Experimental Method

for Mechanical Engineering

First Edition

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Preface

بسم الله الرحمن الرحيم

This book introduces experimental method for engineer which is divided into eleventh chapters. The first chapter discusses on engineering experiment. In the second chapter, technical report writing is discussed. Then, measurement concept is discussed in chapter three, dimension measurement is discussed in chapter four, weight and force measurement is discussed on chapter five, torque measurement is discussed on chapter six, pressure measurement is discussed on chapter seventh, and temperature are discussed on chapter eight, than continued with experimental uncertainties in chapter nine. Chapter ten discusses on experiment and data analysis. In the last chapter, occupational health and safety act was discussed.

In the book, many pictures and illustrations are enclosed to assist the readers' understanding. It should be noted that many pictures and contents are borrowed from other companies' websites, books and brochures. The exact sources are quoted and listed in the references. The book is for engineering education purposes only.

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To our families that always pray for our successful, all this things cannot pay for all what they all have done. Our special thanks also to our postgraduate students.

Above this all, our highest praises, thanks and syukur to Almighty Allah Subhanahu Wa'Talla, the most gracious the most merciful, who gave us the knowledge, courage and patience to accomplish this project. May the peace and blessings of Allah be upon Prophet Muhammad Sallallahu Alaihi Wasallam.

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Chapter.1

1.0 Engineering Experiment

1.1 Experimental Research

The following list of steps explains the process of conducting experimental research in more detail. Researchers should follow these steps in order to ensure the integrity of the process.

1. **Select a topic**.

   This involves simply identifying an area of interest or general subject.

2. **Identify the research problem.**

   Given the topic or subject, the researcher must now identify specific problems or questions that relate to the subject. The researcher may be familiar with subject and may already know the problem they want to research. If the researcher is new to the topic, it may be helpful to examine literature and previous studies, as well as talk to other researchers. The problem selected should be important to the field and be of significance to others in the discipline.

3. **Conduct a literature search**.

   Once the research problem is identified, a literature search should be conducted before proceeding to design the experiment. It is helpful to know what studies have been performed, the designs, the instruments used, the procedures and the findings. This information will guide the researcher and help them create a project that extends or compliments existing research.

4. **Construct a hypothesis**.

   In this step, the researcher states the research question as a hypothesis. This provides the basis for all other decisions in the process and therefore, it is a critical step.

5. **Determine the design of the research**.

   The researcher should review the hypothesis and verify that an experimental design is the appropriate research design needed to answer the question.

Additional information regarding different types of experimental research design will be covered in the next module.

6. **Determine the research methods**.

   In this step, the researcher will identify and plan the details necessary to conduct the research. This includes identifying the test subjects, materials, data collection instruments and methods, and the procedures for the conducting the experiment.

7. **Conduct the experiment to test the hypothesis**.

   The experimental procedures will be carried out in this phase.

8. **Analyze the data**.

   Experimental research data lends itself to a variety of potential statistical analyses. The appropriate analysis is determined by the research question and the type of data.

9. **Formulate conclusions.**

   Review the data and determine if it confirms or disproves the hypothesis.

1.2 Categories of Experiment

Research is a bridge that combines theory and joint experiments. In solving a problem in the field of engineering generally can be done by using two methods of theory and experiment. An expert analyzes or predicts results based on an analytical model using existing theory. If neither theory nor theory is accurate enough, the expert can conduct an experiment based on existing theories.

Figure 1.1: An example of experiment in offshore engineering

An experiment is a procedurally activity which is conducted to support, refute, validate a hypothesis or theory. Experiments provide insight into cause-and-effect by demonstrating what outcome occurs when a particular factor is manipulated. Experiments vary greatly in goal and scale, but always rely on repeatable procedure and logical analysis of the results.

Experiments typically include controls, which are designed to minimize the effects of variables other than the single independent variable. This increases the reliability of the results, often through a comparison between control measurements and the other measurements. Scientific controls are a part of the scientific method. Ideally, all variables in an experiment are controlled (accounted for by the control measurements) and none are uncontrolled. In such an experiment, if all controls work as expected, it is possible to conclude that the experiment works as intended, and that results are due to the effect of the tested variable.

All experiments involve manipulation of one or more independent variables and observing the effect on some outcome (dependent variable). Experiments can be done in the field or in a laboratory. Experiment used in engineering can be categorized based on many factors:

1. Determination of Material Properties and Object Dimensions
2. Determination of Component Parameters, Variables and Performance Indices
3. Determination of System Parameters, Variables and Performance Indices

4. Evaluation and Improvement of Theoretical Methods
5. Product and/or Process Improvement by Testing Exploratory Experimentation
6. Acceptance Testing
7. Use of physical models and analogue
8. Teaching and Learning Through Experimentation

In experiment, the scientific method used is usually:

1. Change only one variable at a time.
2. Examine on one experimental method to verify it is usable
3. Examine the believability of experiment with the ability to repeat.

1.3. Learning Outcome

This module allows students to conduct guided experiments. The guided experiment contains instruction in conducting experiments by students. It helps students in:

1. Conveying basic concepts through practical application.
2. Teaches the procedures, usage and limitation of the measuring equipment.
3. Implant good practices in data taking and magnitude level. Teaches communication manners
4. With own self – inserting records into log book.
5. With others – technical report writing.
6. Teaches experimental techniques
7. Build-up student's potential to analyze and evaluate experimental result critically.

In the end of study, the student should be able to;

1. Choose one suitable problem with the existing facilities in the allocated time.
2. Plan overall method to solve the selected problem.
3. Design the measuring system required.
4. Develop the experimental equipment.
5. Make proper adjustment on equipment and measuring system.
6. Carry out experiment.
7. Date gathering and processing.
8. Result analysis.
9. Prepare and presenting verbal/written report.

1.4 Experimental Stages

In order to carry out an experiment systematically, it has to be divided into various stages:

1. Clearly stated the experiment objective.
2. Proper preparation and planning.
3. Preliminary experiment.
4. Experiment and measurement execution.
5. Repeatability and repetition of experiment.
6. Data Analysis.
7. Report writing.

1.5. Experimental Logbook

For any engineer experiments done for the methods and results to be valid, students must document correctly, so the validity of experimental results can be examined later. Every experiment will have slight variation, thus, students or researchers must have a proper, organized recording method for further analysis purposes. Some experiment might take minutes, hours, days, weeks or even months, and each and every new experiment taken place might be an improved version from the previous one with the intention of getting better result. Thus, keeping track of all the activities happened since the beginning until the end is essential in order to avoid data lost, or mess up. If it is being done the proper way, then it will ease the report writing and presentation process.

The first thing you should write in any log is the date. Then provide some background information to justify why you are doing the experiment, and how you intend to go about doing it

1.5.1. Log Book

Log book, or laboratory journal, is a record book used to note down the experiment processes, activities, remarks, results of experiment and etc. during or after the experiment. It also has the role of:

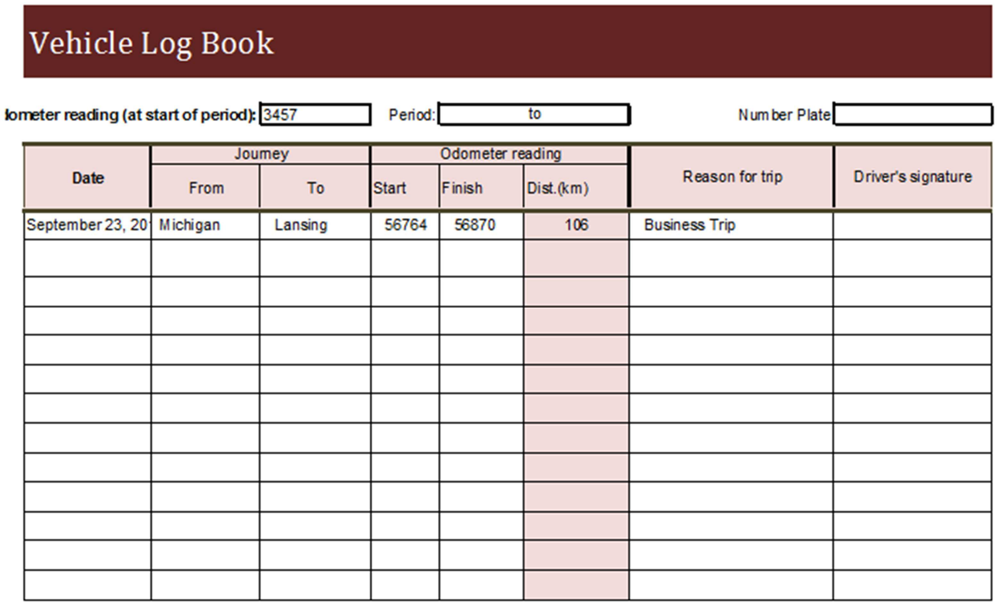
- As a record for patent law.
- Keeping accurate and complete record for experiment progress.

- Organized recording for new finding, information hard to obtain elsewhere, new finding, etc.
- As a tool for arranging, and to concentrate during report writing.

Information recorded in the log book must at least contain Information such as:

- Designing concept, date and name.
- Initial sketches/drawing.
- Initial written explanation.
- Information about first announcement to outsider.
- Initial designing experiment.

Always remember to use binded, with book cover's type of log book. Making sure that each page is numbered properly, and lose page is strongly not recommended.



Vehicle Log Book

ometer reading (at start of period): 3457 Period: to Number Plate

Date	Journey		Odometer reading			Reason for trip	Driver's signature
	From	To	Start	Finish	Dist.(km)		
September 23, 20	Michigan	Lansing	56764	56870	106	Business Trip	

Figure 1.2: An example of log book for vehicle

1.5.2. Log Book for Engineers

It is very hard just to depend on memory to remember all the data obtained from experiment, because some data might take days, weeks or months to gather from the experiment. Thus, organized entry of data into the log book is essential. An engineering student normally would do experiment:

- To justify some theory in the textbook.

- To perform standard experiments.
- To determine the performance of some machine.
- To determine some physical constant.

In order to train student in a practical way about the techniques required to carry out engineering experiment.

Log book of a student should at least include:

- Record for the experiment date.
- Objective of the experiment.
- List of apparatus prepared and notes on how to use those tools. Also record down the apparatus setup and arrangement, and if there is any difficulties in using it.
- List and make proper table to record down results obtained.
- Record all the required information so to obtain the overall experimental errors.
- Obtain sufficient results to evaluate the effectiveness and level of success for the experiment.
- Gives commentary regarding the experiment and discuss the critical result obtained.

1.6. Summary

The design of experiment can be summarized as follow:

- Objective.
- Planning.
- Method Valuation.
- Uncertainty analysis.
- Cost.
- Calibration.
- Data gathering.
- Data reduction.

Chapter.2

2.0 Technical Report Writing

2.1. Technical Report

An engineering technical report is a formal report designed to convey technical information in a clear and easily accessible format. Report writing is an essential skill for engineering students before entering real job. The engineering technical report is divided into sections which allow different readers to access different levels of information. A report must be presented in well-structure, and visually attractive manner; the competent use of technical language, and accurate referencing of all sources is also a requirement.

Engineering reports analyze data, present results and conclusions, and make recommendations in a logic and precise manner. The technical information is presented and convey through combination usage of numbers, symbols, tables, graphs, diagrams and words. Report writing process typically consists of planning, writing and revising stages that need to be improved to achieve a quality document.

