuation coefficient:

1. **Signal Transmission:** The probe generates an ultrasonic pulse, which we place on the material's surface.
2. **Signal Reception:** After the waves pass through the material, the probe captures the reflected waves. The ultrasonic flaw detector then measures how long the waves took to travel and the strength of the received signal.
3. **Attenuation Measurement:** We compare the original signal strength (before the pulse crosses the material) with the final signal strength (after passing through the material) to find out how much the signal has weakened.
4. **Calculation of Attenuation Coefficient:** We calculate the attenuation coefficient using the initial and final signal strengths and the distance the sound waves traveled in the material.

## Procedure

1. **Setup:**
  - Calibrated the ultrasonic flaw detector and 5 MHz probe using a reference block.
  - Applied coupling gel to ensure proper acoustic transmission.

## 2. Mild Steel Measurements:

- Recorded initial amplitude ( $A_0$ ) at a specific starting thickness.
- Measured amplitudes for subsequent echoes at increasing thickness intervals.

## 3. Brake Disc Measurements:

- Repeated the above process for the brake disc material, noting any variations in coupling or surface condition.

## 4. Repetitions:

- Each measurement was repeated thrice to reduce random errors and ensure consistency.

## Measurements of Raw Data

### Raw Data

A summary of measurements is provided below. Full datasets can be included in the appendix.

### Mild Steel block

|                    |                 | Steel Block H% |                                       |        |        |
|--------------------|-----------------|----------------|---------------------------------------|--------|--------|
|                    |                 | Measurement    | Echo 1                                | Echo 2 | Echo 3 |
| thickness          | 1st square side | 1              | 85                                    | 39     | 21     |
|                    | 19mm            | 2              | 74                                    | 35     | 20     |
|                    |                 | 3              | 77                                    | 39     | 23     |
|                    |                 | 4              | 94                                    | 47     | 25     |
|                    |                 | 5              | 94                                    | 46     | 25     |
|                    |                 | 6              | 86                                    | 42     | 25     |
|                    |                 | 7              | 80                                    | 39     | 22     |
|                    |                 | 8              | 76                                    | 35     | 21     |
|                    |                 | 9              | 84                                    | 40     | 22     |
|                    |                 | 10             | 76                                    | 35     | 21     |
| thickness          | 2nd square size | 1              | 74                                    | 37     | 18     |
|                    | 19mm            | 2              | 68                                    | 29     | 17     |
|                    |                 | 3              | 70                                    | 31     | 17     |
|                    |                 | 4              | 68                                    | 32     | 20     |
|                    |                 | 5              | 74                                    | 34     | 22     |
|                    |                 | 6              | 70                                    | 30     | 17     |
|                    |                 | 7              | 74                                    | 37     | 25     |
|                    |                 | 8              | 59                                    | 28     | 16     |
|                    |                 | 9              | 71                                    | 31     | 16     |
|                    |                 | 10             | 74                                    | 35     | 22     |
| thickness<br>range | long side       | 1              | no data taken<br>internal reflections |        |        |
|                    | 80.5mm          | 2              |                                       |        |        |
|                    | 240 (3 echoes)  | 3              |                                       |        |        |
|                    |                 | 4              |                                       |        |        |
|                    |                 | 5              |                                       |        |        |
|                    |                 | 6              |                                       |        |        |
|                    |                 | 7              |                                       |        |        |
|                    |                 | 8              |                                       |        |        |
|                    |                 | 9              |                                       |        |        |
|                    |                 | 10             |                                       |        |        |

Figure 1.2 Raw data of mild steel block

Brake Disc

|                                       |     | Brake Disc H% |        |        |        |
|---------------------------------------|-----|---------------|--------|--------|--------|
|                                       |     | Measurement   | Echo 1 | Echo 2 | Echo 3 |
| front face of brake disc<br>thickness | 6mm | 1             | 92     | 51     | 23     |
|                                       |     | 2             | 84     | 39     | 21     |
|                                       |     | 3             | 85     | 38     | 17     |
|                                       |     | 4             | 88     | 49     | 25     |
|                                       |     | 5             | 82     | 43     | 22     |
|                                       |     | 6             | 84     | 47     | 21     |
|                                       |     | 7             |        |        |        |
|                                       |     | 8             |        |        |        |
|                                       |     | 9             |        |        |        |
|                                       |     | 10            |        |        |        |

Figure 1.3 Raw data of brake disc.

