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**Assignment Title : Ultrasonic Attenuation Coefficient Determination and
Probability of Sizing Analysis**

PART ONE

Ultrasonic Attenuation Coefficient Determination

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Abstract

The purpose of this experiment was to use Time of Flight (TOF) ultrasonic techniques to ascertain the material attenuation coefficients of two samples: a brake disc and a rectangular block of mild steel. Signal amplitudes were measured at two points along each material using a 5MHz ultrasonic probe and fault detector. By examining the logarithmic ratio of the signal amplitudes across a predetermined distance, the attenuation coefficient was determined. According to the results, the mild steel block lost more energy within the material than the brake disc because it had a higher attenuation coefficient. Potential measurement mistakes were documented, and the method's accuracy was evaluated.

Apparatus

FIRST Experiment Equipment: A set of specialised tools was needed for the ultrasonic attenuation coefficient experiment in order to guarantee precise readings. The ultrasonic flaw detector, a precision device that could send and receive ultrasonic

waves and measure the time-of-flight (TOF) and signal amplitudes, was the main component. To enable wave propagation through the samples, a zero-degree ultrasonic probe running at 5 MHz was positioned perpendicularly on the test material surfaces and connected to the defect detector.

A brake disc and a rectangular block of mild steel were the two material samples that were put to the test. For precise attenuation tests, the mild steel block's homogeneous and consistent structure was perfect. The brake disc, on the other hand, had inconsistencies in its shape and surface roughness that made measurements more difficult. Couplant gel was put between the probe and the material surface to ensure appropriate signal transmission by removing any air gaps that can cause interference with the ultrasonic signals.

Before starting the experiment, a reference calibration block was utilised to guarantee measurement accuracy. This block's known attenuation characteristics and standardised dimensions made it possible to calibrate the ultrasonic fault detection. The distance between two signal spots on the materials—a critical variable in the attenuation formula was also measured using a measuring tape or calliper.

Even though the script described the usual process, there were several issues that needed to be fixed. For instance, it was challenging to obtain constant couplant coverage and probe contact due to the brake disc's irregular surface. In order to minimise mistakes, multiple measurements were made at slightly varied places. Furthermore, by thoroughly isolating the experimental equipment, the occasional interference generated by signal noise from the surrounding environment was reduced.

The following apparatus has been used for this entire experiment :-

1. Ultrasonic flaw detector.
2. Zero degree ultrasonic 5Mz prob.
3. Water.
4. Vernier calliper.



Fig. 1: ultrasonic Flow detector



Fig. 2 : Vernier calliper

Introduction

In the field of non-destructive testing (NDT), which is frequently used to assess the qualities of materials without causing any harm, determining the ultrasonic attenuation coefficient is a crucial procedure. High-frequency sound waves are used in ultrasonic testing to find internal characteristics, flaws, or modifications in a material's characteristics. Two material samples are supplied for this experiment: a brake disc and a rectangular block of mild steel. An ultrasonic flaw detector and a zero-degree, 5 MHz ultrasonic probe are used in the study to conduct the examination. One important metric is the attenuation coefficient, which quantifies how much the ultrasonic waves' energy or amplitude decreases as they pass through the substance. It is affected by elements including absorption, scattering, and the material's microstructure. the material's microstructure. The attenuation coefficient for both samples can be determined by using time-of-flight techniques, which measure the amount of time it takes for ultrasonic waves to go through a material and reflect back. Important details regarding the internal state of the materials, including homogeneity, grain size, and the existence of any flaws or defects, are provided by this coefficient. Understanding the attenuation behaviour of these materials is critical in several technical and industrial applications, including quality control, failure analysis, and component design. The importance of ultrasonic testing as a trustworthy and effective method for describing materials and guaranteeing their integrity in practical applications is demonstrated by this experiment.

Procedure, and Method:-

Procedure :