2.2. Importance of Report

Engineers perform technical report to communicate pertinent information that is needed by upper management to make intelligent decisions that will affect a company's future. The technical report contains detailed knowledge decision control upper management project engineer. Many engineers spend between 1/3 and 1/2 of their work time engaged in Technical Writing. Example: Proposals, Regulations, Manuals, Procedures, Requests, Technical Reports and Progress reports

In universities, engineering students will be required to write a variety of reports while at university, such as:

- laboratory/practical reports
- field reports
- industrial experience
- vacation reports.

- thesis

2.3. Content of Report

A technical report should contain the following sections. All experiment reports is usually written in A4 size papers and bound with the provided front cover. Generally, there is no fix number of pages one is required to write a quality report. It is all depend on the content of the report. Short and precise report is much preferred than a long and less precise one. Typically for a long formal report, the number of pages are not more than 15 pages and for the short report not more than 7 pages

Table 2.1: Content of technical report

Section	Details
Title page	Must include the title of the report. Reports for assessment, where the word length has been specified, will often also require the summary word count and the main text word count – The report title or heading should at least contain: • Experiment title • Names of student or reporter • The date of experiment. – Note that: • Experiment title should be brief but informative.
Abstract	A summary of the whole report including important features, results and conclusions. The abstract is often written last as its purpose is to provide a summary of the report's essential information. All material in the abstract will also be in the report, particularly the Introduction. The abstract should appear on a separate page after the title page, and it is usually about 100– 200 words in length.
Preliminary pages	1. Content • The heading for the list of contents is Contents. The list should clearly include: o all major section/subdivision headings; numbered and worded exactly as in the text of the report (minor headings are optional) o page numbers for each section/subsection • The contents page may be set out with each level of subheading indented by a tab space. This allows the reader to understand at a glance the structure of the report, and to differentiate between important and less significant information. 2. List of Figures a) The heading for the list of figures is Figures.

	b) The list is only necessary if more than a few figures appear in the main text of the report. c) The list includes the figure number, caption, and page number, ordered as in the text. 3. List of Tables • The heading for the list of tables is Tables. • The list is only necessary if more than a few tables appear in the main text of the report. • The list includes the table number, caption, and page number, ordered as in the text. 4. Symbol • Where symbols are used extensively (typically more than 10 symbols are used), a list of definitions should appear at the beginning of the report. • If there is no list, symbols should be defined in the text when first used. • The heading for the list is Symbols. • The list of symbols should include appropriate information such as the symbol, definition, quantity to which the symbol refers, and the unit of measurement. • Use an appropriate number of significant figures or level of accuracy when presenting measurements.
Introduction	States the objectives of the report and comments on the way the topic of the report is to be treated. Leads straight into the report itself. Must not be a copy of the introduction in a lab handout.
Theory	Explains theory is used to analyze the experimental data
Experimental Set up & Data	1. Equipment 2. Methods 3. Observations and results 4. Experimental error assessment
Analysis & Discussion	Data experiment should be analyzed and discussed in detail
Conclusion	A short, logical summing up of the theme(s) developed in the main text
References	Details of published sources of material referred to or quoted in the text (including any lecture notes and URL addresses of any websites used.
Bibliography	Other published sources of material, including websites, not referred to in the text but useful for background or further reading.
Acknowledgements	List of people who helped you research or prepare the report, including your proofreaders
Appendices	Any further material which is essential for full understanding of your report (e.g. large scale diagrams, computer code, raw data, specifications) but not required by a casual reader

2.3.1. Introduction

In an essay, article, or book, an introduction is a beginning section which states the purpose and goals of the following writing. This is generally followed by the body and conclusion. The introduction typically describes the scope of the document and gives the brief explanation or summary of the document. It may also explain certain elements that are important to the essay if explanations are not part of the main text. The readers can have an idea about the following text before they actually start reading it. ln technical writing, the introduction typically includes one or more standard subsections: abstract or summary, preface, acknowledgments, and foreword.

The Introduction gives the reader the necessary background information. It can include:

- a description of purpose(s) and objective(s) / topic(s)
- a statement of the problem(s)
- a survey of background information
- a review of previous work/research and the relationship to the current project
  the method(s) of approach
- an indication of the scope and limitations of study
- an outline of material presented in the rest of the report

2.3.2. Theory

A theory written in a report can be quickly understood when it is written using a set of familiar symbols used in corresponding field of study. In every engineering field there will be a set of symbols that is used to describe theories. The usage of symbols in the theory must be consistent to avoid confusion and wrong interpretation. In a mathematical analysis, all equations must be written clearly and on separate line and numbered.

Theories are inherently speculative and approximate and experiments are not done to validate anything that is well established, understood and proven beyond any doubt it is correct. Assumptions made in the theories must be firstly questioned if the experimental did not confirm the predicted results. Any conclusion resulted from that assumption must be reexamined in detail. For presentation purposes, the main theory statement must be highlighted but the detail mathematical development is better to be placed in appendices.

2.3.3. Experimental Set up and Data

In the experimental set up, researchers should describe and explain clearly and detail all the experimental procedure to be extended that a reader can repeat the experiment without requiring further study. The operating principles of an experiment apparatus should be described clearly. It is recommended that when describing an apparatus it is better to include a clear diagram or photograph of it. The following items should be included:

1. Equipment
2. Methods
3. Observations and results
4. Experimental error assessment

Figure 2.1: Experimental setting up of the tandem arrangement of the rounded-shape FPSO in marine dynamic basin Tank.

2.3.4. Result and Discussion

As discussed above, introduction provides background information on the problem and will define the hypotheses that will be examined in the experiment. The discussion section talks about whether the hypothesis was supported by the experiment or not. The discussion section is the place to discuss patterns or trends in your results and what those patterns mean for your research.

Discuss how the experimental results compare to the findings of others who have done similar projects or sought to answer similar questions. If the results support the findings of other researchers, then cite their research and briefly describe what the similarities and differences in approaches and results were. If the results are different from previous findings, discuss why the result is differently than other researchers. If there are a few possibilities but this is not sure exactly why the results were different, talk about those possibilities but also state that more work could be done on the topic. Clarify if there may have been differences in experimental process or even errors that caused the results to differ.

Experimental observation means: Recording data such as: pressure, Temperature, Speed, etc. and the difficulty in operating the apparatus

1. All generic results and raw data must be neatly arranged in table.
2. Each measurement dimension must be stated clearly and the layout of the table should relay the differences between generic result and raw data.
3. All tables must be labeled and numbered.
4. A sample of specific calculation must be written in the report.
5. A typical calculation carried out during reducing the raw data into generic result such as averaging and calculating dimensionless parameter should be written in log book only.
6. If for some reasons, the author is compelled to show the calculation in detail, it can be referred from the main text through appendix that contains the calculation in great detail.
7. Assessing the experimental error.
   a. All experimental results should include the range of accuracy they are subjected to.
   b. The accuracy given should correspond with the accuracy of the apparatus etc.
   c. Also consider that sometimes a figure will demonstrate a numerical trend more effectively than a table.
   d. All results/finding are explained typically through graphs, diagrams etc.
   e. Consideration should be given as to whether the data is better communicated to the reader by a table or a figure.
   f. Using tables or bulleted lists will focus the reader on relevant and needed information.

g. This technique is easier for the reader than reading another paragraph.
h. For example, write an introductory comment and then list advantages and disadvantages of two types of dwellings in a table.
i. If the raw data have intrinsic significance on the experiment other than their influence on the calculated result then two graphs; one for raw data and the other for the calculated result, should be presented.
j. Do not include any graph without giving any explanation or describing its trend.
k. All result must be discussed in detail and interpreted with the aids of existing relevant theory.

2.3.5. Conclusion

The conclusion of a report must be related to, and resulting from, the material which appears in the report. The content of the Conclusion will be linked to the Introduction. The Conclusion places findings in perspective without introducing any new material, and it may include:

- a clear and concise summary of the main points
- the context and significance of the information
- a reference to the original aim(s) / purpose(s) of the report
- the application(s) of the results
- the limitations and advantages of the findings
- the student’s judgment/evaluation

2.3.6. Recommendations

Not all reports include recommendations, but if they are required recommendations should emerge from the conclusions of the report. This section is important to those who must act on the findings. Student may include a brief, persuasive statement before presenting the recommendations clearly listed in numbered or bullet points. A series of recommendations may be worded in instructional language; for example, each beginning with a verb. Recommendations may involve:

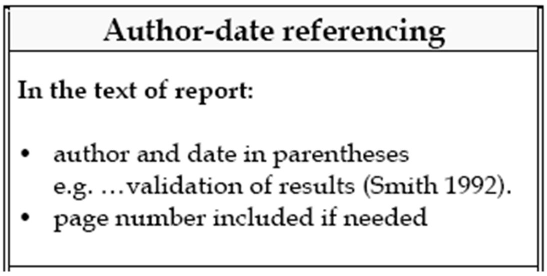
- strategies, procedures or techniques for solving the problem(s)

- an indication of further work which needs to be completed

2.3.7. References

A reference list (not to be confused with a bibliography) must appear at the end of a report, listing all sources that have been referred to in the text. The heading for this list will be References. (Students should ensure that all sources are referenced in the text as well as in the reference list at the end of the report. The format of the reference list will depend on the system of referencing chosen for the report. There are two different types of reference lists used in engineering:

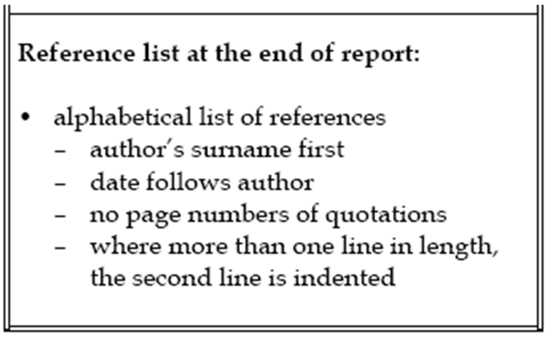
- alphabetical reference list according to author – used with the author-date (Harvard) system



Author-date referencing

In the text of report:

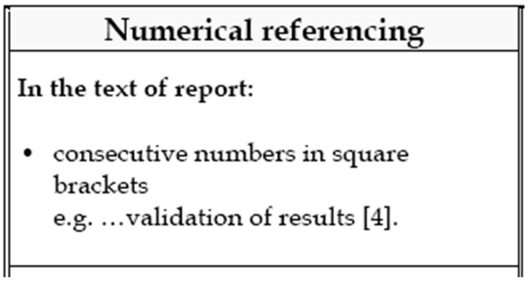
- author and date in parentheses
  e.g. …validation of results (Smith 1992).
- page number included if needed



Reference list at the end of report:

- alphabetical list of references
  - author's surname first
  - date follows author
  - no page numbers of quotations
  - where more than one line in length, the second line is indented

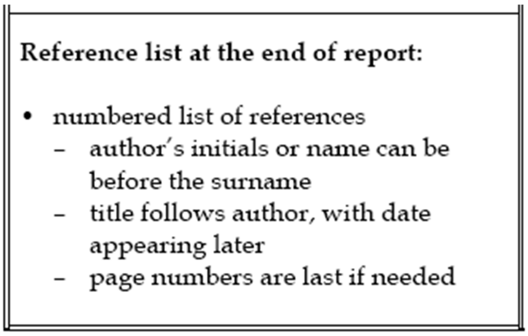
- numbered reference list in order of their appearance in the text – used with the numerical (endnote) system



Numerical referencing

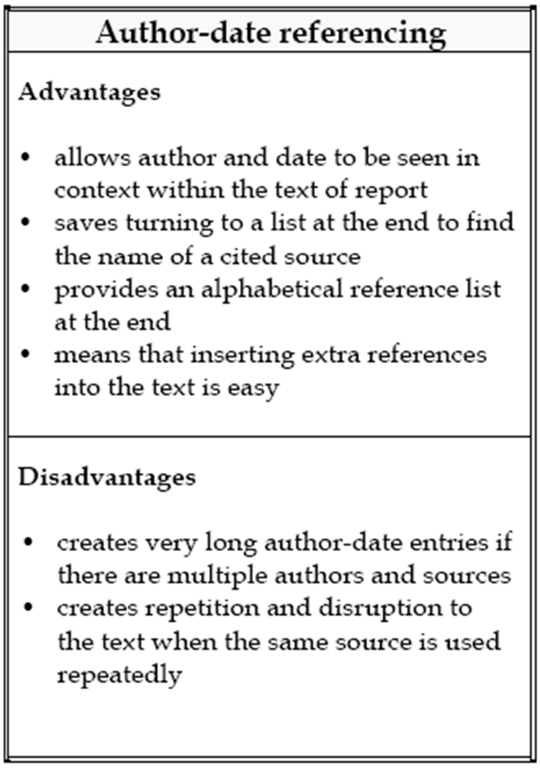
In the text of report:

- consecutive numbers in square brackets
  e.g. …validation of results [4].