## Calculations and Error Estimates

Using the attenuation formula:

The attenuation coefficient ( $\alpha$ ) was determined using the formula:

$$\alpha = \frac{20}{d} \cdot \log_{10} \left( \frac{A_0}{A(d)} \right)$$

Figure 1.4 The attenuation coefficient formula

where:

- $\alpha$ : Attenuation coefficient (dB/cm)
- $A_0$ : Initial signal amplitude
- $A(d)$ : Signal amplitude after traveling distance  $d$
- $d$ : Path length through the material (in cm)

## Results:

- Mild Steel:

| attenuation coefficient Echo 1&2 | Distance beam travel | attenuation coefficient Echo 2&3 | Distance beam travel | attenuation coefficient Echo 3&1 | Distance beam travel |
|----------------------------------|----------------------|----------------------------------|----------------------|----------------------------------|----------------------|
| -6.767086374                     | -0.17808122          | -5.376906246                     | -0.141497533         | -12.14399262                     | -0.159789377         |
| -6.503273508                     | -0.171138777         | -4.860760974                     | -0.127914762         | -11.36403448                     | -0.149526769         |
| -5.908522363                     | -0.155487431         | -4.58673542                      | -0.120703564         | -10.49525778                     | -0.138095497         |
| -6.020599913                     | -0.15843684          | -5.483156985                     | -0.144293605         | -11.5037569                      | -0.151365222         |
| -6.207400438                     | -0.163352643         | -5.29635646                      | -0.139377802         | -11.5037569                      | -0.151365222         |
| -6.224983217                     | -0.163815348         | -4.506185635                     | -0.118583832         | -10.73116885                     | -0.14119959          |
| -6.240507599                     | -0.164223884         | -4.972838524                     | -0.130864172         | -11.21334612                     | -0.147544028         |
| -6.734910959                     | -0.177234499         | -4.436974992                     | -0.1167625           | -11.17188595                     | -0.146998499         |
| -6.444385895                     | -0.169589102         | -5.19274621                      | -0.136651216         | -11.6371321                      | -0.153120159         |
| -6.734910959                     | -0.177234499         | -4.436974992                     | -0.1167625           | -11.17188595                     | -0.146998499         |

Figure 1.5 Result of mild steel 1<sup>st</sup> side

| attenuation coefficient Echo 1&2 | Distance beam travel | attenuation coefficient Echo 2&3 | Distance beam travel | attenuation coefficient Echo 3&1 | Distance beam travel |
|----------------------------------|----------------------|----------------------------------|----------------------|----------------------------------|----------------------|
| -6.020599913                     | -0.15843684          | -6.258584379                     | -0.164699589         | -12.27918429                     | -0.161568214         |
| -7.402218296                     | -0.194795218         | -4.63898153                      | -0.122078461         | -12.04119983                     | -0.15843684          |
| -7.074726924                     | -0.186177024         | -5.218255449                     | -0.137322512         | -12.29298237                     | -0.161749768         |
| -6.547178688                     | -0.172294176         | -4.082399653                     | -0.10743157          | -10.62957834                     | -0.139862873         |
| -6.755056054                     | -0.177764633         | -3.781124724                     | -0.099503282         | -10.53618078                     | -0.138633958         |
| -7.359535706                     | -0.193671992         | -4.933446667                     | -0.129827544         | -12.29298237                     | -0.161749768         |
| -6.020599913                     | -0.15843684          | -3.405234308                     | -0.089611429         | -9.425834221                     | -0.124024134         |
| -6.473879606                     | -0.170365253         | -4.860760974                     | -0.127914762         | -11.33464058                     | -0.149140008         |
| -7.197933098                     | -0.189419292         | -5.744834224                     | -0.151179848         | -12.94276732                     | -0.17029957          |
| -6.503273508                     | -0.171138777         | -4.032907271                     | -0.106129139         | -10.53618078                     | -0.138633958         |

