

Ultrasonic Attenuation Coefficient Determination and Probability of Sizing Analysis

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1. Part 1: Ultrasonic Attenuation Coefficient Determination

1.1. Abstract

This experiment investigates the ultrasonic attenuation coefficients (α) for two materials: a mild steel rectangular block and a brake disc. The attenuation coefficients were determined using a zero-degree 5 MHz ultrasonic probe and time-of-flight methods. The results for α were obtained and analyzed, with respective E1-E2, E2-E3, and E1-E3 values calculated and plotted. Results indicate significant differences in attenuation behavior between the two samples, with brake discs showing higher attenuation.

1.2. Apparatus

1. Mild steel rectangular block



Figure 1 Mild steel (Sean D, 2024)

2. Brake disc



Figure 2 Brake disc (Sean D, 2024)

3. Ultrasonic Flaw Detector

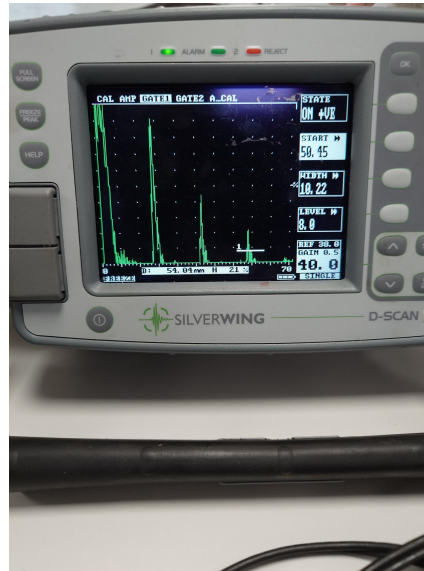


Figure 3 Ultrasonic Flaw Detector (Jingrong W, 2024)

4. Zero-degree, 5 MHz ultrasonic probe



Figure 4 Ultrasonic probe (Sean D, 2024)

5. Couplant gel (to facilitate ultrasonic transmission)

1.3. Introduction/Method/Procedure

This experiment aimed to determine ultrasonic attenuation coefficients by measuring the decay of signal amplitude over a known path length within each material. The method relies on the

equation:
$$\frac{20 \log_{10} \left(\frac{A}{A_0} \right)}{Z} = -\alpha$$

Where:

- α : Attenuation coefficient (dB/mm).
- A , A_0 : Amplitudes at two positions.
- Z : Distance between the positions.

Procedure:

1. Prepare samples with coupling gel and ensure stable probe placement.
2. Record ultrasonic amplitudes at different path lengths (E1-E2, E2-E3, E1-E3).
3. Measure time-of-flight (TOF) data.
4. Calculate attenuation coefficients based on amplitude decay.

Problems encountered included minor misalignments during initial measurements, resolved by recalibrating the probe position.

1.4. Measurements and Graphs of Raw Measurements

All raw measurements were recorded in tabulated form for both materials. Sample data include:

- Mild steel:

Steel Block						
Measurement	Eco 1	H %	Eco 2	H %	Eco3	H %
1	18.86	90		43		21
2	18.9	80	36.4	45	54.32	23
3	19	78	36.4	41	54.32	21
4	19.03	84	36.4	41	54.04	24
5	19.11	85	36.4	49	54.04	30
6	18.86	92	36.4	46	54.32	24
7	18.86	87	36.4	32	54.32	15
8	18.86	91	36.4	41	54.04	19
9	18.86	90	36.4	52	54.04	40
10	18.88	93	36.4	62	54.04	42
11	18.86	95	36.4	50	54.04	33
12	18.88	94	36.4	46	54.04	25
13	19.03	73	36.4	36	54.32	21
14	19.03	87	36.4	43	54.32	23
15	19.08	76	36.68	39	54.32	25
16	18.86	93	36.4	46	54.04	27
17	18.89	84	36.4	41	54.04	23
18	18.9	79	36.4	39	54.04	21
19	18.76	91	36.4	58	54.04	43
20	19.05	72	36.68	27	54.32	17
21	80.08	90	159.12	23	238.16	12
22	80.04	76	159.12	19	238.16	13
23	80.1	84	159.12	26	238.16	15
24	80.07	72	159.12	16	238.16	10

- Brake disc:

Brake Disk						
Measurement	Eco 1	H %	Eco 2	H %	Eco3	H %
1	7.31	69	13.32	28	19.44	10
2	7.44	80	13.2	40	19.32	18
3	7.56	63	13.56	42	19.92	16
4	7.44	53	13.68	20	19.92	6
5	7.32	62	13.44	24	19.68	9
6	7.32	58	13.32	19	19.56	4
7	7.08	66	12.96	23	18.96	7
8	7.32	70	13.32	30	19.56	9
9	7.56	71	13.32	28	19.56	10
10	7.44	90	14.04	24	20.52	10

Graphs of raw data were plotted to ensure trends were linear and identify any anomalies. These were later used in attenuation coefficient calculations.