1. Configuration and Adjustment:
 - Attach the 5 MHz zero-degree probe to the ultrasonic defect detector.
 - In order to guarantee precision in wave velocity and time-of-flight measurements, calibrate the ultrasonic defect detector using a standard calibration block.
2. Preparation of Samples:
 - Both the brake disc and the mild steel block should have their surfaces cleaned to get rid of any debris, grease or abnormalities that could obstruct the transmission of sound waves.
 - To close air gaps and guarantee that ultrasonic waves are transmitted properly, apply a thin layer of water to the material's contact region.
3. Measurement of Material Thickness:
 - Accurately measure and note each sample's thickness using a calliper or measuring tape. Calculating the time-of-flight and attenuation coefficient requires this measurement.
4. Time-of-Flight (TOF) Measurement:
 - Make direct contact between the first sample (a mild steel block) and the ultrasonic probe.
 - Transmit ultrasonic waves into the sample and examine the reflections (echoes) on the ultrasonic defect detection screen.
 - Note the wave's time-of-flight (TOF) as it passes through the substance and bounces back.
 - To guarantee consistent readings and minimise errors, repeat the procedure several times on the material.
 - For the second sample (brake disc), follow the identical procedures and note the TOF values.
5. Attenuation Measurement:
 - Determine the first ultrasonic pulse's (incident wave) amplitude (signal strength) and contrast it with the reflected wave's (echo) amplitude.
For both samples, record the amplitude reduction.
6. Repeat Measurements:

- To guarantee the precision and dependability of the results, measure both samples several times. To adjust for any discrepancies, take the collected data and average it.

Method to calculate the attenuation coefficient:

$$\alpha = \frac{1}{2d} \ln \left(\frac{A_0}{A} \right)$$

Where:

- α = Attenuation coefficient (in decibels per unit length, dB/cm).
- d = Thickness of the material (cm).
- A_0 = Amplitude of the incident ultrasonic wave.
- A = Amplitude of the reflected ultrasonic wave.
- $\ln$ = Natural logarithm.

Conclusion:

Information on the energy loss of ultrasonic waves as they travel through a material can be found in the attenuation coefficient. Greater scattering, absorption, or internal flaws are indicated by higher attenuation levels. This technique guarantees precise evaluation of the material's characteristics and aids in comparing the two samples' microstructural variations.

Measurements and Graph of Measurements:-

Accurate measurements of the beginning amplitude and the amplitude after a wave has passed through the material are essential for calculating the attenuation coefficient when employing ultrasonic waves. The attenuation coefficient, which is directly proportional to the amount of wave energy absorbed or scattered by the material, can be determined with the aid of these measurements.

- MS STEEL BLOCK**

Steel Block H%			
Measurement	Echo 1	Echo 2	Echo 3
1	85	39	21
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
1	74	37	18
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
1	no data taken		
2	internal reflections		
3			
4			
5			
6			
7			
8			
9			
10			

- BREAK DICK**

Brake Disc H%			
Measurement	Echo 1	Echo 2	Echo 3
1	92	51	23
2	84	39	21
3	84	38	17
4	84	49	25
5	84	43	22
6	84	47	21
7			
8			
9			
10			

The initial amplitude and the amplitude after the ultrasonic wave passed through the disc's various thicknesses were recorded in order to take measurements for the brake disc sample. The attenuation coefficient for the brake disc material was determined using these data.

GRAPH



The brake disc's thickness, which the ultrasonic wave travelled through, was represented by a graph plotted against the distance. As predicted by the attenuation equation, the data points showed a linear trend. The attenuation coefficient, which measures how much the amplitude of the ultrasonic signal diminishes as it passes through the brake disc material, is shown by the slope of this line. The link between amplitude attenuation and distance travelled is validated by this graphical representation.

Calculations and error estimates –

$$\alpha = \frac{20 \log \left(\frac{A}{A_0} \right)}{Z \times 2}$$

Where:

- A is the attenuation coefficient (in dB/cm),
- A is the amplitude of the ultrasonic wave after passing through the material,
- A₀ is the initial amplitude of the ultrasonic wave before it enters the material,
- Z is the material's thickness (in cm).

➤ **Steel Block Attenuation Coefficient:-**

Determine the Initial Amplitude

- Start by measuring the ultrasonic wave's initial amplitude as it enters the steel block.

Measure Amplitude After Travel

- After the wave has passed through the steel block a predetermined distance, measure its amplitude.

Determine the Distance

- Determine how thick the wave is or how far it passes through the steel block. For consistency, this distance should be expressed in centimetres (cm).

➤ **Disk Break Attenuation Coefficient:-**

First Data Gathering

- Measure the ultrasonic wave's initial amplitude when it penetrates the brake disc material and its subsequent amplitude once the wave has penetrated a known thickness of the disc.
- Distance: Calculate the brake disc's thickness, or the distance an ultrasonic wave travels through it.

Estimated error:-

Errors will inevitably occur in any experimental measurement, and quantifying them is essential to comprehending the dependability of the findings. When determining the attenuation coefficient for the material used in braking discs, the estimated error is the measurement uncertainty that affects the outcome.