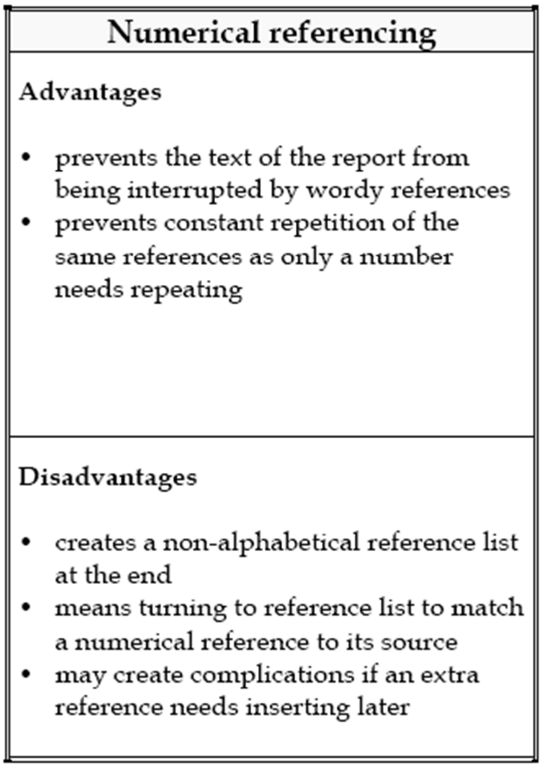


Reference list at the end of report:

- numbered list of references
  - author's initials or name can be before the surname
  - title follows author, with date appearing later
  - page numbers are last if needed



Author-date referencing
Advantages • allows author and date to be seen in context within the text of report • saves turning to a list at the end to find the name of a cited source • provides an alphabetical reference list at the end • means that inserting extra references into the text is easy
Disadvantages • creates very long author-date entries if there are multiple authors and sources • creates repetition and disruption to the text when the same source is used repeatedly



Numerical referencing
Advantages • prevents the text of the report from being interrupted by wordy references • prevents constant repetition of the same references as only a number needs repeating
Disadvantages • creates a non-alphabetical reference list at the end • means turning to reference list to match a numerical reference to its source • may create complications if an extra reference needs inserting later

- The reference list only includes the sources referred to in the report.
- A bibliography is a wider list of all texts that have been read in preparation for writing.
- A bibliography is not usually included in an engineering report

Chapter.3

3.0 Measurement Concept

3.1. Introduction

Measurement is the assignment of a number to a characteristic of an object or event which can be compared with other objects or events. The scope and application of a measurement is dependent on the context and discipline. The measurement system is the main part for experimentation. Mostly measurements use the International System of Units (SI) as a comparison framework. Proper design and application of the measurement system is vital to the success of experimental study.

In order to design properly and apply measurement systems, two kinds of information are required as follows:

1. It should be familiar with accepted methods of specifying the accuracy of any measurement system.
2. It should be aware of the different devices available for measuring specific variables such as temperature, acceleration, pressure, and voltage, so that the most appropriate apparatus will be chosen

Designing a measurement system means using suitable techniques, acceptable devices, validation testing, suitable calibration, and planning on how to handle, analyze and present measured data. Usually we need to know what to be measured, and then we can decide the devices required for the test or measurement.

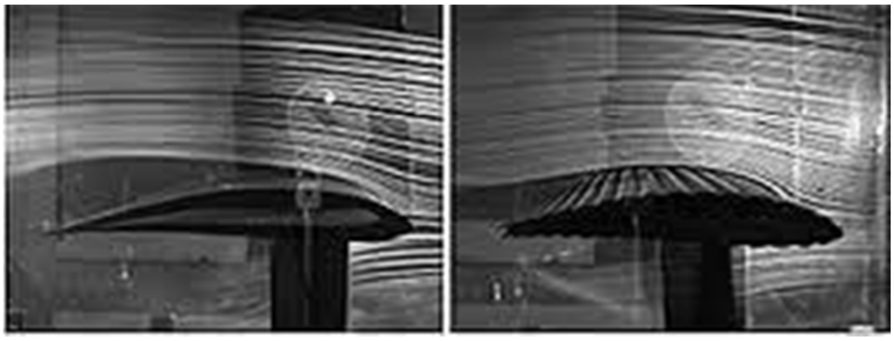


Figure 3.1: An example of measurement in aeronautics.

Regardless of the measurement system design, the following items should be followed to minimize errors;

- if several parameters need to be controlled, experimental procedure must be so designed that changes in one parameter would not influence the value of other parameters. If unable to do so, the number of influencing parameters should be reduced.
- The measurement should be designed so that the variable being measured is the only dependent variable. Others variables have to be controlled.
- measuring devices must be sensitive enough to detect any changes in the variable being measured but not the other
- signal path of a measurement system must be designed so that effects of foreign or external variables can be minimized
- Experimental plan must be so designed that effects of foreign variables are only due to random occurrences

3.2 Basic Definitions

Signal output can be influenced by many variables that result in distortion. Careful planning is needed to minimize such influence. Only during calibration one can input values can be known beforehand and the information can be used to relate input signal and output signal. One important step in designing measurement system is finding the way to do repeatable calibration that can best simulate the input signal during the actual measuring.

Table 3.1: Basic definitions in measurement

Names	Definitions
Data	Raw values obtained from experiment. Normally numerical values
Population	Collection of raw values – finite or infinite values
Sample	Part of population – collection of values obtained by experiment, finite and can represent the population
True value	Actual magnitude of measured entity e.g. pressure, velocity, temperature, etc. Actual value can be estimated but never known exactly
Indicated value	Value as displayed by measurement system. It is the source of raw data
Resolution	Equipment resolution refers to the smallest scale readable from the equipment. For instance, a thermometer that can give reading between 0° C and 100°C on 12-inch scale can have higher resolution compared to a similar thermometer but on a 6-inch scale
Error	In measurement system, it is logical to define error as the difference between the reading of the instrument and the true value of the measured quantity. Error is the difference between actual value (Va) and result (Vr). $Error = Vr - Va$ However, the nature of parameters involved in error calculations is difficult to ascertain, so the actual value of error is rarely known for sure. size of quantity In some situations, error is measured in term of fraction error $fraction\ error = \frac{quantity\ error}{size\ of\ quantity}$ And most commonly used method is percentage error percentage error = quantity error = 100

3.3. Calibration

A calibration is the act of applying a known value to the input of a measuring instrument for the purpose of observing the output. Calibration affords the opportunity to check the measurement instrument against a known standard, and subsequently to reduce error.

However, the exact true value won't be known because calibration involves comparison between an instrument and the standard. The standard, itself being physical devices, is also not perfect. Thus, it is incapable of telling us the true value.

Calibration procedures involve a comparison of particular instrument with either;

1. a primary standard
2. a secondary standard with a higher accuracy than the instrument to be calibrated
3. a known input source

A flowmeter, for instance, can be calibrated by;

- comparing it with a standard flow-measurement facility at SIRIM, British Standard Institute (BSI), or National Institute of Standards & Technology (NIST),
- comparing it with another flowmeter of known accuracy,
- directly calibrating with a primary measurement such as weighing a certain amount of water in a tank and recording the time elapsed for this quantity to flow through the meter.

3.3.1. Calibration Concept

A calibration is the act of applying a known value to the input of the measuring system for the purpose of observing the system output. The known value applied to the input is known as the standard. The relationship between the input (independent variables) and the output (dependent variables) of the measuring system is established during the calibration of the measuring system.

By application of a range of known values to the input and observation of the system output, a direct calibration curve can be developed for the measurement system.

On such a curve the input x is plotted on the abscissa against the measurement output y on the ordinate. In a calibration the input value should be a controlled input variable, while the measured output value becomes the dependent variable of the calibration.

A calibration curve forms the logic by which a measurement system's indicated output can be interpreted during an actual measurement. Alternatively, a calibration curve can be used as part of developing a functional relationship, an equation known as a correlation, between input and output. A correlation will have the form $y = f(x)$ and is determined by applying physical reasoning and curve fitting techniques to the calibration curve. The correlation can then be used in later measurements to ascertain the unknown input value based on the output value, the value indicated by the measurement system.