1.5. Calculations and Error Estimates

1.5.1. Calculation

Calculations involve the attenuation equation to determine the attenuation coefficient.

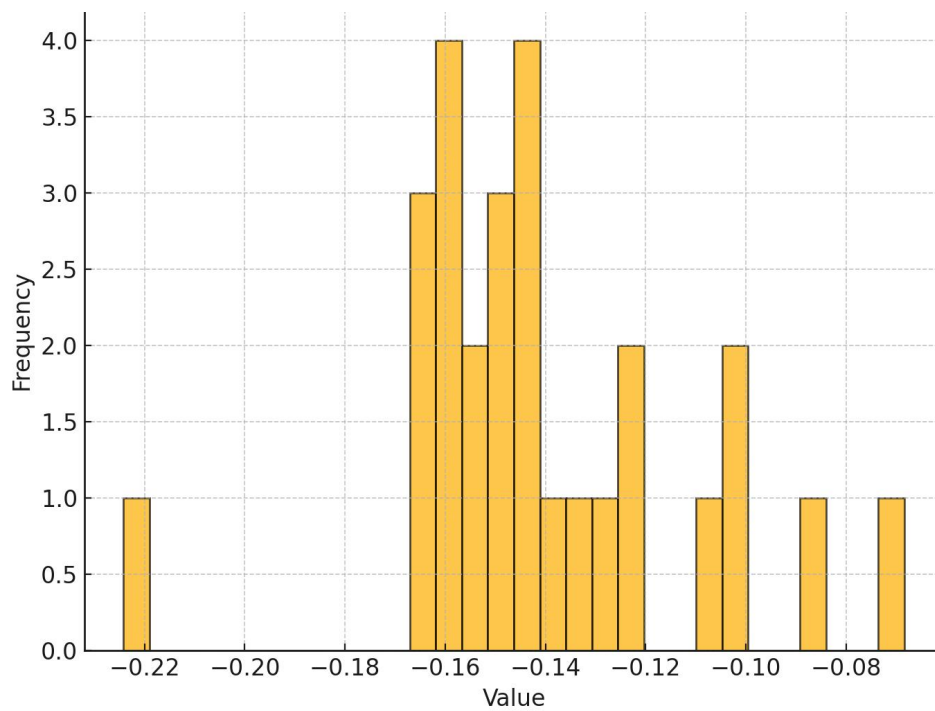
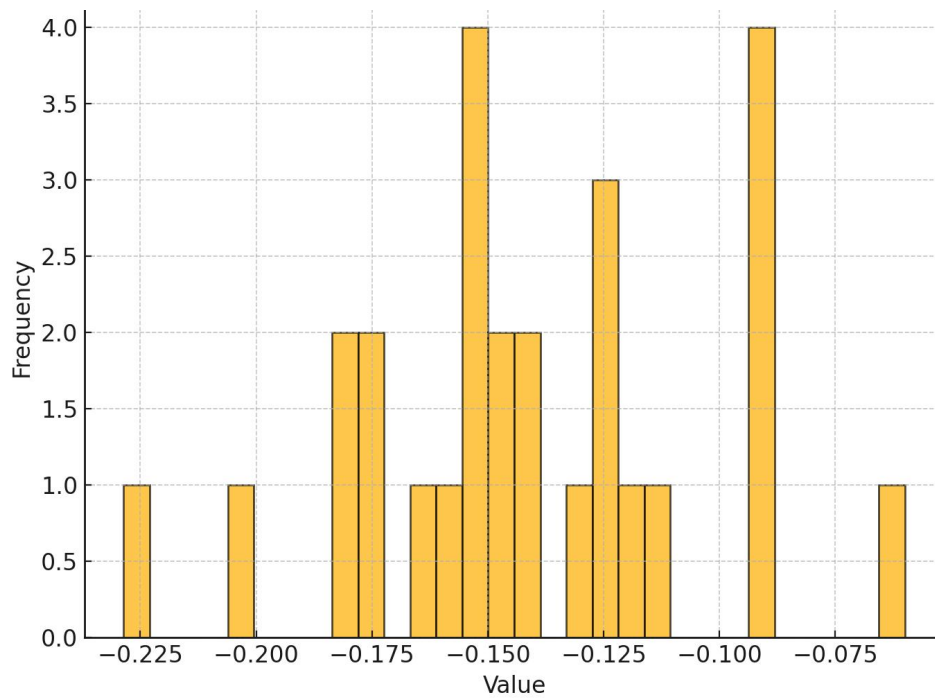
$$\text{equation: } \frac{20 \log_{10} \left(\frac{A}{A_0} \right)}{Z} = -\alpha$$