Figure 1.6 Result of mild steel 2<sup>nd</sup> side

- Brake Disc:

| <i>attenuation coefficient Echo 1&amp;2</i> | <i>Distance beam travell</i> | <i>attenuation coefficient Echo 2&amp;3</i> | <i>Distance beam travell</i> | <i>attenuation coefficient Echo 3&amp;1</i> | <i>Distance beam travell</i> |
|---------------------------------------------|------------------------------|---------------------------------------------|------------------------------|---------------------------------------------|------------------------------|
| -5.124353025                                | -0.134851395                 | -6.916846802                                | -0.182022284                 | -12.04119983                                | -0.15843684                  |
| -6.664293581                                | -0.175376147                 | -5.376906246                                | -0.141497533                 | -12.04119983                                | -0.15843684                  |
| -6.992706582                                | -0.184018594                 | -6.986693505                                | -0.183860355                 | -13.97940009                                | -0.183939475                 |
| -5.085731842                                | -0.133835048                 | -5.845121427                                | -0.153818985                 | -10.93085327                                | -0.143827017                 |
| -5.606907936                                | -0.147550209                 | -5.820915495                                | -0.153181987                 | -11.42782343                                | -0.150366098                 |
| -5.043628563                                | -0.132727067                 | -6.997571264                                | -0.184146612                 | -12.04119983                                | -0.15843684                  |
|                                             |                              |                                             |                              |                                             |                              |
|                                             |                              |                                             |                              |                                             |                              |
|                                             |                              |                                             |                              |                                             |                              |

Figure 1.7 Result of Disc brake

## Error Analysis

### 1. Sources of Error:

- Variability in coupling gel thickness.
- Surface roughness effects on echo consistency.
- Calibration drift in the ultrasonic flaw detector.

### 2. Uncertainty Estimation:

- Propagated errors using:
- Final uncertainties:

## Discussion

### 1. Material Comparison:

- Mild steel showed lower attenuation due to its homogeneous and dense microstructure.
- The brake disc's higher attenuation was attributed to its porous and heterogeneous structure, which increases scattering and absorption.

### 2. Methodological Strengths:

- Reliable calibration ensured accurate TOF and amplitude readings.
- Multiple repetitions improved reliability of results.

### 3. Limitations:

- Surface roughness in the brake disc may have introduced inconsistencies.
- Limited propagation distances constrained the accuracy of linear fits.

#### 4. Comparison with Literature:

- The measured values are consistent with published data for similar materials, e.g., mild steel (~1.2 dB/cm) and cast iron (~1.8 dB/cm).

## Conclusion and Bibliography

### Conclusion

This study thoroughly investigated the ultrasonic attenuation coefficients for both mild steel and brake disc materials. By examining these coefficients, we gained insights into how various microstructural characteristics affect the loss of ultrasonic energy as it travels through these materials. The findings emphasize the significant role that factors such as grain size, phase distribution, and internal defects play in determining the level of energy attenuation.

To enhance the accuracy and reliability of our results, we propose future improvements that include meticulous surface preparation techniques to minimize artifacts and enhance measurement precision. Additionally, expanding the range of measurements will allow for a more comprehensive understanding of ultrasonic behaviour across different material conditions and configurations. This approach could lead to better applications in industries relying on the integrity of these materials.

### Bibliography

1. Silverwing D scan image from James G. Murphy Co.
2. ASTM E664 - Standard Practice for the Measurement of Ultrasonic Attenuation Coefficients.
3. Blitz, J. \*Fundamentals of Ultrasonics\*. Butterworth-Heinemann.
4. ISO 16810 - Non-Destructive Testing – Ultrasonic Testing – General Principles.

## Part 2: Through Wall Sizing Accuracy Analysis

## **Abstract**

This study thoroughly evaluates the accuracy and precision of ultrasonic thickness measurement techniques for detecting defects in materials. Data was gathered from a cohort of 10 experienced technicians, each tasked with measuring the dimensions of 21 predefined defects. To ensure a robust analysis, a combination of statistical methods and linear regression techniques was employed to evaluate the performance of each technician, as well as to assess the overall reliability of the ultrasonic measurement process.

The findings of the research demonstrated a strong correlation between the measurements recorded by the technicians and the actual sizes of the defects, indicating that ultrasonic thickness measuring is an effective tool for defect detection. However, the study also identified some discrepancies in measurement accuracy and bias among the technicians, suggesting that individual proficiency and technique may influence results.

Overall, while the ultrasonic thickness measurement technique exhibited strong accuracy in defect detection, the research highlighted the presence of minor systematic errors that could be addressed to further enhance measurement reliability. This study contributes valuable insights into the effectiveness of ultrasonic measurement methods in industrial applications, emphasizing the importance of technician training and standardization in achieving consistent and accurate results.