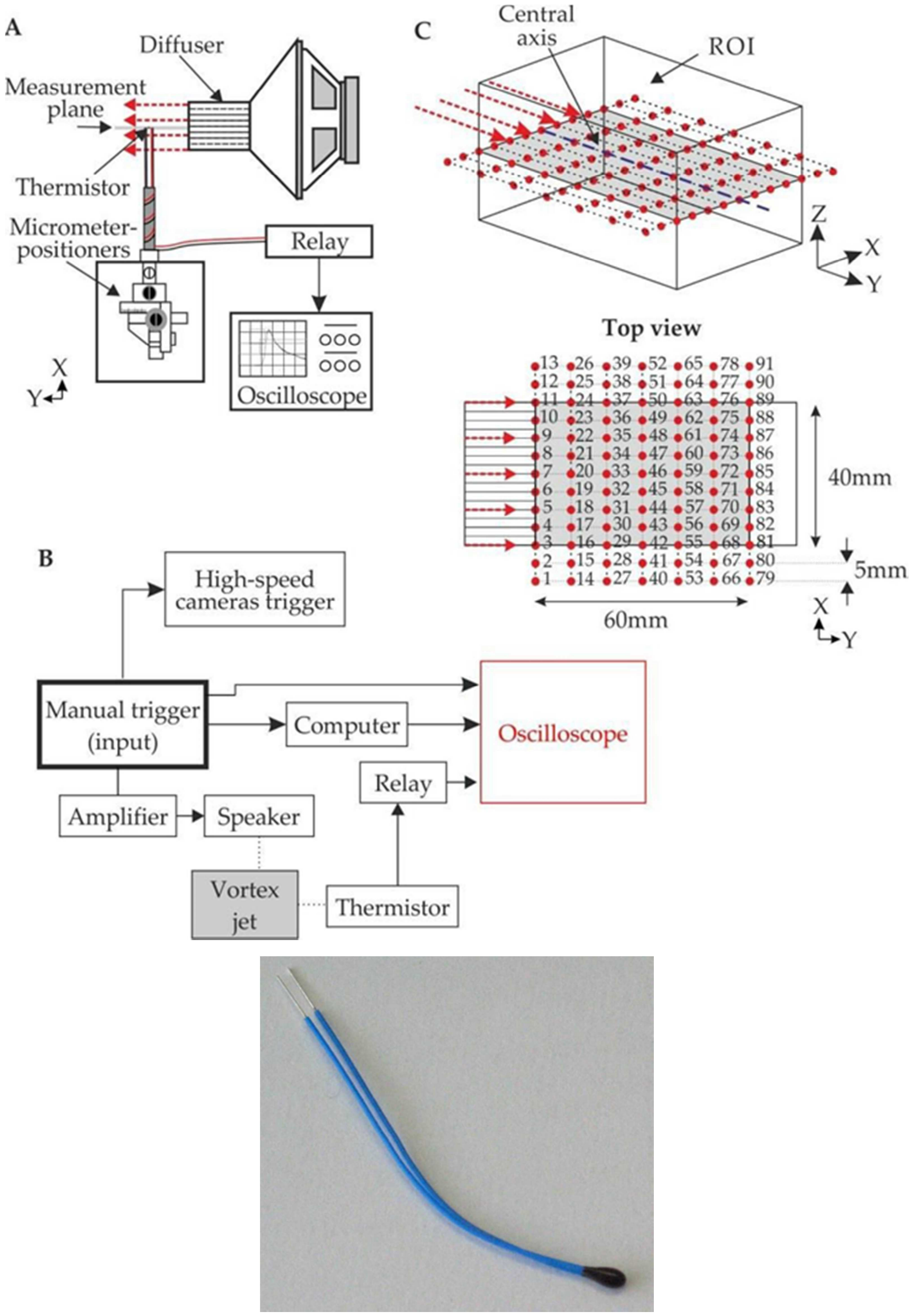


Figure 3.2: Calibration measurement.

3.3.2. Static and Dynamic Calibrations

3.3.2.1. Static Calibration

Static calibration refers to the input-output relations obtained when only one input of the instrument is varied at a time, all other inputs being kept constant. A known value is input to the system under calibration and the system output is recorded. Static refers to a calibration procedure in which the values of the variables remain constant during a measurement that is they do not change with time. Most common type of calibration which is only the magnitudes of the known input and the measured output are important.

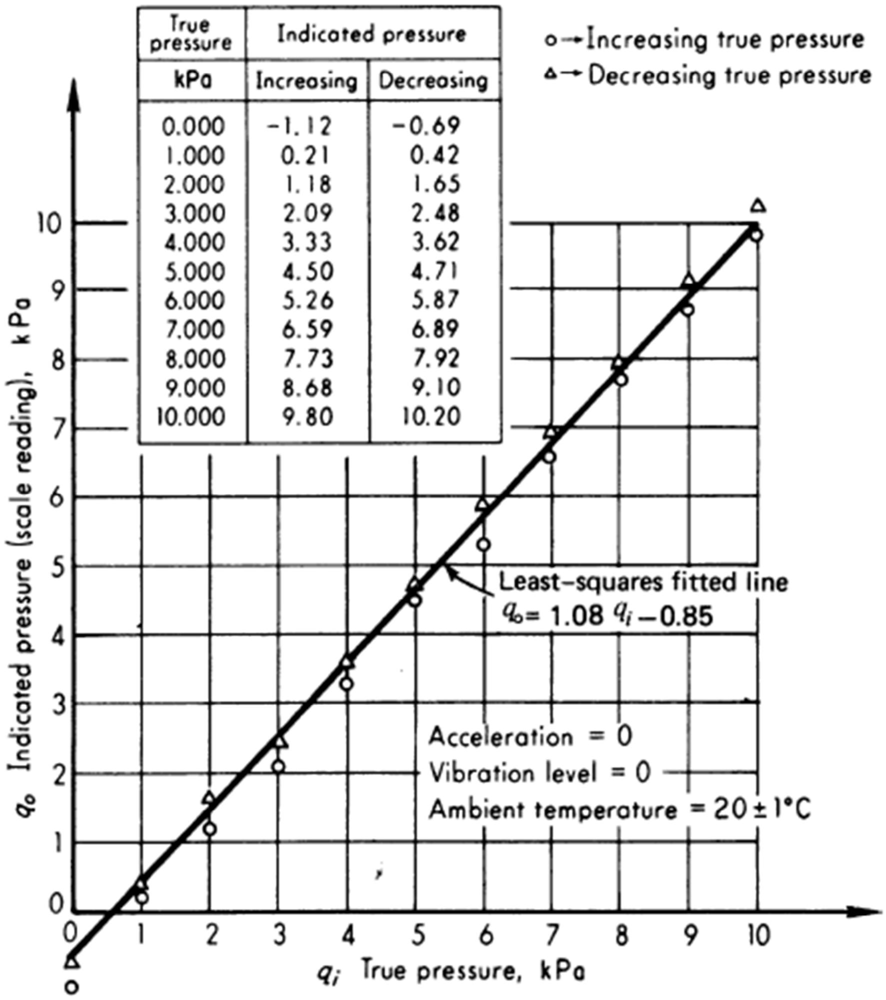
Steps for calibration:

a) Identify all the possible inputs of the instrument.
b) Decide which of the inputs will be significant in your application.
c) Determine the apparatus and methods to control (vary or maintain constant) all significant inputs over the desired range.
d) By varying one input and holding the other inputs constant, develop the sensor input-output relations.

Example: Calibration of the pressure gage sensor

- The objective in this example is to determine the relationship between the desired input (pressure) and the output (scale reading).
- The first step of the calibration process requires identifying the desired, interfering and modifying inputs of the pressure gage.
- In the second step you must determine how, or in what conditions, you are going to use the sensor.

Then you must ensure that, by choosing the appropriate experimental conditions, all the inputs of the pressure gage, except the fluid pressure, are kept constant. The fluid pressure (true value) must be varied with another instrument, in increments, over some range, causing the measured value also to vary:



True pressure	Indicated pressure	
kPa	Increasing	Decreasing
0.000	−1.12	−0.69
1.000	0.21	0.42
2.000	1.18	1.65
3.000	2.09	2.48
4.000	3.33	3.62
5.000	4.50	4.71
6.000	5.26	5.87
7.000	6.59	6.89
8.000	7.73	7.92
9.000	8.68	9.10
10.000	9.80	10.20

The average calibration curve is taken as a straight line of equation:

$$q_o = mq_i + b$$

m and b can be obtained with the least-squares criterion.

In this example, $m = 1.08$ and $b = -0.85\ kPa$

The reading qo allow us to write an estimate of the true pressure as

$$q_i = (q_o + 0.85)/1.08$$

However, this value, obtained from the least-squares line, must have some plus-or-minus error, given by the standard deviation (σ)

$$\sigma^2 = \frac{\Sigma\,[(q_o - b)/m - q_i]^2}{N}$$

$$\sigma = 0.18\ kPa$$

Thus if the reading from the gage is 4.32 kPa, our estimate of the true pressure would be

$q_i \pm 3\sigma = (4.32 + 0.85)/1.08 \pm (3\,x\,0.18)$

$= 4.79 \pm 0.54\,kP\mathrm{a}$

Note: By taking an error of three times the standard deviation, we ensure that the true pressure will be in the defined range [4.79-0.54 ; 4.79+0.54] with a probability of 99.7%.

The total error of measurement is in two parts:

- the bias, 0.47 kPa (=4.79 - 4.32)
- the imprecision, ± 0.54 kPa

3.3.2.1. Dynamic Calibration

Dynamic calibration is time dependent in both magnitude and frequency content. The input-output magnitude relation between a dynamic input signal and a measurement system will depend on the time-dependent of the input signal. Time-dependent dynamic calibration is calibrated. Variables are to be measured and a performed in addition to the static. A dynamic calibration determines the relationship between an input of known dynamic behavior and the measurement system output.

3.3.3.3. Sensitivity

The sensitivity of an instrument refers to its ability to detect changes in the measured quantity. It can be defined as the slope of the calibration curve if the input/output relationship is linear. The output quantity must be taken as the actual physical output:

> *Which is an angular displacement for the pressure gage: 5 degrees/kPa, if the spacing between two marks is 5 degrees.*
>
> *Thus the static sensitivity of the pressure gage is 5 x 1.08 (slope of the calibration curve)= 5.4o/kPa*

The sensitivity of an instrument refers to the true quantity that is being measured (qi in our example). The sensitivity of the instrument to interfering and/or modifying inputs can also be of interest.

The slope of a static calibration curve yields the static sensitivity of measurement system. As shown in the calibration curve (Figure 3.3), the static sensitivity, K, at any particular static input value, say $x1$, is evaluated by

$K = K(x1) = (dy/dx)x = x1$

Static sensitivity is a measure relating the change in the indicated output associated with a given change in a static input. "Sensitivity" is also the smallest change in measurement that measuring equipment can detect.

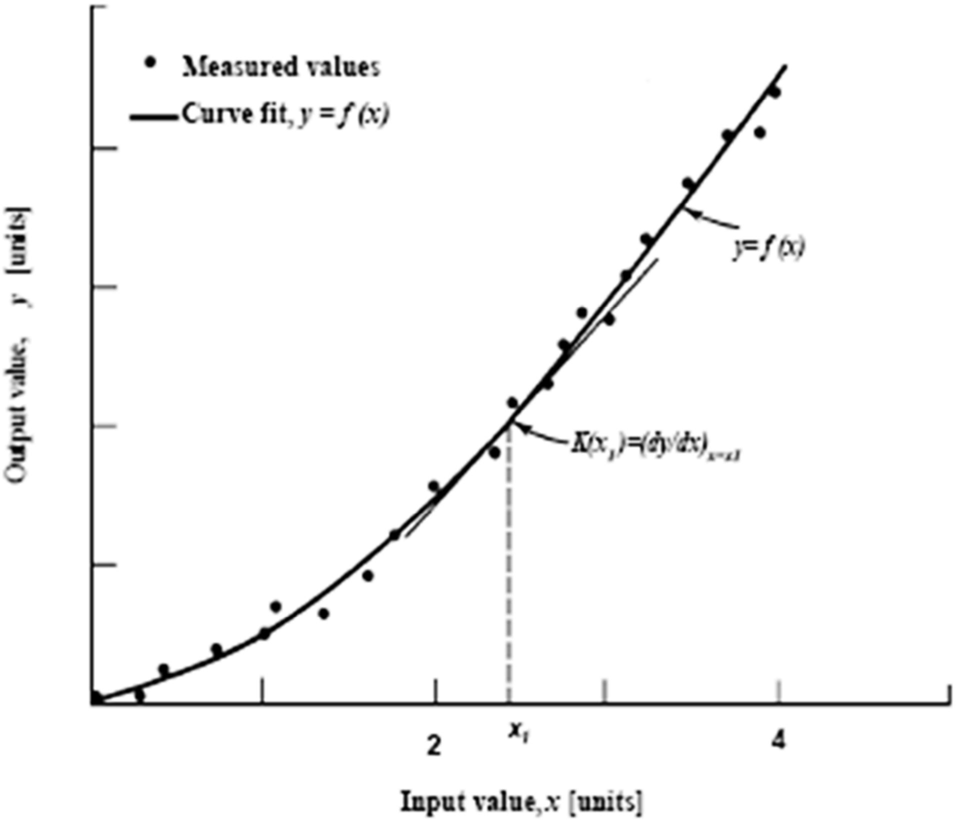


Figure 3.3: Static sensitivity

3.3.3.4. Range

The proper procedure for calibration is to apply known input ranging from the minimum and to the maximum values for which the measurement system is to be used. These limits define the operating range of the system. Input operating range is defined as

$$r_x = x_{max} - x_{min} \tag{3.1}$$

Similarly, the output operating range is defined as

$$r_y = y_{max} - y_{min} \tag{3.2}$$

It is important to avoid extrapolation beyond the range of known calibration during measurement since the behavior of the measurement system is uncharted in these regions.