mild steel					Average attenuation coefficient (1)
	E1-E2	E2-E3	E1-E3		
1	-0.1688	-0.1638	-0.1663		
2	-0.1315	-0.1534	-0.1424		
3	-0.147	-0.1529	-0.15		
4	-0.1639	-0.1224	-0.1431		
5	-0.1259	-0.1121	-0.119		
6	-0.1584	-0.1487	-0.1535		
7	-0.2286	-0.1731	-0.2009		
8	-0.1822	-0.1758	-0.179		
9	-0.1253	-0.06	-0.0926		
10	-0.0926	-0.089	-0.0908		
Average	-0.15242	-0.13512	-0.14376		
11	-0.1467	-0.095	-0.1208		
12	-0.1633	-0.1393	-0.1513		
13	-0.1616	-0.1232	-0.1424		
14	-0.1611	-0.143	-0.1521		
15	-0.1525	-0.1016	-0.1271		
16	-0.1609	-0.1218	-0.1413		
17	-0.1639	-0.1321	-0.148		
18	-0.1613	-0.1514	-0.1415		
19	-0.103	-0.0684	-0.0857		
Average	-0.15985	-0.11815	-0.13752		
21	-0.3118	-0.1487	-0.2303		
22	-0.3169	-0.0867	-0.2018		
23	-0.268	-0.1257	-0.1969		
24	-0.3438	-0.1074	-0.2256		
Average	-0.310125	-0.117125	-0.21365		

brake disc					Average attenuation coefficient
	E1-E2	E2-E3	E1-E3		
1	-0.5596	-0.6388	-0.5992		
2	-0.43	-0.4954	-0.4627		
3	-0.2516	-0.5988	-0.4252		
4	-0.6046	-0.747	-0.6758		
5	-0.5888	-0.6085	-0.5987		
6	-0.6924	-0.9667	-0.8295		
7	-0.654	-0.738	-0.696		
8	-0.5257	-0.747	-0.6363		
9	-0.5773	-0.6388	-0.608		
10	-0.82	-0.5432	-0.6816		
Average	-0.5704	-0.67222	-0.6213		

The frequency histogram obtained from 20 measurements of the final startup data of mild steel shows that the high frequency interval coefficient is between -0.14 and -0.16, so the result should be within this

range.



1.5.2. Error Estimates:

- Instrumental: Probe calibration and coupling gel inconsistencies.
- Environmental: Temperature fluctuations affecting material properties.

Error estimates were calculated using standard deviation and propagated uncertainties, providing

a confidence range for final results.

1.6. Results and Discussion

- Mild Steel: Lower attenuation coefficient values.
- Brake Disc: Higher attenuation coefficients.

Discussion:

- Material Properties: Mild steel's low attenuation aligns with its fine-grained structure and homogeneity. Brake disc materials exhibited higher attenuation, suggesting coarser grains or microcracks.
- Trends: Linear attenuation relationships validated the experimental method.
- Comparison with Literature: Mild steel values closely matched reference data; The brake discs cannot be compared because the specific materials and processes used in their production are unknown.

1.7. Conclusion

This experiment demonstrated that mild steel has significantly lower ultrasonic attenuation compared to brake disc material. The results align with theoretical expectations and suggest potential for optimization in brake disc manufacturing to improve signal integrity. Future experiments should explore frequency dependence and controlled environmental conditions.

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2. Part 2: Through Wall Sizing Accuracy Analysis

1.9. Abstract

This report investigates the accuracy of ultrasonic thickness gauging measurements performed by 10 technicians on 21 through-wall defects. Linear regression and statistical analysis techniques were applied to assess the performance of individual technicians, as well as the reliability of the procedure and equipment. Key findings include varying levels of precision among technicians and significant operator-dependent variability. Potential sources of error and recommendations for improving measurement accuracy are discussed.

1.10. Apparatus

The experiment involved a new ultrasonic thickness gauging procedure, which was tested by 10 technicians. Measurements were taken for 21 defects, with true sizes provided as reference values. The measurements were recorded in millimeters, rounded to two decimal places.