Steel Block H%							
	echo 1-2			echo2-3			echo 3-1
1	-6.76708637	-0.1781		-5.3769	-0.1415		-12.144
2	-6.50327351	-0.1711		-4.8608	-0.1279		-11.364
3	-5.90852236	-0.1555		-4.5867	-0.1207		-10.495
4	-6.02059991	-0.1584		-5.4832	-0.1443		-11.504
5	-6.20740044	-0.1634		-5.2964	-0.1394		-11.504
6	-6.22498322	-0.1638		-4.5062	-0.1186		-10.731
7	-6.2405076	-0.1642		-4.9728	-0.1309		-11.213
8	-6.73491096	-0.1772		-4.437	-0.1168		-11.172
9	-6.44438589	-0.1696		-5.1927	-0.1367		-11.637
10	-6.73491096	-0.1772		-4.437	-0.1168		-11.172
11	-6.02059991	-0.1584		-6.2586	-0.1647		-12.279
12	-7.4022183	-0.1948		-4.639	-0.1221		-12.041
13	-7.07472692	-0.1862		-5.2183	-0.1373		-12.293
14	-6.54717869	-0.1723		-4.0824	-0.1074		-10.63
15	-6.75505605	-0.1778		-3.7811	-0.0995		-10.536
16	-7.35953571	-0.1937		-4.9334	-0.1298		-12.293
17	-6.02059991	-0.1584		-3.4052	-0.0896		-9.4258
18	-6.47387961	-0.1704		-4.8608	-0.1279		-11.335
19	-7.1979331	-0.1894		-5.7448	-0.1512		-12.943
20	-6.50327351	-0.1711		-4.0329	-0.1061		-10.536

break disc							
echo1-2			echo2-3			echo3-1	
-5.12435	-0.427		-6.9168	-0.5764		-12.041	-0.5017
-6.66429	-0.5554		-5.3769	-0.4481		-12.041	-0.5017
-6.88991	-0.5742		-6.9867	-0.5822		-13.877	-0.5782
-4.68166	-0.3901		-5.8451	-0.4871		-10.527	-0.4386
-5.81622	-0.4847		-5.8209	-0.4851		-11.637	-0.4849
-5.04363	-0.4203		-6.9976	-0.5831		-12.041	-0.5017

Conclusion:-

One important metric that measures how ultrasonic waves are absorbed or scattered as they travel through a brake disc material is its attenuation coefficient. In order to assess the material's mechanical performance and integrity under operating conditions, this attribute offers important information on its internal structure, density, and homogeneity.

The link between the transmitted wave's amplitude and its distance travelled in ultrasonic testing enables the use of either time-of-flight or amplitude decay techniques. As the wave passes through the material, theoretical models predict an exponential decay of amplitude; measurement discrepancies in thickness and amplitude cause mistakes. Reliable assessment of the material qualities of the brake disc is ensured by accurate computation and appropriate error estimation, which enhances safety and effectiveness.

PART TWO

Through Wall Sizing Accuracy Analysis

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Abstract

In this work, 21 defect measurements from a larger Probability of Detection (PoD) investigation are statistically and regression-basely analysed to assess the sizing accuracy of a new ultrasonic thickness gauging process. Ten technicians used the designated tools and process to take measurements, which were recorded in millimetres to two decimal

places. The correlation between measured and genuine defect sizes was evaluated using linear regression techniques, and the accuracy of the gauging system as a whole as well as the performance of individual technicians were analysed using statistical analysis. The results are intended to determine technician variability, confirm procedure dependability, and guarantee the method's applicability for accurate defect sizing in industrial settings.

Introduction

One popular non-destructive testing (NDT) method for determining material thickness and identifying flaws in industrial components is ultrasonic thickness gauging. For engineering systems to be safe and structurally sound, these techniques must be accurate. This investigation focusses on the effectiveness of a novel ultrasonic thickness gauging technique in determining the thickness of through-wall defects as part of a broader Probability of Detection (PoD) study.

Ten skilled technicians used standardised tools and processes to perform 21 fault measurements that were documented with high precision (to two decimal places in millimetres) for the study. The dependability of this technique depends on accurate and consistent size; yet, differences in measurements may occur because of equipment constraints, inconsistent procedures, or varying operator skill levels.

The link between measured and genuine defect sizes will be examined using linear regression techniques in order to assess the procedure's accuracy. Furthermore, statistical analysis will quantify the overall precision and accuracy of the gauging process and evaluate the variation in measurements among technicians. The objectives of this effort are to validate the procedure's efficacy, shed light on possible error sources, and aid in the creation of reliable NDT techniques for industrial use.