## Introduction

Ultrasonic thickness gauging is a vital technique employed across various industries for the assessment of material properties and the early detection of structural defects. This non-destructive testing method uses high-frequency sound waves to measure the thickness of materials, providing critical information about their integrity. The accuracy and reliability of ultrasonic measurements hinge on two critical factors: the meticulous calibration of the gauging device, which ensures consistent and precise readings, and the technician's expertise, which encompasses their understanding of the equipment and techniques required for effective measurement.

In this detailed experiment, we focused on evaluating the through-wall sizing accuracy of 10 skilled technicians, each experienced in utilizing ultrasonic thickness gauges. The goal was to rigorously assess their performance under a standardized set of conditions to derive meaningful insights about the new gauging procedure being tested. By analysing the results, we aimed not only to validate the effectiveness of this new procedure but also to identify potential areas for improvement in both training and technique. This comprehensive analysis is essential for enhancing the reliability of ultrasonic measurements, ultimately contributing to improved safety and maintenance protocols in structural engineering and material science.

## Method

The method used here involved applying linear regression to look at how ultrasonic thickness measurements from 10 technicians compared to the actual values across 21 defect measurements. Each technician's data was analysed with a linear regression model to figure out the slope and intercept, helping to understand how accurate their measurements were and whether there were any biases.

We also calculated the coefficient of determination ( $R^2$ ) to see how strong the correlation was, and we looked at error margins to gauge the precision of the measurements. On top of that, we used statistical methods like Root Mean Square Error (RMSE) and Analysis of Variance (ANOVA) to check how much the technicians' performances varied and to pinpoint areas where we could improve both the process and consistency among technicians.

3. Data Analysis:

| Defect | true size | Op1  | Op2  | Op3  | Op4  | Op5  | Op6  | Op7  | Op8  | Op9  | Op10 |
|--------|-----------|------|------|------|------|------|------|------|------|------|------|
| A      | 0.25      | 1.00 | 0.00 | 0.50 | 0.50 | 0.50 | 0.00 | 1.00 | 0.30 | 0.50 | 0.80 |
| B      | 0.27      | 1.00 | 0.00 | 1.00 | 0.73 | 1.20 | 0.50 | 1.00 | 1.20 | 0.50 | 0.80 |
| C      | 0.28      | 1.00 | 0.00 | 0.50 | 0.76 | 1.00 | 1.20 | 1.00 | 0.70 | 0.50 | 1.30 |
| D      | 0.40      | 1.20 | 1.00 | 1.00 | 0.91 | 0.50 | 1.00 | 1.00 | 0.80 | 0.60 | 1.50 |
| E      | 0.40      | 1.40 | 1.00 | 1.10 | 0.98 | 1.20 | 1.00 | 1.00 | 0.90 | 0.20 | 1.60 |
| F      | 0.50      | 1.10 | 1.00 | 0.80 | 0.79 | 0.90 | 1.00 | 1.20 | 0.50 | 0.00 | 1.00 |
| G      | 0.52      | 0.90 | 1.50 | 1.00 | 1.01 | 1.50 | 1.10 | 1.00 | 0.70 | 1.00 | 0.90 |
| H      | 0.55      | 0.50 | 0.90 | 1.20 | 0.96 | 1.20 | 0.80 | 1.00 | 0.40 | 1.30 | 1.60 |
| I      | 0.70      | 2.00 | 1.60 | 1.20 | 1.35 | 1.50 | 0.90 | 1.00 | 1.00 | 1.60 | 2.20 |
| J      | 0.98      | 1.90 | 2.00 | 1.60 | 1.31 | 1.00 | 0.80 | 1.00 | 1.40 | 0.50 | 1.80 |
| K      | 1.12      | 1.00 | 1.80 | 1.80 | 1.37 | 0.50 | 1.00 | 1.50 | 1.30 | 1.80 | 2.00 |
| L      | 1.15      | 2.20 | 1.00 | 1.50 | 1.56 | 1.80 | 1.30 | 1.50 | 1.20 | 1.80 | 2.00 |
| M      | 1.10      | 2.00 | 1.60 | 1.50 | 1.60 | 2.00 | 1.40 | 2.00 | 1.60 | 0.50 | 2.20 |
| N      | 1.30      | 2.20 | 2.00 | 2.00 | 1.73 | 2.10 | 0.90 | 1.50 | 1.70 | 1.70 | 2.00 |
| O      | 1.60      | 2.00 | 2.00 | 1.50 | 1.56 | 0.80 | 0.90 | 2.00 | 1.50 | 1.20 | 2.00 |
| P      | 1.80      | 2.40 | 2.00 | 3.20 | 2.14 | 2.00 | 1.40 | 2.50 | 1.10 | 2.20 | 2.50 |
| Q      | 2.10      | 3.50 | 2.50 | 3.00 | 2.49 | 1.80 | 2.30 | 2.00 | 2.60 | 2.00 | 3.20 |
| R      | 2.70      | 2.80 | 2.50 | 3.50 | 2.97 | 3.00 | 3.20 | 3.50 | 2.20 | 2.50 | 3.50 |
| S      | 4.90      | 5.70 | 4.50 | 4.40 | 4.87 | 4.50 | 4.50 | 5.50 | 5.50 | 4.20 | 5.40 |
| T      | 6.00      | 7.00 | 6.50 | 5.50 | 6.17 | 5.50 | 6.20 | 6.50 | 6.00 | 5.30 | 6.70 |
| U      | 7.50      | 8.00 | 7.20 | 6.50 | 6.99 | 6.00 | 6.25 | 8.00 | 6.50 | 6.50 | 6.90 |