3.3.3.5. Accuracy & Inaccuracy

The accuracy (lack of error) of an instrument can be evaluated in terms of the concepts of precision and bias. In practice, every device will produce an error on the measured quantities. Knowing the accuracy of that device will allow us to put bounds on the error. The accuracy of a system can be estimated during calibration. If we assume that the input value is known exactly, then the known input value can be called the true value. The accuracy of a measurement system refers to its ability to indicate a true value exactly. Accuracy is related to absolute error. Absolute error, e, is defined as the difference between the true value applied to a measurement system and the indicated value of the system:

$$e = true\ value - indicated\ value \tag{3.4}$$

Percent relative accuracy is defined as

$$A = 1 - \frac{e}{true\ value}\, x\ 100\ \% \tag{3.5}$$

By definition, accuracy can be determined only when the ‘true value’ is known, such as during a calibration.

The total inaccuracy of the measuring instrument is defined by the combination of bias and imprecision.

3.3.3.6. Precision & Imprecision

The precision of a measuring instrument is the degree to which it produces similar results for the same inputs on a number of occasions. Repeatability or precision of a measurement system refers to the ability of the system to indicate a particular value upon repeated but independent applications of a specific value of input. But note that a system that repeatedly indicates the same wrong value upon repeated application of a particular input would be considered to be very precise regardless of its known accuracy.

The imprecision (or random error) is a type of error that is not known precisely for a given measurement, just bounded. It is different for every reading and we cannot remove it.

3.3.3.7. Bias

The bias on a measurement is the part of the error that can be removed by calibration. It has the same value for all measurements.

3.3.3. Sequence Calibration

A sequence calibration applies a sequential variation in the input value over the desired input range. This may be accomplished by increasing the input value (upscale direction) or by decreasing the input value (downscale direction) over the full input range.

3.3.3.1. Hysteresis

Sequence calibration is an effective diagnostic technique for identifying and quantifying hysteresis. Hysteresis error refers to differences between an upscale sequence calibration and a downscale sequence calibration. The hysteresis error of the system is given by

$$e_h = y_{up} - y_{down} \tag{3.6}$$

The effect of hysteresis in a sequence calibration curve is illustrated in figure 3.4

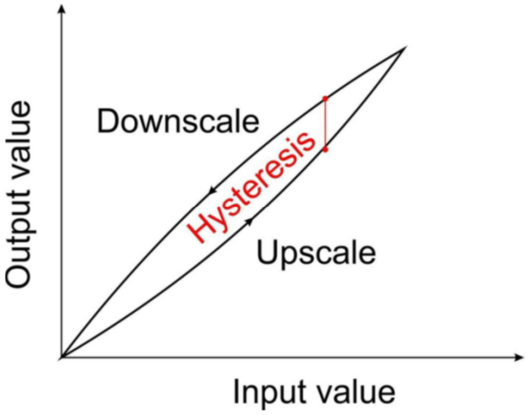


Figure 3.4: Sequence calibration curve due to hysteresis

Hysteresis is usually specified for a measurement system in terms of the maximum hysteresis error as a percentage of Full-Scale Output range (FSO)

$$\%e_h = \frac{[e_h(x)]_{max}}{r_o} x100 \qquad (3.7)$$

Hysteresis occurs when the output of a measurement system is dependent on the previous value indicated by the system. Such dependencies can be brought about through some realistic system limitations such as friction or viscous damping in moving parts or residual charge in electrical components. Some hysteresis is normal for any system and affects the precision of the system

3.3.4. Random Calibration

A random calibration applies a randomly selected sequence of values of a known input over the intended calibration range. It breaks up hysteresis effects and observation errors. It ensures that each application of input value is independent of the previous. Generally, such a random variation in input value will more closely simulate the actual measurement situation.

A random calibration provides an important diagnostic test for the delineation of several measurement system performance characteristics based on a set of random calibration test data. In particular, linearity error, sensitivity error, zero error, and instrument repeatability error can be quantified from a static random calibration

3.3.5.1. Linearity Error

Many instruments are designed to achieve a linear relation between an applied static input and indicated output values. Such a linear static calibration curve would have the general form:

$$y_L(x) = a_o + a_1 x \qquad (3.8)$$

Where: the curve fit $y_L(x)$ provides a predicted output, value based on a linear relation between x and y.

In real systems, truly linear behavior is only approximately achieved. Relationship between $y_L(x)$ and measured value y(x) is a measure of the nonlinear behavior of a system:

$$e_L(x) = y(x) - y_L(x) \tag{3.9}$$

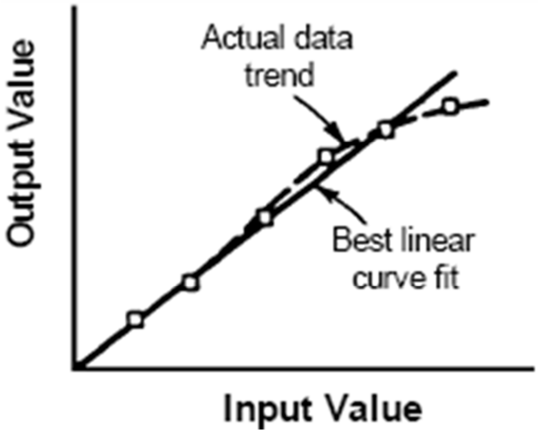


Figure 3.5: Linearity Error

Where: $e_L(x)$ is the linearity error Figure 3.5. Such behavior is illustrated in Figure 3.5 in which a linear curve has been fitted through a calibration data set. For a measurement system that is essentially linear in behavior, the extent of possible non-linearity in a measurement device is often specified in terms of the maximum expected linearity error as a percentage of full-scale output range:

$$\%(e_h)max = \frac{[e_h(x)]_{max}}{r_o} x100 \tag{3.10}$$

3.3.5.2. Sensitivity Error

The scattered data measured during a calibration affects the precision in the slope of calibration curve. As shown in Figure 3.6, if we fix the zero intercept at zero (a zero output from the system for zero input), then the scatter in the data leads to precision error in estimating the slope of the calibration curve.

Sensitivity error, e_K , is a statistical measure of the precision error in the estimate of the slope of calibration curve. Static sensitivity of a device is also temperature dependent and this is often specified by manufacturer.

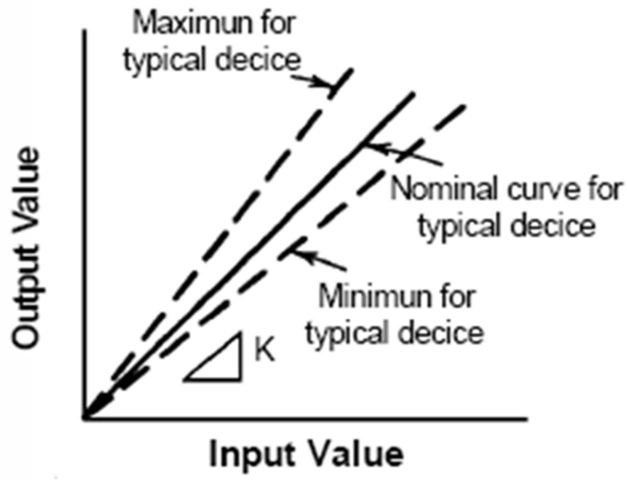


Figure 3.6: Sensitivity error

3.3.5.3. Zero Error

If zero intercept is not fixed but the sensitivity is constant, then drifting of the zero intercept introduces a vertical shift of the calibration curve (Figure 2.5). This shift of the zero intercept of calibration curve is known as the zero error, e_z of the measurement system. Zero error can usually be reduced by periodically adjusting the output from measurement system under a zero input condition. However, some random variation in zero intercept is common, particularly with electronic and digital equipment subjected to temperature variations.

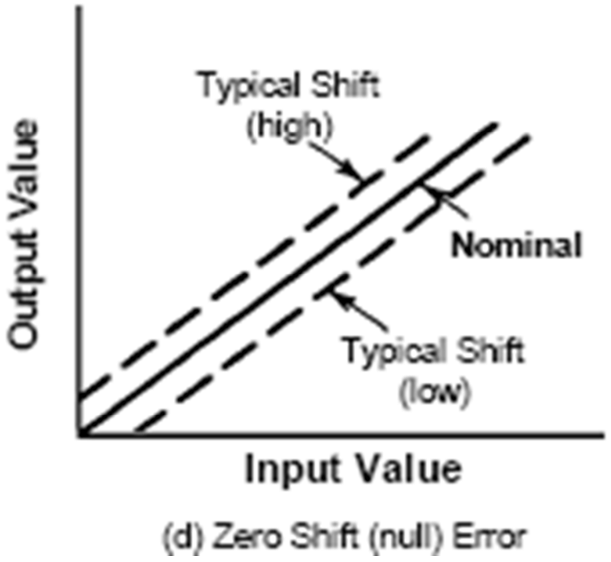


Figure 3.7: Zero Error

3.3.5.4. Repeatability

The ability of a measurement system to indicate the same value upon repeated but independent application of the same input is known as the instrument repeatability. Specific claims of repeatability are based on multiple calibration tests (replication). Repeatability as shown in Figure 3.8, is based on a statistical measure called the standard deviation (σ_x), a measure of the variation in the output for a given input.

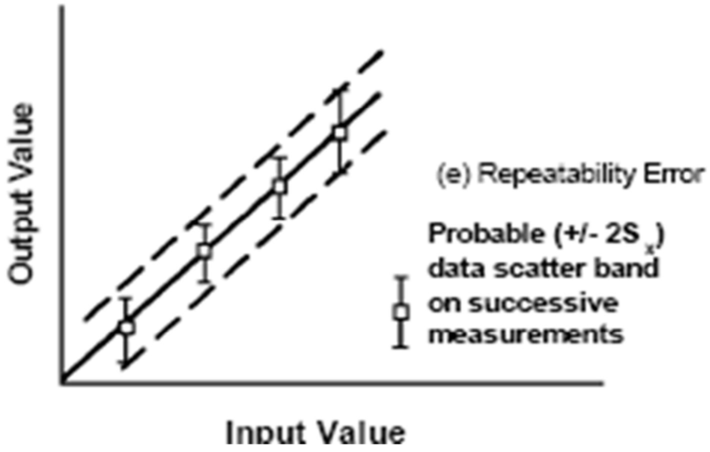


Figure 3.8: Repeatability

The value claimed is usually in terms of maximum expected error as a percentage of full-scale output range:

$$\%(e_r)max = \frac{2\sigma_x}{r_o} x100 \tag{3.11}$$

Instrument repeatability reflects only the error found under controlled calibration conditions. It does not include the additional errors introduced during measurement due to variation in the measured variable or due to procedure.