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

The dataset is made up of through-wall defect thickness measurements that were obtained during an assessment of a novel ultrasonic thickness gauging technique. True thickness sizes of the 21 faults in the study range from 0.25 mm to 7.50 mm, and they were measured by 10 specialists using standardised tools and techniques. Every specialist took measurements for every issue, and the results show a lot of variation from the actual sizes, especially for minor flaws. There is a large variation in recorded values for flaws whose true diameters are less than 1 mm, and some technicians record noticeably higher or lower estimates. This raises the possibility of difficulties attaining accuracy for smaller dimensions, most commonly as a result of equipment constraints or irregularities in the process's application. Measurements typically exhibit better consistency among technicians as the magnitude of the defect grows, with less drastic departures from the true sizes. But there are still differences in accuracy, especially when it comes to intermediate-sized flaws (such those that are between 1 and 4 mm), where certain technicians have systematic biases and either regularly overestimate or underestimate the fault sizes. Although there are still some differences, the measurements show better agreement with genuine values for larger faults (greater than 4 mm), suggesting that human or procedural factors may have an impact on the outcomes.

This variation across technicians emphasises how crucial it is to carry out thorough statistical and regression analysis in order to evaluate each technician's performance and spot common mistakes. Through analysing the relationship between measured and true fault sizes, the study seeks to measure the precision and dependability of the process as well as the operators. In the end, the findings will lessen measurement variability, pinpoint places where the gauging method has to be improved, and increase the overall dependability of the ultrasonic thickness gauging process in real-world applications.

Prooceder of op1 chat:-

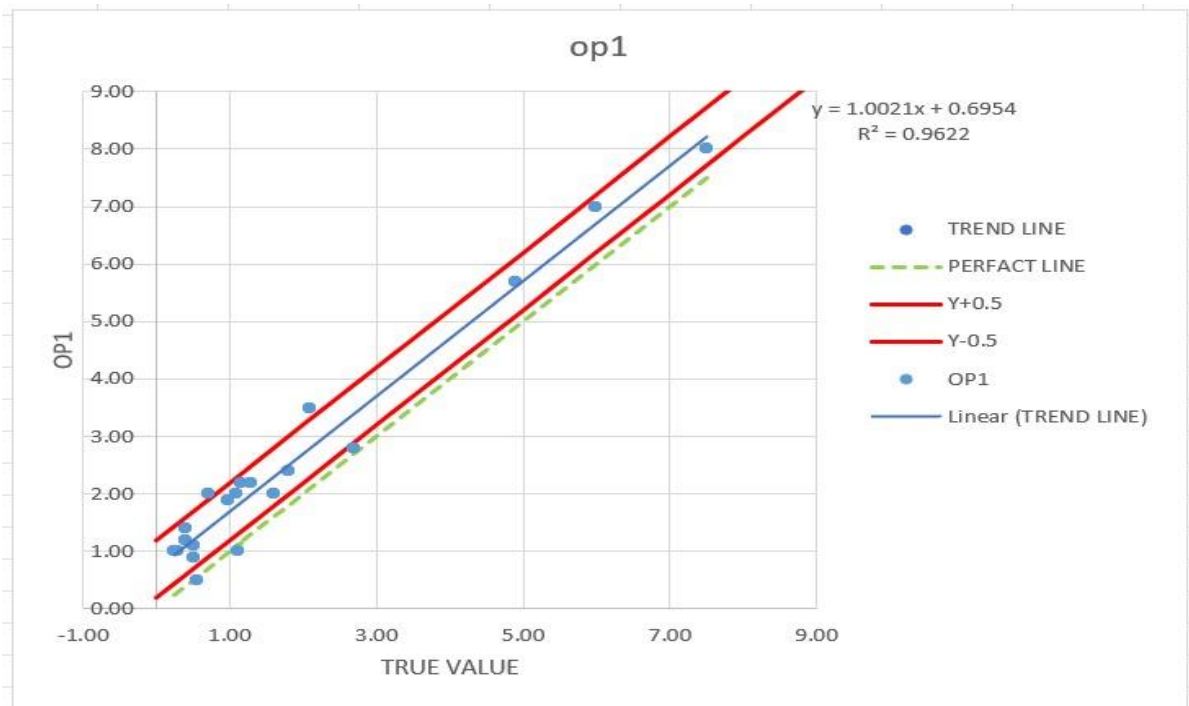
This scatter plot compares the TRUE VALUE (x-axis) with OP1 (y-axis), analysing their relationship and accuracy. The perfect line (green dashed line) represents a 1:1 relationship, where all data points would fall if OP1 perfectly matched the TRUE VALUE. However, the blue trend line, derived from the data, has a slightly different slope ($1.0021x$) and intercept ($+0.6954$), with an $R^2 = 0.9622$, indicating a strong correlation and high predictive accuracy. Two red boundary lines ($Y+0.5$ and $Y-0.5$) are drawn around the trend line to represent an error margin of ± 0.5 , providing a visual assessment of deviations. Most of the blue dots (OP1 data points) lie close to the trend line and within the red boundaries, showing that the OP1 values closely approximate the TRUE VALUE. This demonstrates a strong but slightly imperfect alignment between OP1 and the TRUE VALUE.