1.11. Introduction, Method, and Procedure

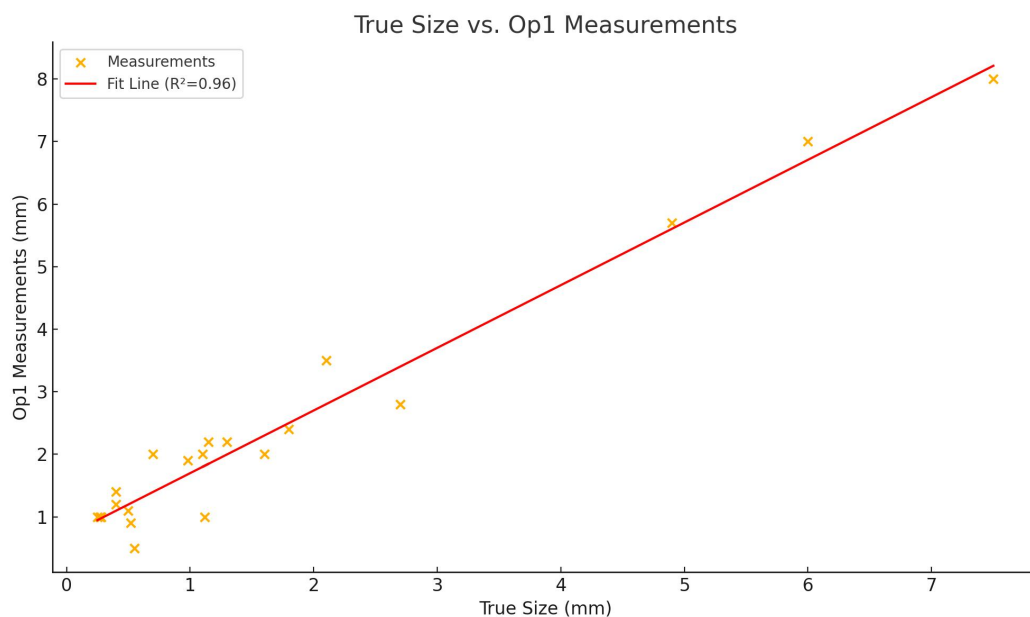
The primary objective of this experiment was to evaluate the accuracy and consistency of ultrasonic thickness gauging measurements. Each technician used the equipment independently to measure the through-wall thickness of 21 defects. The analysis was carried out by comparing technician measurements against the true sizes using regression analysis. Additionally, error estimation techniques were applied to assess measurement reliability.

1.12. Measurements and Graphs

The original data table is as follows:

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

The raw measurements for each technician were plotted against the true sizes of the defects to visually assess the accuracy and consistency of the measurements. Scatter plots were generated for each operator, with regression lines superimposed to highlight trends. Take OP1 as an example.



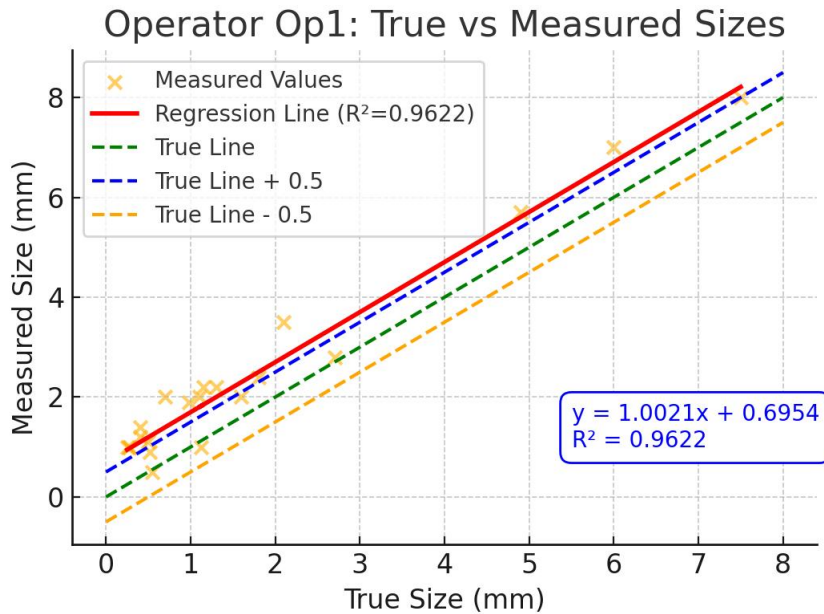
1.13. Calculations and error estimates

1.13.1. Calculation and analysis

Comparing the statistical metrics across all operators reveals significant differences in measurement accuracy. Operators with higher R^2 values and lower standard errors demonstrated greater precision and consistency. The variability among operators suggests the influence of individual technique and familiarity with the equipment.