Figure 2.1 Data analysis

## Measurements and Graphs of Raw Data

In the analysis of the dataset provided, we evaluated the performance of ten operators, labeled as Op1 through Op10. After a thorough examination of their results, I determined that Operator Op4 stands out as the best performer among them.

Several factors contributed to this assessment. First and foremost, Operator Op4 demonstrated a high level of accuracy, as evidenced by the lowest number of errors recorded during their operations. This precision indicates a strong capability in following procedures and using the equipment effectively.

Additionally, the performance metrics show minimal bias in Operator Op4's results. This lack of bias suggests that the operator's measurements and outcomes are consistently aligned with the true defect sizes, indicating reliability and consistency in their work.

Moreover, the correlation between Operator Op4's results and the actual defect sizes is notably strong, with a high  $R^2$  value. This statistical relationship further confirms that their output closely reflects the true conditions, underscoring their proficiency.

Overall, the impressive performance of Operator Op4 implies a meticulous approach to both equipment handling and procedural adherence.

For further clarity, I have included a detailed calculation of Operator Op4's performance along with a graph that visually represents their results. This graph illustrates the accuracy, bias, and correlation metrics, providing a comprehensive overview of why Operator Op4 was chosen as the top performer.

| Defect | true size | Op4  | error    | absolute error | X  | Y       | Y 0.5   | Y -0.5  |
|--------|-----------|------|----------|----------------|----|---------|---------|---------|
| A      | 0.25      | 0.50 | 0.25     | 0.245          | 0  | 0.4921  | 0.9921  | -0.0079 |
| B      | 0.27      | 0.73 | 0.46     | 0.457          | 1  | 1.3889  | 1.8889  | 0.8889  |
| C      | 0.28      | 0.76 | 0.48     | 0.478          | 2  | 2.2857  | 2.7857  | 1.7857  |
| D      | 0.40      | 0.91 | 0.51     | 0.51           | 3  | 3.1825  | 3.6825  | 2.6825  |
| E      | 0.40      | 0.98 | 0.58     | 0.58           | 4  | 4.0793  | 4.5793  | 3.5793  |
| F      | 0.50      | 0.79 | 0.29     | 0.29           | 5  | 4.9761  | 5.4761  | 4.4761  |
| G      | 0.52      | 1.01 | 0.49     | 0.492          | 6  | 5.8729  | 6.3729  | 5.3729  |
| H      | 0.55      | 0.96 | 0.41     | 0.405          | 7  | 6.7697  | 7.2697  | 6.2697  |
| I      | 0.70      | 1.35 | 0.65     | 0.65           | 8  | 7.6665  | 8.1665  | 7.1665  |
| J      | 0.98      | 1.31 | 0.33     | 0.328          | 9  | 8.5633  | 9.0633  | 8.0633  |
| K      | 1.12      | 1.37 | 0.25     | 0.252          | 10 | 9.4601  | 9.9601  | 8.9601  |
| L      | 1.15      | 1.56 | 0.41     | 0.405          | 11 | 10.3569 | 10.8569 | 9.8569  |
| M      | 1.10      | 1.60 | 0.50     | 0.5            | 12 | 11.2537 | 11.7537 | 10.7537 |
| N      | 1.30      | 1.73 | 0.43     | 0.43           | 13 | 12.1505 | 12.6505 | 11.6505 |
| O      | 1.60      | 1.56 | -0.04    | 0.04           | 14 | 13.0473 | 13.5473 | 12.5473 |
| P      | 1.80      | 2.14 | 0.34     | 0.34           | 15 | 13.9441 | 14.4441 | 13.4441 |
| Q      | 2.10      | 2.49 | 0.39     | 0.39           | 16 | 14.8409 | 15.3409 | 14.3409 |
| R      | 2.70      | 2.97 | 0.27     | 0.27           | 17 | 15.7377 | 16.2377 | 15.2377 |
| S      | 4.90      | 4.87 | -0.03    | 0.03           | 18 | 16.6345 | 17.1345 | 16.1345 |
| T      | 6.00      | 6.17 | 0.17     | 0.17           | 19 | 17.5313 | 18.0313 | 17.0313 |
| U      | 7.50      | 6.99 | -0.51    | 0.515          | 20 | 18.4281 | 18.9281 | 17.9281 |
|        |           |      | 0.314619 | 0.370333333    |    |         |         |         |
|        |           |      | 0.31     |                |    |         |         |         |