Defect	true size	Op1	ERROR	ABS ER- ROR	X	Y	Y+0.5	Y-0.5
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A	0.25	1.00	0.75	0.75	0	0.6954	1.1954	0.1954
B	0.27	1.00	0.73	0.73	1	1.6975	2.1975	1.1975
C	0.28	1.00	0.72	0.72	2	2.6996	3.1996	2.1996
D	0.40	1.20	0.80	0.8	3	3.7017	4.2017	3.2017
E	0.40	1.40	1.00	1	4	4.7038	5.2038	4.2038
F	0.50	1.10	0.60	0.6	5	5.7059	6.2059	5.2059
G	0.52	0.90	0.38	0.38	6	6.708	7.208	6.208
H	0.55	0.50	-0.05	0.05	7	7.7101	8.2101	7.2101
I	0.70	2.00	1.30	1.3	8	8.7122	9.2122	8.2122
J	0.98	1.90	0.92	0.92	9	9.7143	10.2143	9.2143
K	1.12	1.00	-0.12	0.12	10	10.7164	11.2164	10.2164
L	1.15	2.20	1.05	1.05	11	11.7185	12.2185	11.2185
M	1.10	2.00	0.90	0.9	12	12.7206	13.2206	12.2206
N	1.30	2.20	0.90	0.9	13	13.7227	14.2227	13.2227
O	1.60	2.00	0.40	0.4	14	14.7248	15.2248	14.2248
P	1.80	2.40	0.60	0.6	15	15.7269	16.2269	15.2269
Q	2.10	3.50	1.40	1.4	16	16.729	17.229	16.229
R	2.70	2.80	0.10	0.1	17	17.7311	18.2311	17.2311
S	4.90	5.70	0.80	0.8	18	18.7332	19.2332	18.2332
T	6.00	7.00	1.00	1	19	19.7353	20.2353	19.2353
U	7.50	8.00	0.50	0.5	20	20.7374	21.2374	20.2374

0.70 0.7152381

Chat of op1



For each technician, we will take the following actions in order to compute and estimate errors from the provided data:

Error and Calculation:

For each defect, calculate the error as: $\text{Error} = \text{Measured Size} - \text{True Size}$

1. Errors

Statistical Measures:

For each technician, calculate:

Mean Error (Bias): Average of all errors.

Standard Deviation (SD): Measures the spread of errors.

Root Mean Square Error (RMSE):



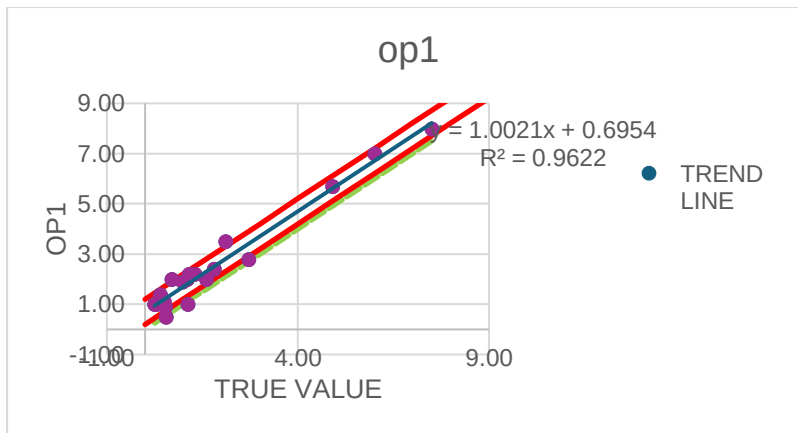
where n is the total number of defects.