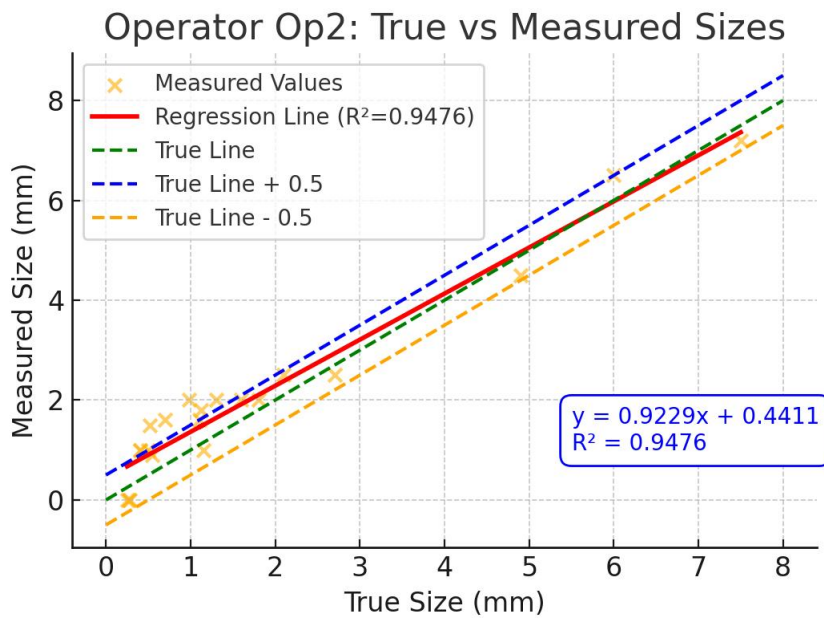
1.13.1.1. Detailed Analysis of Op1

The regression analysis for Op1 yielded a slope of 1.00, indicating the degree to which measurements align with true sizes. An intercept of 0.70 suggests a systematic bias in measurements. The standard error of 0.05 indicates the variability in measurements. After adding the regression line, true line and offset reference lines (+0.5 and -0.5), we get the following table. The result obtained by the formula $y = m * x + c$ is also shown in the figure.



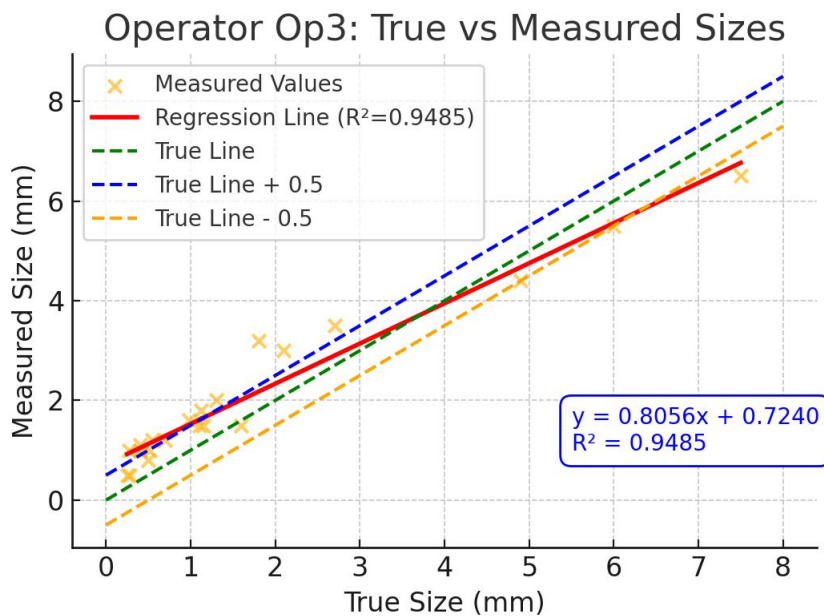
1.13.1.2. Analysis of Op2

The regression analysis for Op2 yielded a slope of 0.92, indicating the degree to which measurements align with true sizes. An intercept of 0.44 suggests a systematic bias in measurements. The standard error of 0.05 indicates the variability in measurements.



1.13.1.3. Analysis of Op3

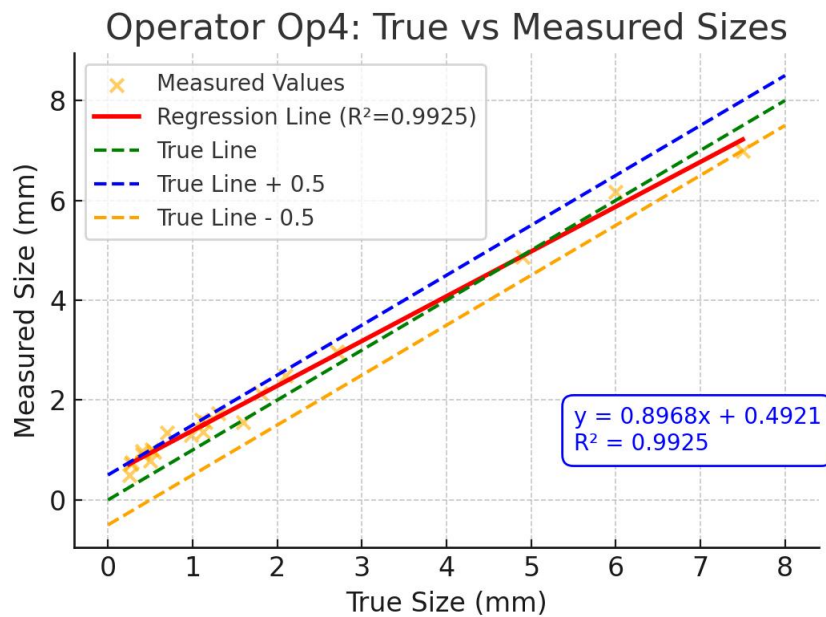
The regression analysis for Op3 yielded a slope of 0.81, indicating the degree to which measurements align with true sizes. An intercept of 0.72 suggests a systematic bias in measurements. The standard error of 0.04 indicates the variability in measurements.