3.3.5. Standard

Measurement system is calibrated by comparing it with several standards whose values are known beforehand. Standard that is the basis of the comparison with an equipment that is well trusted by its user. Or, it could be an object that has well formulated physical properties to be used for comparison. Or, it could be a technique that has been well accepted, and known to produce trusted values. Not to confuse the meaning of the term 'unit' and 'dimension'. A dimension is a physical variable used to specify the behavior or nature of a particular system. Unit is the basic term we use to measure dimension. For instance, mass, length and time are basic dimensions that are related to unit kilogram, meter and second. Unit is defined by primary standard. Primary standard must define each unit so that it can be exact and accurate. Primary standard is needed, otherwise a unit can't be defined consistently – e.g. 1 unit meter can be defined as the length of a rod, or a distance travelled by light at a specified fraction of a second. To avoid confusion, each unit is defined by agreements at the international level. Some considerations for primary standards

- Universal availability
- Continuous reliability
- Stability
- Minimum sensitivity to surrounding environmental elements

International Measuring System only provide standard for four basic dimensions – mass, length, time, and temperature.

Standard for other dimensions are derived from the four basic ones

Standard for mass

- Dimension of mass is defined in SI system by one unit kilogram.

- One kilogram is the mass of a platinum-iridium bar kept at the International Bureau of Weights and Measures in Sevres, France.

Standard for Length

- Dimension of length is defined in SI system by one unit meter.
- Primary standard being used is the one defined in 1982 where one meter is defined as distance travelled by light in vacuum in 3.335641 × 10-9 seconds.

Standard for time

- One second is defined as the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-133 atom
- Standard for time is maintained by Bureau Internationale de l'Heure (BIH) in Paris, France.
- Meanwhile, standard for cyclical frequency is based on standard time. Standard unit is hertz

$$1Hz = 1\,cycle/second$$

- Cyclical frequency is related to circular frequency, whose unit is radians / second

$$1\,Hz = 2\pi\,radians/second$$

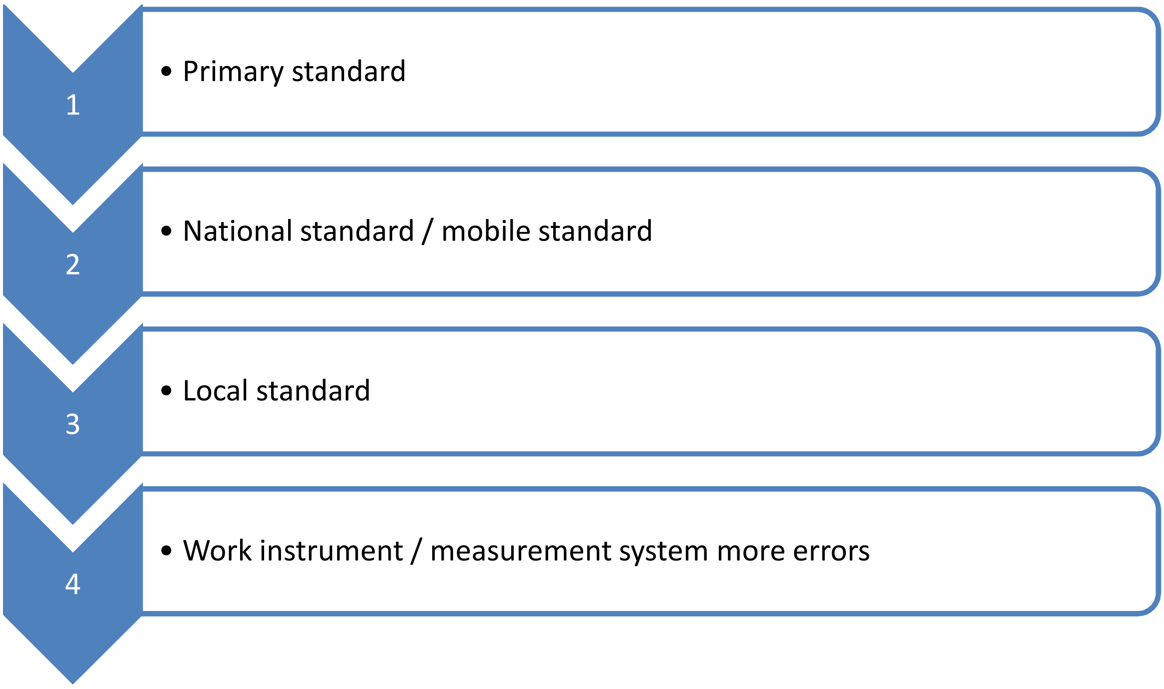
Standard for temperature

- In 1927, US, UK and Germany proposed one standard for temperature that was later known as International Temperature Scale 1927 (ITS-27).
- The standard, which was accepted by more than 30 nations, was almost the same as the thermodynamic scale proposed by Kelvin in 1848
- Due to rapid development in engineering fields, several adjustments had been made especially during conferences in 1948 and 1968 where the official name of the scale was changed to International Practical Temperature Scale of 1968 (IPTS-68)
- Now, IPTS-68 has been accepted as the primary standard for temperature by the International Committee on Weights and Measures
- Basic unit for temperature is Kelvin (K) which is defined as 1/273.16 of thermodynamic triple point of water
- Some countries are still using absolute Rankine (°R) scale

- Rankine scale is related to Celsius and Fahrenheit scale as below;
- °C = K – 273.15
- °F = °R – 459.67
- °F = [°C] ×9/5 + 32.0

3.3.5.1. Hierarchy of Standard

- Primary standard serves as the ultimate reference
- However, primary standard is not practical for use in normal or day-to-day calibration
- Therefore, there is a secondary standard which is a duplicate of the primary standard
- Secondary standard provides close approximation of the primary standard and yet is more accessible.
- Besides secondary standard, there are other levels of standard.



Due to the nature of secondary standard as a duplicate, some amount of uncertainty exists. The lower we go down the hierarchy, the more errors are introduced into the standards. The term standard can also carry a different meaning. Standard can also means a standard testing procedure. Standard testing procedure is to ensure consistent way to do measurement. Example, Power Test Code published by American Society of Mechanical Engineers (ASME)

3.3.5.1. Lab Accreditation

In Malaysia, SIRIM is responsible for maintaining secondary standards at the national level. Some companies that are involved in the manufacture of measurement devices do have their own standards Firms that offer calibration services have to have their calibration equipment calibrated by SIRIM. Only then, they can be recognized and qualified to offer calibration services.

Chapter.4

4.0 Dimension Measurement

4.1. Ruler

A ruler is a straightedge with equally spaced markings along its length which is used in geometry, technical drawing, engineering and building to measure distances or to rule straight lines. Rulers have long been made from different materials such as wood, plastic, and metals and in a wide range of sizes.

Desk rulers are used for three main purposes: to measure, to aid in drawing straight lines and as a straight guide for cutting and scoring with a blade. Practical rulers have distance markings along their edges.

4.1.1. Straight Ruler

A line gauge is a type of ruler used in the printing industry. These may be made from a variety of materials, typically metal or clear plastic. Units of measurement on a basic line gauge usually include inches, agate, picas, and points. More detailed line gauges may contain sample widths of lines, samples of common type in several point sizes, etc

Figure 4.1: Straight ruler.

4.1.2. Folding Ruler

Measuring instruments similar in function to rulers are made portable by folding or retracting into a coil when not in use. Folding ruler is ideal for carpenters and other professional craftsmen. When extended for use, they are straight, like a ruler. The illustrations on Figure 4.2 show a 2 m carpenter's rule, which folds down to a length of 24 cm to easily fit in a pocket, and a 5 m tape, which retracts into a small housing.

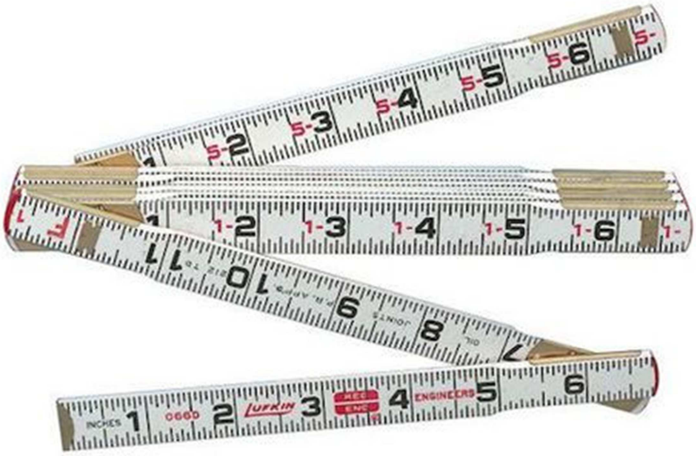


Figure 4.2: Folding ruler

4.1.3. Retractable Flexible Ruler

A flexible length measuring instrument which is not necessarily straight in use is the tailor's fabric tape measure, a length of tape calibrated in inches and centimeters. It is used to measure around a solid body, e.g., a person's waist measurement, as well as linear measurement, e.g., inside leg. It is rolled up when not in use, taking up little space.

Figure 4.3: Retractable flexible rule or tape measure

4.2. Caliper

These tools are comparators, used for transferring a dimension from one place to another. Calipers can be set from a sample of work, from a rule or from a micrometer. Most accurate setting can be obtained from a sample piece of work. Quite accurate results can be obtained by setting calipers from micrometer. The caliper legs should move smoothly but not too easily.

4.2.1. Outside Caliper

Outside calipers are used to measure the external size of an object. To adjust a caliper to the work, open the legs wider than the work and then bring them down to the work.

Figure 4.4: Outside caliper

4.2.2. Inside Caliper

Inside calipers are available in the same size range as outside calipers. They have straight legs, turned out at the top and are used to take inside measurements.

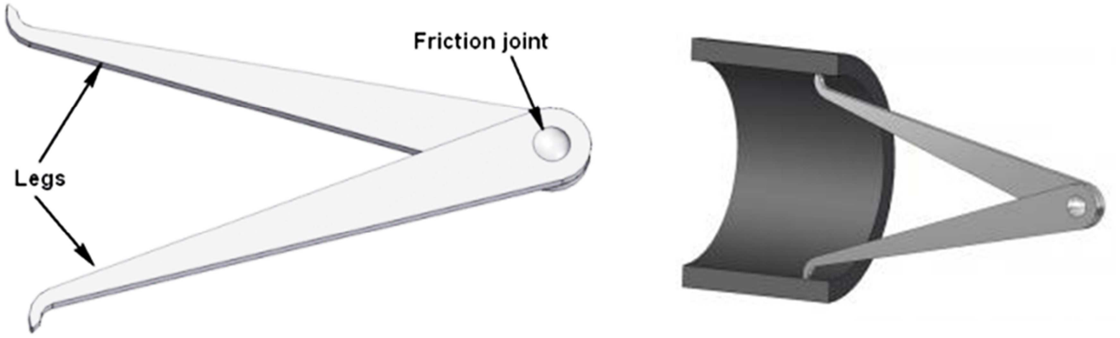


Figure 4.5: Inside caliper

4.2.3. Spring joint caliper

The spring joint calipers have legs pivoted on a roller and the legs are tensioned by means of a strong bow spring. The adjustment for measuring is made by opening and closing the legs by means of an adjusting nut.