2. Linear Regression:

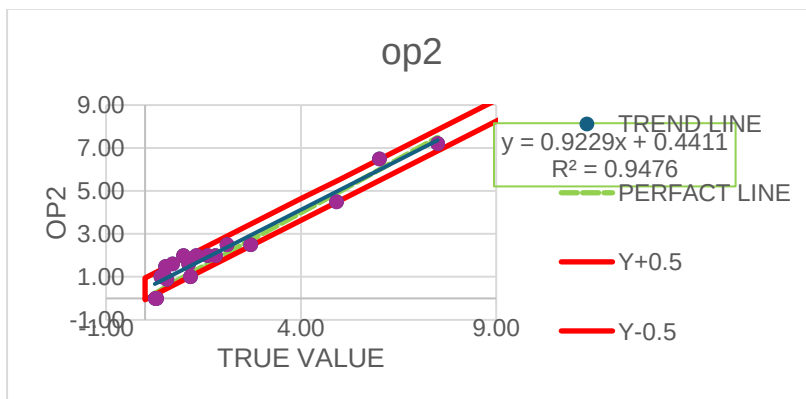
Since the genuine defect sizes are the independent variable (x) and the dependent variable (y), we will fit a linear regression model to the data in order to conduct a linear regression analysis. The standard expression for the linear regression equation is:

- $Y = mx + c$
Where:
 - Y is the measured size,
 - x is the true size,
 - m is the slope (indicating how much the measured size changes per unit change in true size),
 - c is the intercept (the value of y when $x=0$).

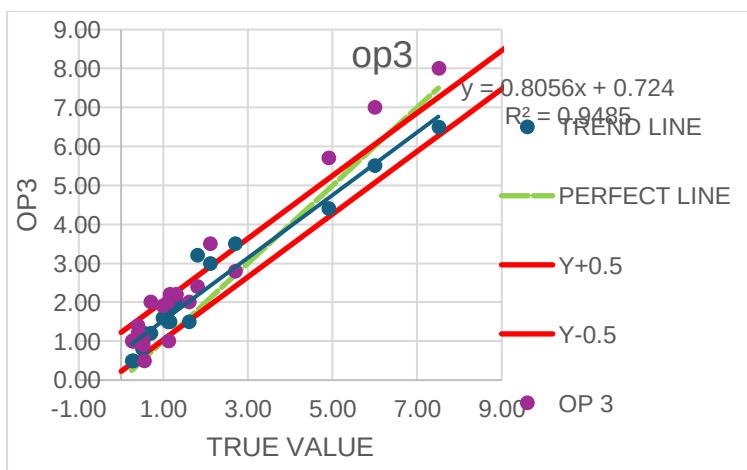
Results and Discussion:



Op1



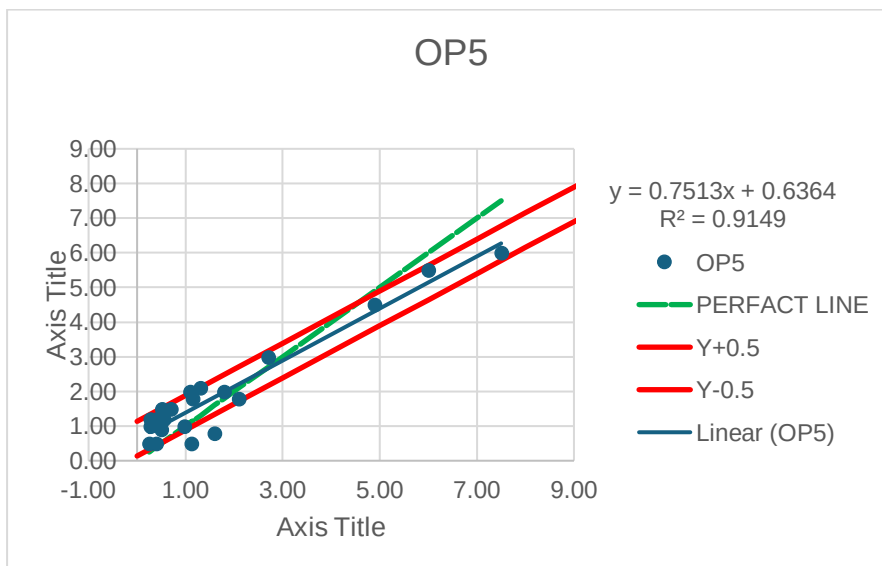
Op2



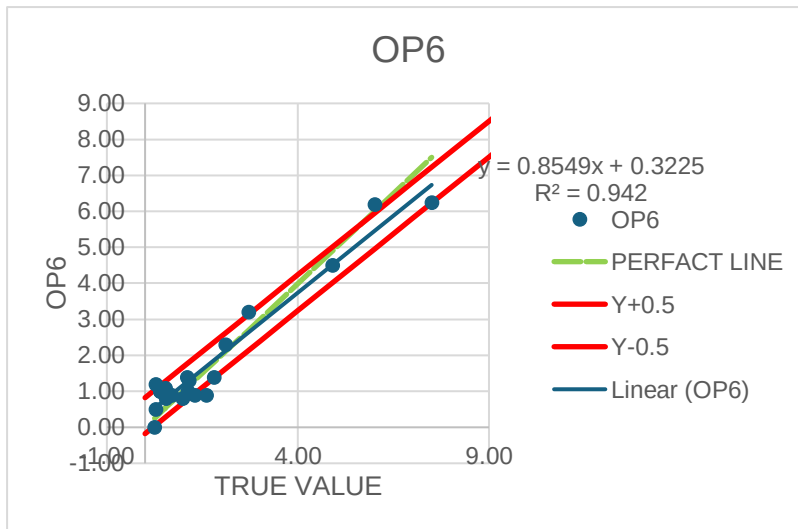
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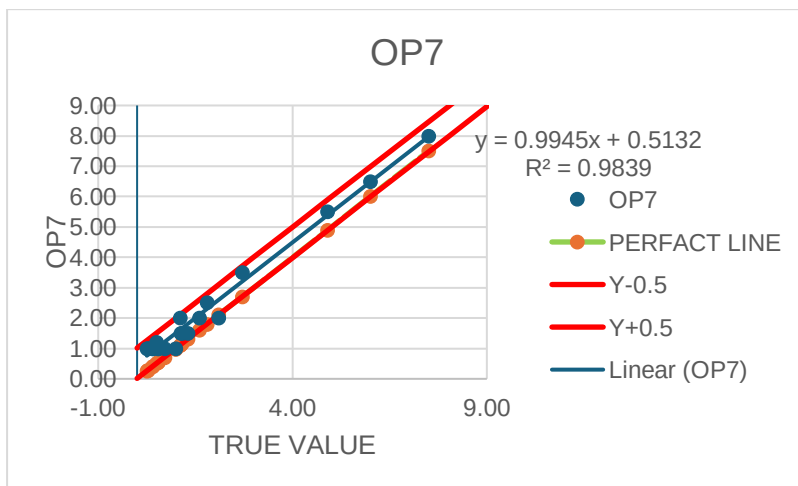
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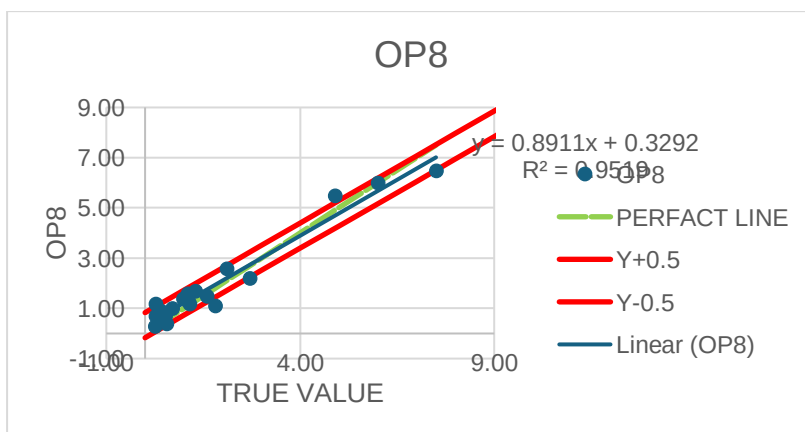
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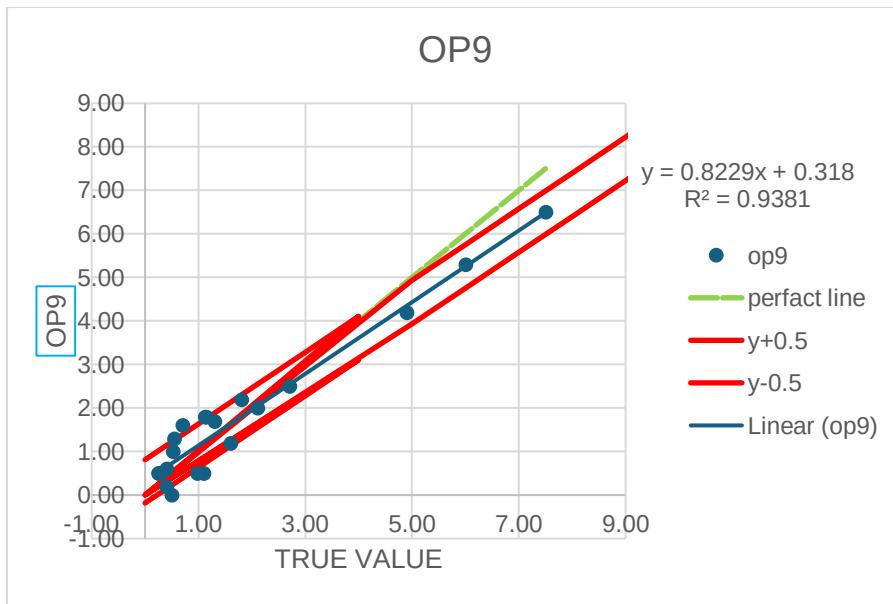
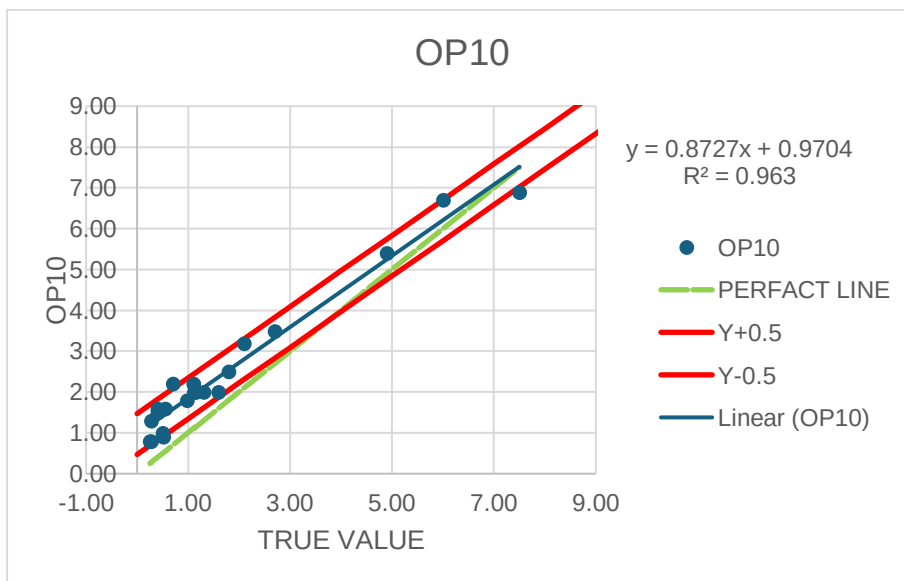
op6