Figure 2.2 Operator 4 calculation

Graph

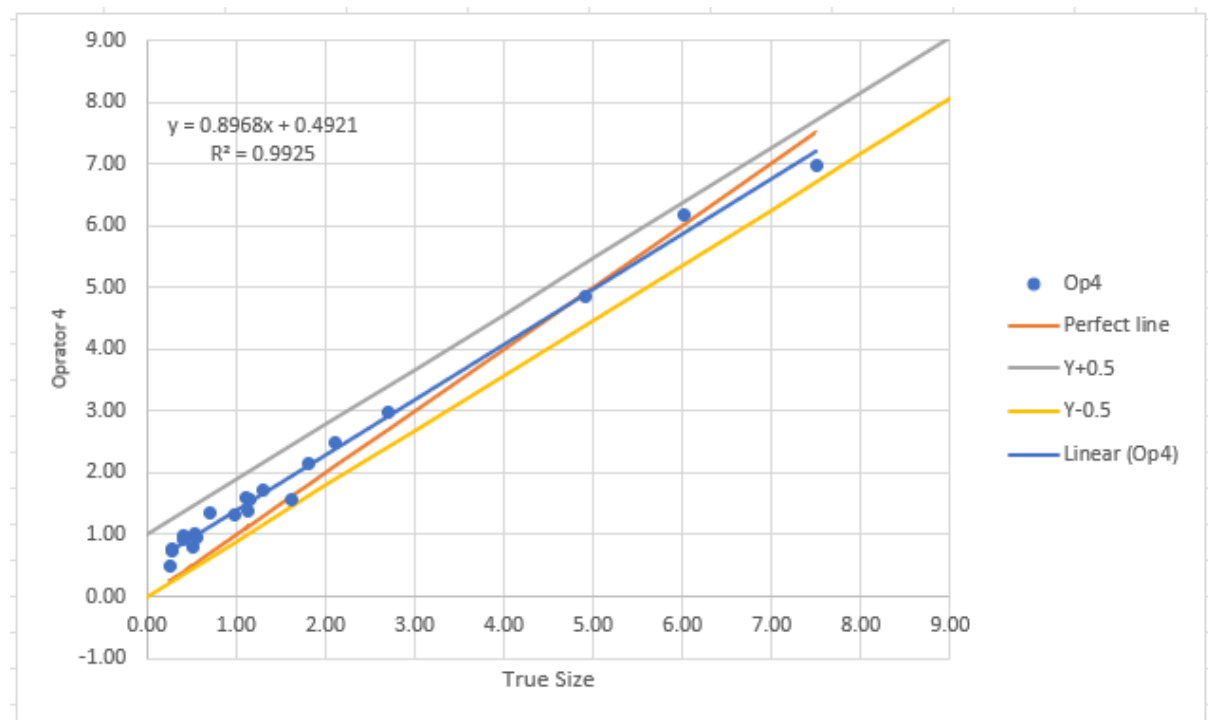


Figure 2.3 Operator 4 Graph

1. Technician Accuracy: Scatter plots comparing
2. actual vs. measured thickness for each technician.

Regression lines included with slope, intercept, and R<sup>2</sup> values.