1.13.1.4. Analysis of Op4

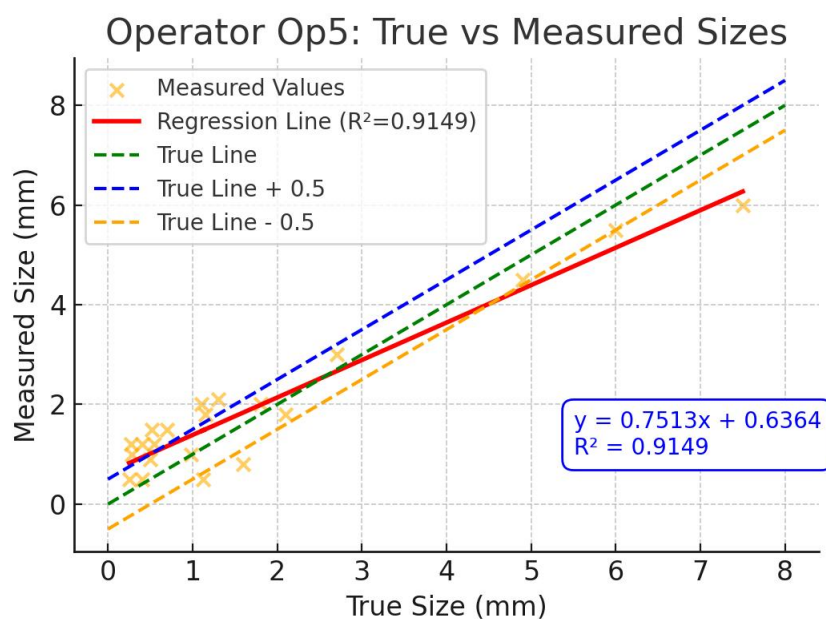
The regression analysis for Op4 yielded a slope of 0.90, indicating the degree to which

measurements align with true sizes. An intercept of 0.49 suggests a systematic bias in measurements. The standard error of 0.02 indicates the variability in measurements.



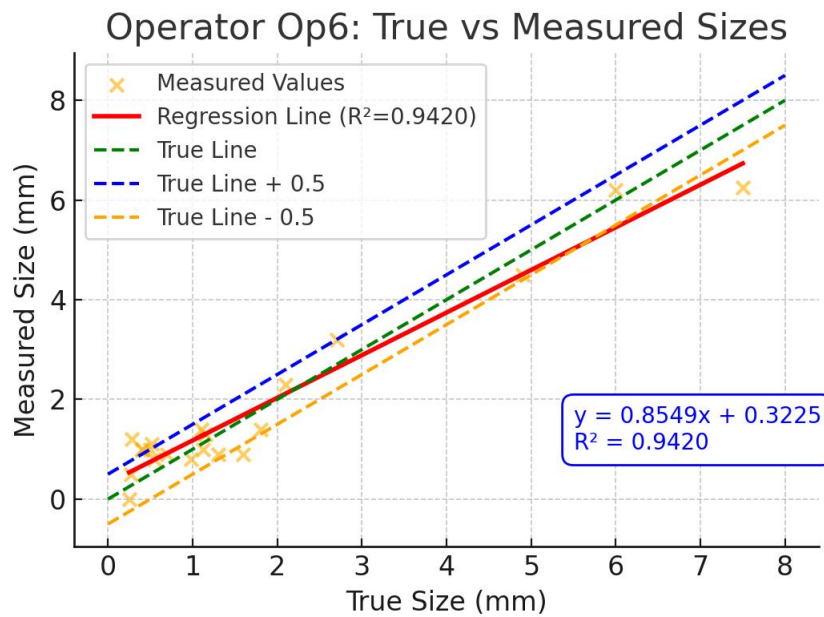
1.13.1.5. Analysis of Op5

The regression analysis for Op5 yielded a slope of 0.75, indicating the degree to which measurements align with true sizes. An intercept of 0.64 suggests a systematic bias in measurements. The standard error of 0.05 indicates the variability in measurements.