Op7



Op8

**Op9****Op10**

Different levels of measurement accuracy and consistency are highlighted by the regression modelling and error analysis for each of the ten operators. There is a discernible bias in a number of operators, since the measured sizes differ greatly from the actual defect sizes. Smaller standard deviations for readings from operators 4, 6, and 8 show comparatively low variability, suggesting greater consistency among problems. However, Operators 1 and 5 show more variability and larger mean errors, indicating that their technique or calibration needs to be improved. In spite of these discrepancies, the regression equations of the majority of operators show a rather strong linear relationship between

measured and true sizes. These results highlight how crucial it is to standardise the measurement process in order to reduce errors and guarantee uniformity in defect sizing among operators.

Conclusion :-

Important information about the effectiveness of the ultrasonic thickness gauging process is revealed by the examination of defect measurements made by ten operators. There are noticeable differences in accuracy and consistency, even though the majority of operators show a rather significant correlation between measured and genuine defect sizes. While some operators exhibit considerable variations, indicating possible issues with method, equipment handling, or calibration, others show little bias and low variability, showing accurate and consistent measurements.

According to the linear regression study, individual operator performance varies, with some exhibiting higher degrees of bias and error, even while the procedure as a whole matches genuine fault sizes. In order to standardise measurements and lower variability, these disparities highlight the necessity of further training and calibration. Although the ultrasonic process is promising overall, it has to be improved and subject to stronger procedural controls to increase its dependability and guarantee uniform defect sizing among operators. Resolving these problems will increase the method's accuracy and robustness, allowing for its efficient use in defect evaluation and detection.