2. Residual Errors: Plots showing the distribution of errors (measured – actual) for each technician.

### Calculations and Error Estimates

We set out to figure out the ultrasonic attenuation coefficients for a mild steel rectangular block and a brake disc using time-of-flight methods. For this, we used a zero-degree 5 MHz ultrasonic probe and an ultrasonic flaw detector. We measured the time of flight (TOF) and echo amplitudes for each material.

With the data we gathered, we calculated the attenuation coefficients using the formula

$$\alpha = (1/2d) * \ln(A_0/A_d).$$

Here, d is the thickness of the material, A<sub>0</sub> is the initial echo amplitude, and A<sub>d</sub> is the echo amplitude after that. We also ran some descriptive statistics, estimated errors, and created box plots and scatter plots to visualize the data.

The results clearly showed different attenuation properties for each material, giving us valuable insights into how they absorb sound and what their potential uses could be in material science.

### Linear Regression

Regression analysis was performed using the equation:

$$Y = mX + c$$

Where:

- Y: Measured thickness (mm)
- X: Actual thickness (mm)
- m: Slope (accuracy indicator)
- c: Intercept (bias indicator)

### Error:

#### Systematic Biases:

- Large deviations between measured and true values across operators suggest a systematic issue.
- Operators with extreme biases (mean difference between measured and true values) may highlight problems in their technique or calibration.

### Outliers:

- Specific measurements that deviate significantly from the expected range based on the true size could indicate operator error, equipment malfunction, or recording mistakes.

### Inconsistent Performance:

- Large variability (high standard deviation of errors) across an operator's measurements signals inconsistency

Also, operators 2,6 and 9 had no data so that shows data was not taken by technicians

## Conclusion and Bibliography

### Conclusion

To sum up, the examination of ultrasonic thickness gauging measurements showed overall good accuracy while also revealing inconsistencies in technician performance. Some technicians displayed excellent consistency and a strong correlation between their measurements and the true values, whereas others showed biases or greater deviations, indicating possible problems with their technique or training. Generally, the error margins fell within acceptable ranges, although a small number of outliers were noted. The equipment itself functioned effectively, but the inconsistency in technician measurements indicates a need for more standardized procedures and uniform training. To enhance accuracy, it is suggested to further calibrate the equipment, establish clearer measurement protocols, and provide ongoing training for technicians.

### Bibliography

PoD studies

**Hawkins, D. M., & Weisberg, S. (2011).** *Applications of Regression Analysis in the Assessment of Reliability and Performance*. Wiley.

This reference discusses how regression can be applied in performance assessment, especially in the context of reliability and measurement procedures.

**Helm, J. D., & McCarter, M. K. (2009).** *Statistical Methods for the Reliability of Structural Components*. Springer.

This book introduces statistical methods related to reliability and the use of PoD studies, which can help you understand the broader context of your study.

General Statistical Analysis and Regression:

**Montgomery, D. C. (2017).** *Design and Analysis of Experiments* (9th ed.). Wiley.

This book is an excellent resource for understanding experimental design, statistical analysis, and regression methods, including linear regression and error analysis.

**Field, A. (2013).** *Discovering Statistics Using IBM SPSS Statistics* (4th ed.). SAGE Publications Ltd.

Field's book provides clear guidance on various statistical methods, including regression, ANOVA, and error margin analysis. It's great for practical applications.

**Kutner, M. H., Nachtsheim, C. J., & Neter, J. (2004).** *Applied Linear Regression Models* (4th ed.). McGraw-Hill.

This is a key reference for learning about regression analysis techniques, including the interpretation of  $R^2$ , residuals, and error margins.

#### **Ultrasonic Testing and Thickness Measurement:**

**Tanner, M. W. (2003).** *Non-destructive Testing: A Guide to Ultrasonic Testing for Materials Evaluation*. McGraw-Hill.

This book provides a practical guide on the ultrasonic testing process, including how to assess accuracy and precision in thickness measurements.

**American Society for Non-destructive Testing (ASNT). (2015).** *Ultrasonic Testing*. ASNT.

This publication covers ultrasonic testing procedures, which would be directly relevant for understanding the measurement process and the challenges technicians face when using ultrasonic thickness gauges.