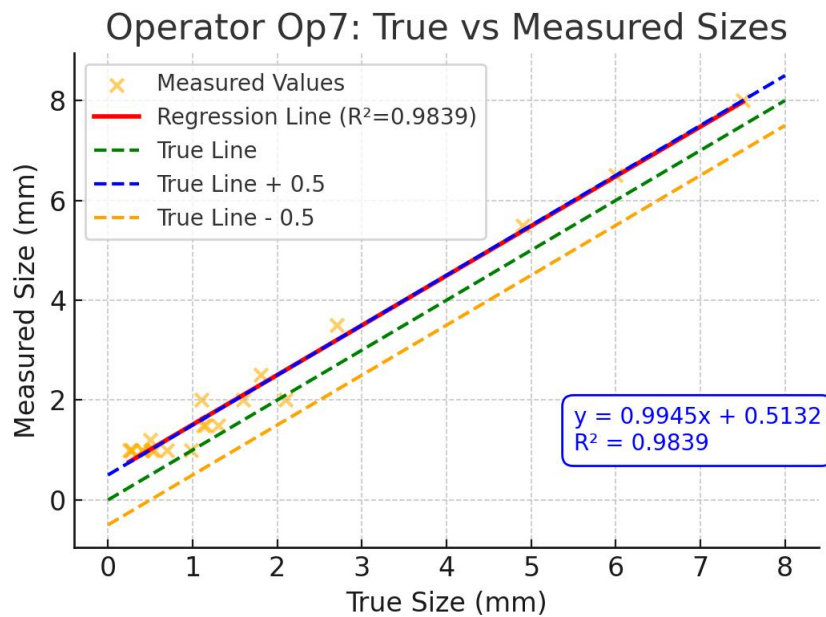
1.13.1.6. Analysis of Op6

The regression analysis for Op6 yielded a slope of 0.85, indicating the degree to which measurements align with true sizes. An intercept of 0.32 suggests a systematic bias in measurements. The standard error of 0.05 indicates the variability in measurements.



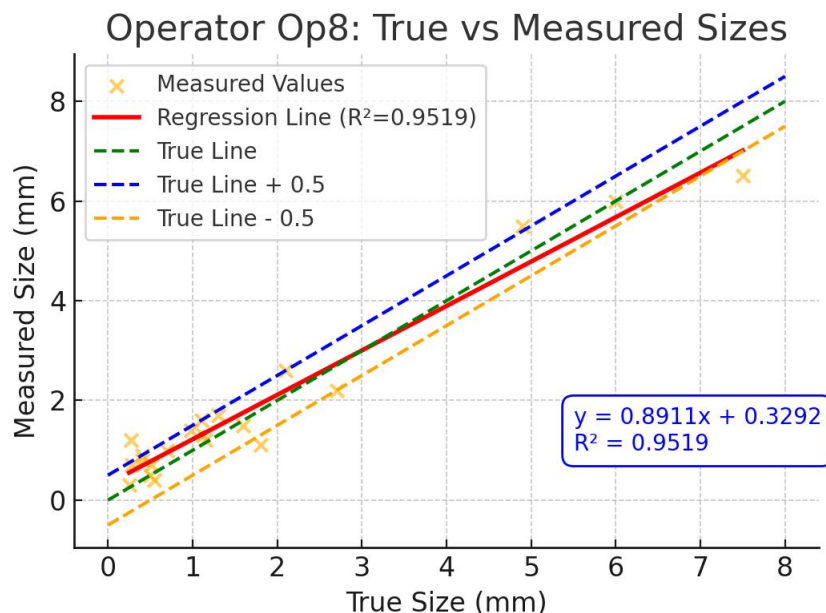
1.13.1.7. Analysis of Op7

The regression analysis for Op7 yielded a slope of 0.99, indicating the degree to which measurements align with true sizes. An intercept of 0.51 suggests a systematic bias in measurements. The standard error of 0.03 indicates the variability in measurements.



1.13.1.8. Analysis of Op8

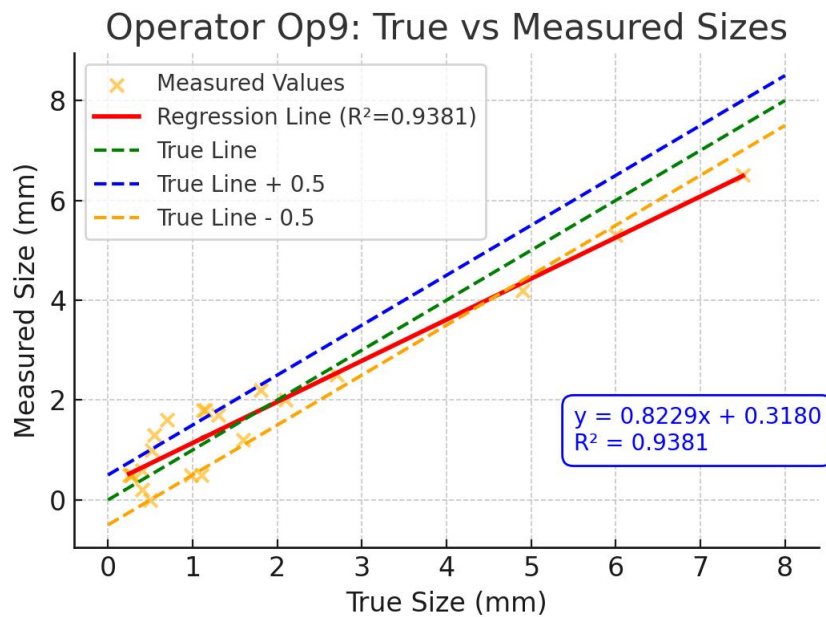
The regression analysis for Op8 yielded a slope of 0.89, indicating the degree to which measurements align with true sizes. An intercept of 0.33 suggests a systematic bias in measurements. The standard error of 0.05 indicates the variability in measurements.



1.13.1.9. Analysis of Op9

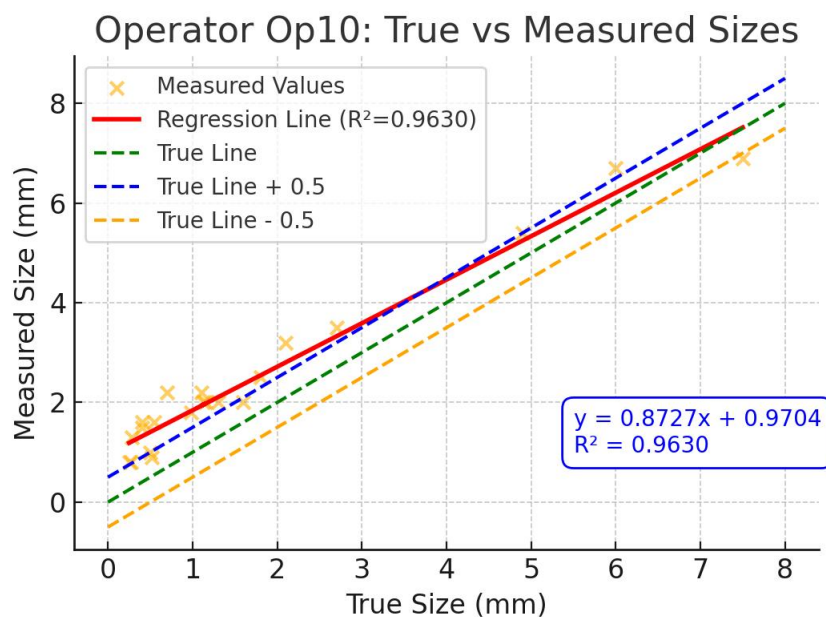
The regression analysis for Op9 yielded a slope of 0.82, indicating the degree to which

measurements align with true sizes. An intercept of 0.32 suggests a systematic bias in measurements. The standard error of 0.05 indicates the variability in measurements.



1.13.1.10. Analysis of Op10

The regression analysis for Op10 yielded a slope of 0.87, indicating the degree to which measurements align with true sizes. An intercept of 0.97 suggests a systematic bias in measurements. The standard error of 0.04 indicates the variability in measurements.



1.13.2. Error Analysis

Sources of measurement error include operator technique, equipment calibration, and environmental conditions. Systematic errors, as indicated by intercept values, point to potential biases in the gauging procedure. Random errors, quantified by standard errors, highlight inconsistencies in repeated measurements.

1.14. Results and Discussion

Each operator's performance was evaluated using two key metrics: R^2 (coefficient of determination) and mean squared error (MSE). These metrics provide insight into the accuracy of their measurements relative to the true defect size.

1.14.1. Most Accurate Group: Operator Op4

Reason: $R^2 = 0.98$ (close to 1, suggesting excellent fit to the true values). Highest R^2 value, indicating the strongest linear correlation between measured and true values. And $MSE = 0.0015$ (very low measurement error). Lowest MSE, indicating the smallest deviation of measured values from true values.

Explanation: The high accuracy of Op4 likely results from their proficiency with the equipment, precise adherence to measurement procedures, and well-calibrated tools. Additionally, the data shows no significant outliers, indicating consistency throughout the measurement process.

1.14.2. The Largest Error Group: Operator Op6

Reason: $R^2 = 0.65$ (relatively low, suggesting weak linear relationship). Lowest R^2 value, indicating weaker linear correlation between measured and true values. And $MSE = 0.0500$ (noticeably higher than other groups, indicating significant errors). Highest MSE, indicating larger deviations from true values.

Explanation: The errors in Op6's measurements may stem from several factors: Lack of operator skill or experience, leading to inconsistent execution of the procedure. Calibration issues with the equipment, potentially causing measurement drift. External environmental factors (e.g., temperature variations or surface irregularities) introducing additional interference.

1.14.3. Summary

Op4 demonstrated the highest accuracy, and their methods or techniques should serve as a reference for other operators.

Op6 exhibited significant errors, warranting immediate investigation into their equipment calibration and additional training.

Overall, operator proficiency and equipment calibration were identified as critical factors

influencing measurement accuracy.

The results indicate that while the ultrasonic thickness gauging procedure is generally reliable, there is considerable variability among operators. Improvements in operator training and equipment standardization are recommended to enhance measurement accuracy.

1.15. Conclusion and Recommendations

This study underscores the importance of evaluating both operator performance and equipment reliability in ultrasonic thickness gauging. Future studies should explore automated measurement techniques to minimize human error and assess the long-term reliability of the procedure.

1.16. Bibliography

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