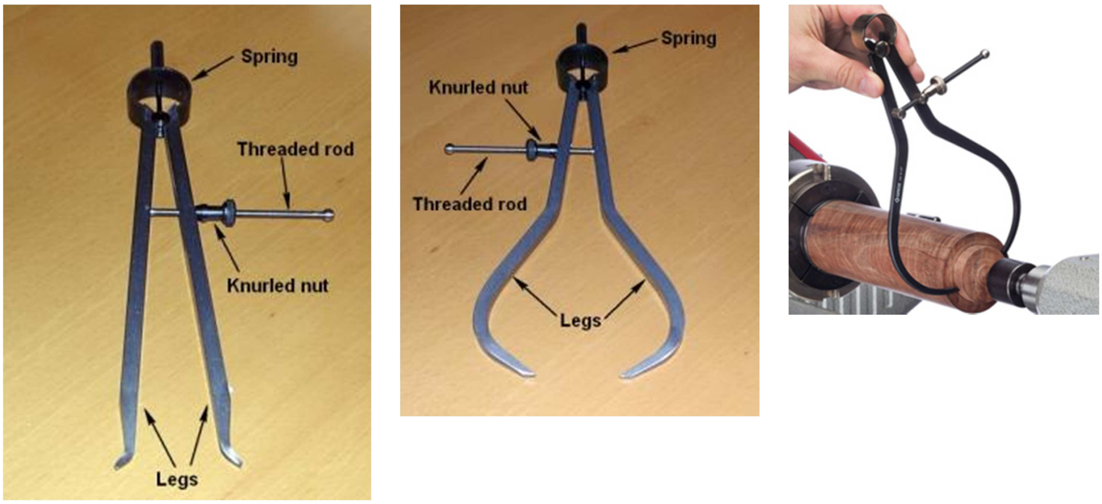


Figure 4.6: Spring joint caliper

4.2.4. Transfer caliper

Transfer calipers are used for measuring chamfered grooves or flanges. A screw attaches a small auxiliary leaf to one of the caliper legs. The measurement is made as with ordinary calipers. The leaf is locked to the leg. The legs may be opened or closed as needed to clear the obstruction. The legs are then brought back and locked to the leaf, restoring them to the original setting.

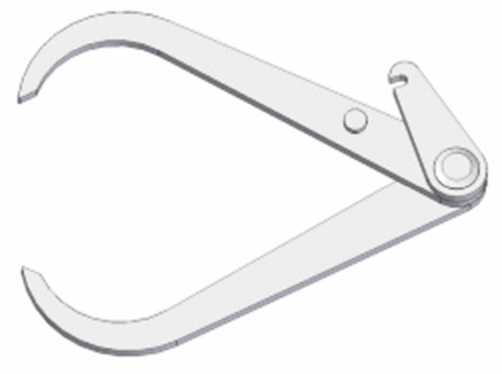


Figure 4.7: Transfer caliper

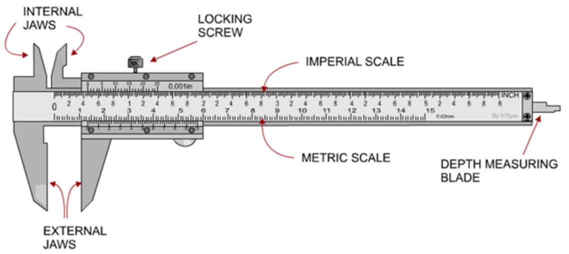
4.2.5. Odd Leg Caliper

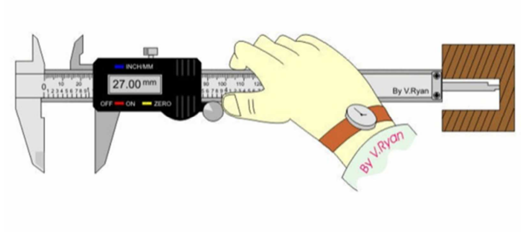
Odd leg calipers are used to draw lines parallel to an edge. They consist of one caliper leg and an leg with an adjustable scriber point. Odd leg calipers can also be used to lay out the center of round stock.

Figure 4.8: Odd leg caliper

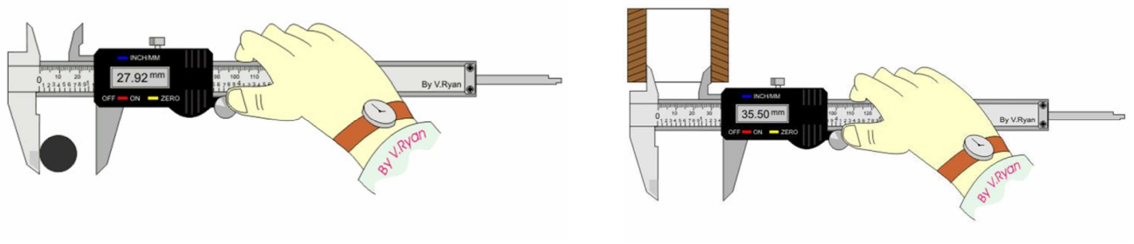
4.3. Vernier Caliper

The Vernier Caliper is a precision instrument that can be used to measure internal and external distances extremely accurately. The example shown below is a manual caliper. Measurements are interpreted from the scale by the user. This is more difficult than using a digital vernier caliper which has an LCD digital display on which the reading appears. The manual version has both an imperial and metric scale. Manually operated vernier calipers can still be bought and remain popular because they are much cheaper than the digital version. Also, the digital version requires a small battery whereas the manual version does not need any power source.





Measuring depth

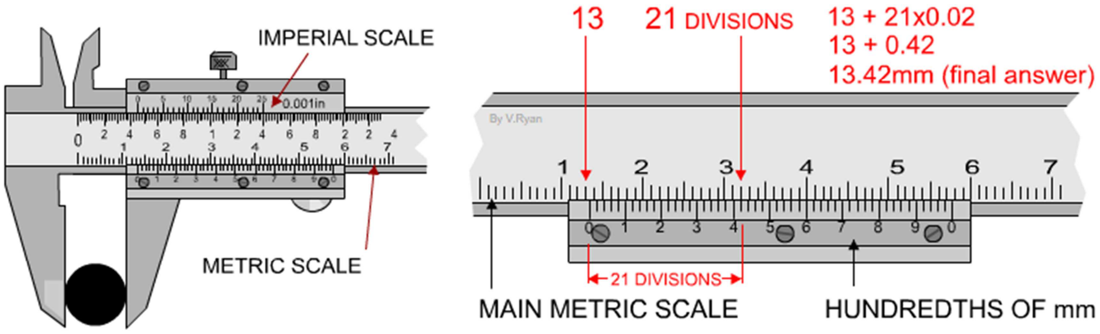


Measuring outside diameter Measuring inside diameter

Figure 4.9: Vernier caliper

Example 1:

The external measurement (diameter) of a round section piece of steel is measured using a vernier caliper, metric scale.



MATHEMATICAL METHOD

A. The main metric scale is read first and this shows that there are 13 whole divisions before the 0 on the hundredths scale. Therefore, the first number is 13.

B. The' hundredths of mm' scale is then read. The best way to do this is to count the number of divisions until you get to the division that lines up with the main metric scale. This is 21 divisions on the hundredths scale.

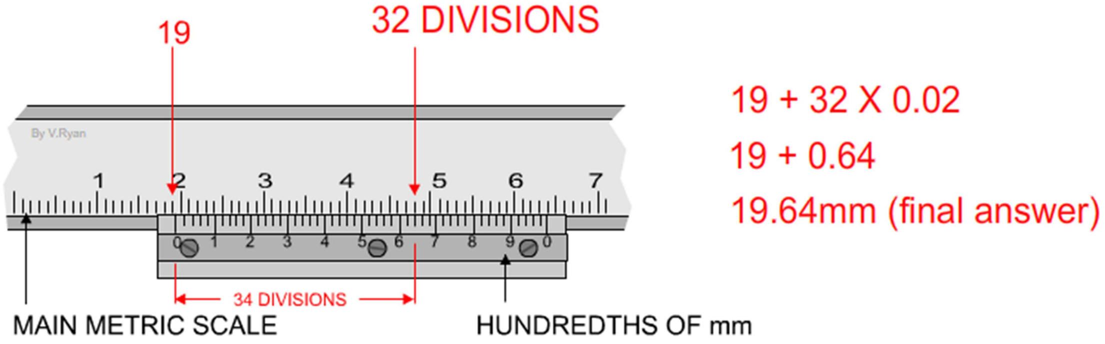
C. This 21 is multiplied by 0.02 $(100/50x0.01)$ giving 0.42 as the answer (each division on the hundredths scale is equivalent to 0.02mm).

D. The 13 and the 0.42 are added together to give the final measurement of 13.42mm (the diameter of the piece of round section steel)

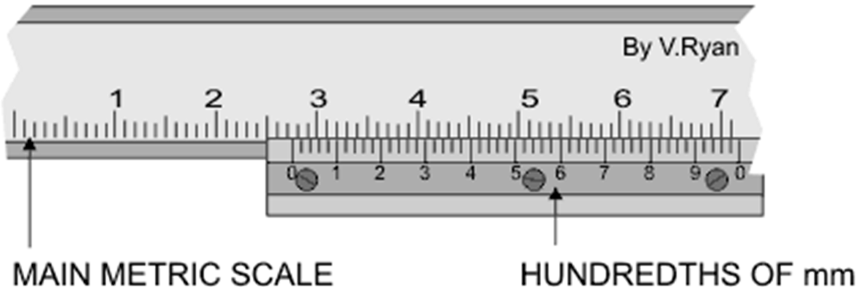
COMMONSENSE METHOD

Alternatively, it is just as easy to read the 13 on the main scale and 42 on the hundredths scale. The correct measurement is being 13.42mm.

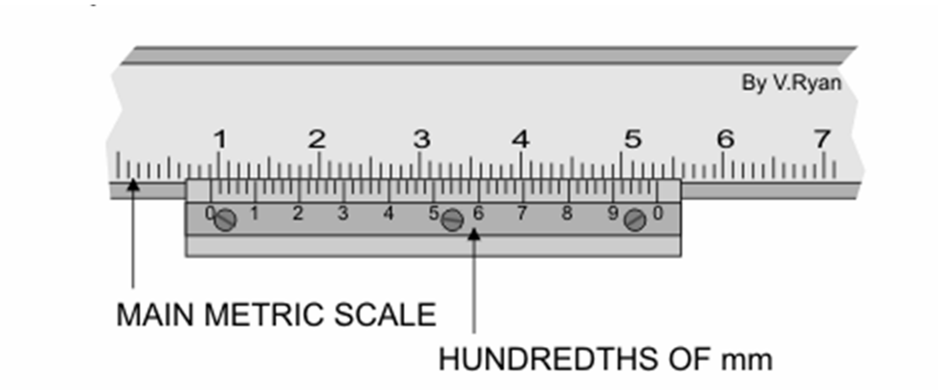
Example 2:



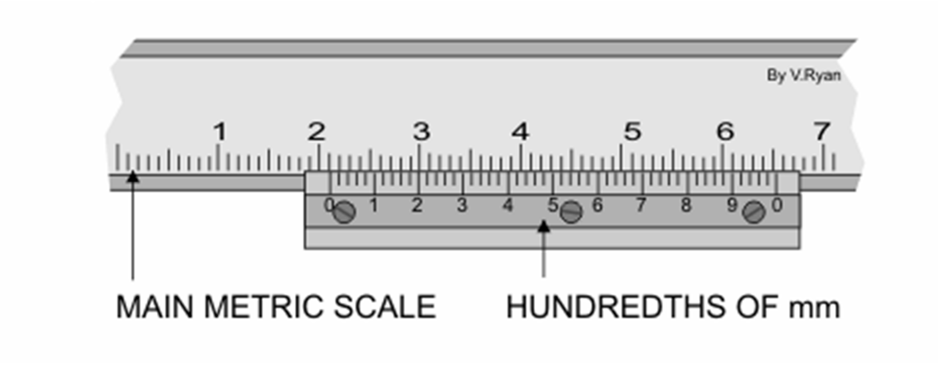
Exercise 1:



Exercise 2:



Exercise 3:



4.4. Screw gauges

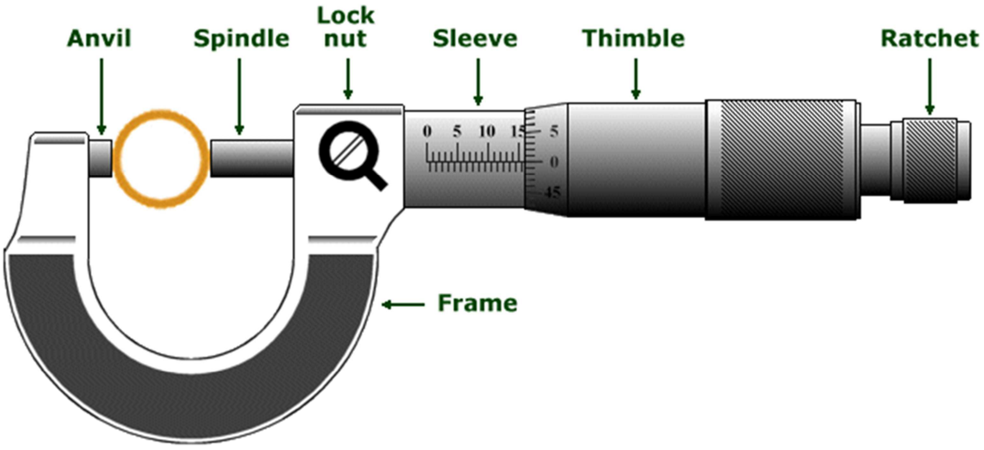
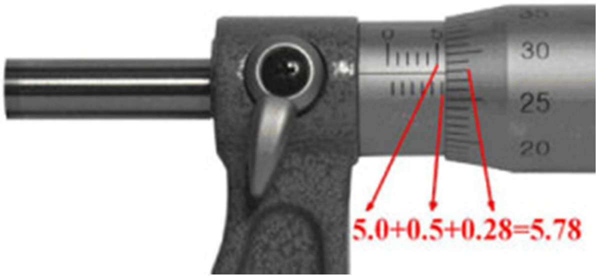


Figure 4.10: Screw gauges

Similar to the way a vernier caliper is read, a micrometer reading contains two parts:

1. the first part is contributed by the main scale on the sleeve
2. the second part is contributed by the rotating vernier scale on the thimble

Example 1:



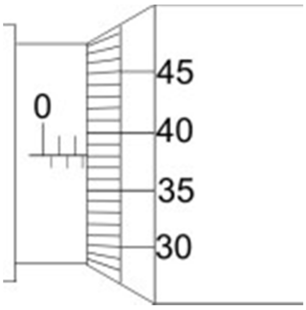
The above image shows a typical micrometer screw gauge and how to read it. Steps:

- To obtain the first part of the measurement: Look at the image above, you will see a number 5 to the immediate left of the thimble. This means 5.0 mm. Notice that there is an extra line below the datum line, this represents an additional 0.5 mm. So the first part of the measurement is 5.0+0.5=5.55.0+0.5=5.5 mm.
- To obtain the second part of the measurement: Look at the image above, the number 28 on the rotating vernier scale coincides with the datum line on the sleeve. Hence, 0.28 mm is the second part of the measurement.

You just have to add the first part and second part of the measurement to obtain the micrometer reading: 5.5+0.28=5.785.5+0.28=5.78 mm.

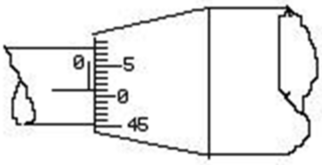
Example 2:

To ensure that you understand the steps above, here's one more example:

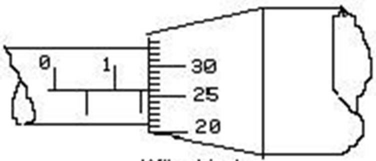


First part of the measurement: 2.5 mm, Second part of the measurement: 0.38 mm, Final measurement: 2.88 mm

Example 3:



Without object



With object

The reading on the bottom is the measurement obtained and the reading at the top is the zero error. Find the actual measurement. Measurement with zero error: 1.76 mm. Zero error: + 0.01 mm (positive because the zero marking on the thimble is below the datum line). Measurement without zero error: 1.76–(+0.01) = 1.751.76 – (+0.01) = 1.75 mm

4.5. Dial Gauges

An indicator is any of various instruments used to accurately measure small distances and angles, and amplify them to make them more obvious. The name comes from the concept of indicating to the user that which their naked eye cannot discern; such as the presence, or exact quantity, of some small distance for example, a small height difference between two flat surfaces, a slight lack of concentricity between two cylinders, or other small physical deviations. Dial indicators typically measure ranges from 0.25 mm to 300 mm with graduations of 0.001 mm to 0.01 mm. Various names are used for indicators of different types and purposes, including dial gauge, clock, probe indicator, pointer, test indicator, dial test indicator, drop indicator, plunger indicator, and others.

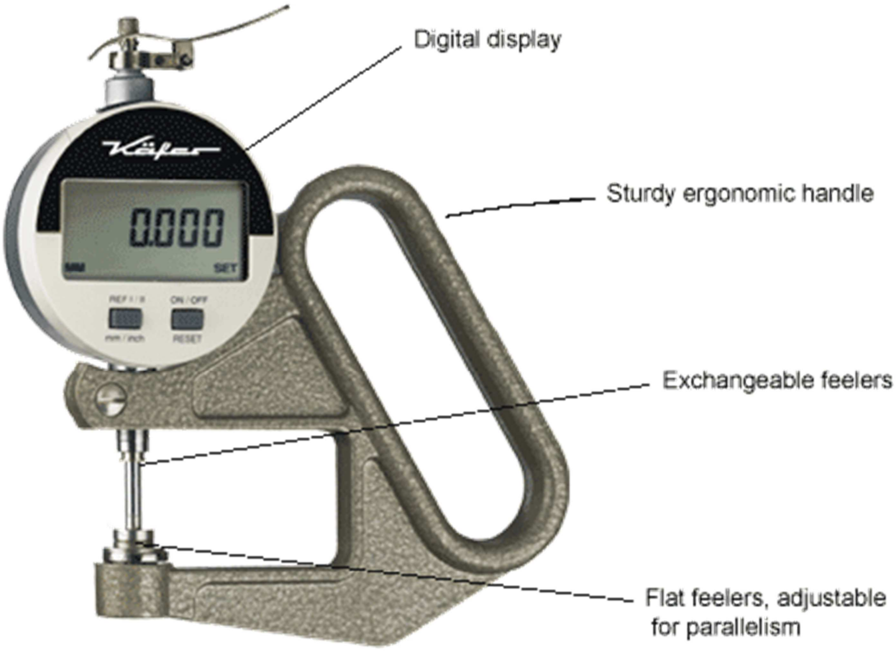


Figure 4.11: Digital thickness gauge

Chapter.5

5.0 Weight & Forces Measurement

5.1. Principle of Measurement of Mass

Mass (symbolized m) is a dimensionless quantity representing the amount of matter in a particle or object. Mass is measured by determining the extent to which a particle or object resists a change in its direction or speed when a force is applied. The standard unit of mass in the International System (SI) is the kilogram (kg).

In its conventional form, this class of measuring instrument compares the sample, placed in a weighing pan (weighing basin) and suspended from one end of a beam with a standard mass or combination of standard masses in a scale pan (scale basin) suspended from the other end

To weigh an object in the measuring pan, standard weights are added to the scale pan until the beam is in equilibrium as closely as possible. Then a slider weight usually present is moved along a scale on or parallel to the beam (and attached to it) until fine balance is achieved. The slider position gives a fine correction to the mass value.

5.1.1. Steelyard Balance

The steelyard comprises a balance beam which is suspended from a pivot which is very close to one end of the beam. The two parts of the beam which flank the pivot are the arms.

The arm from which the object to be weighed (the load) is hung is short and is located close to the pivot point. The other arm is longer, is graduated and incorporates a counterweight which can be moved along the arm until the two arms are balanced about the pivot, at which time the weight of the load is indicated by the position of the counterweight

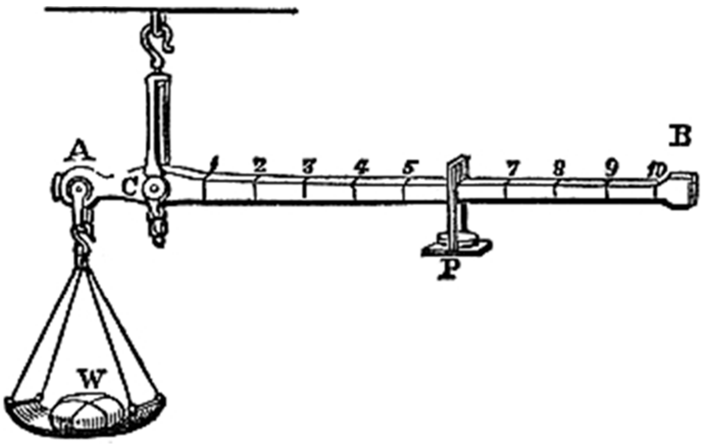


Figure 5.1: Steelyard balance

Precise measurements are achieved by

- ensuring that the fulcrum of the beam is friction- free
- by attaching a pointer to the beam which amplifies any deviation from a balance position; and finally
- by using the lever principle, which allows fractional weights to be applied by movement of a small weight along the measuring arm of the beam
- allowing for the buoyancy in air, whose effect depends on the densities of the weights and the sample.

5.2. Principle of Measurement of Force

Weight (W) is a quantity representing the force exerted on a particle or object by an acceleration field, particularly the gravitational field of the Earth at the surface. In the International System (SI) of Units, weight can be expressed in terms of the force, in Newtons, exerted on a mass in a gravitational field. The weight of an object is the force of gravity on the object and may be defined as the mass times the acceleration of gravity,

$$w = mg \tag{5.1}$$

When an elastic body is subjected to stress, its dimension or shape changes in proportion to the applied stress over a range of stresses. This led to Hooke's law which states that strain, the relative change in dimension, is proportional to stress. If the stress applied to a body goes beyond a certain value known as the elastic limit, the body does not return to its original state once the stress is removed. Hooke's law applies only in the region below the elastic limit.

Because measurement of distortion or of motion provides the means of determining the magnitude of a force, Newton's and Hooke's laws are key concepts in force measurements.

Equipment that can be used to measure force:

- Spring scale
- Proving ring
- Load cell and Strain gauge

5.2.1. Spring Balance

A spring scale or spring balance or newton meter is a type of weighing scale. It consists of spring fixed at one end with a hook to attach an object at the other. Use a spring with a known spring constant (Hooke's law) and measure the displacement of the spring to produce an estimate of the gravitational force applied by the object. A spring balance can be calibrated for the accurate measurement of mass in the location in which they are used. It cannot be used for commercial applications unless their springs are temperature compensated or used at a fairly constant temperature.

Figure 5.2: Spring balance

5.2.1.1. Hooke's Law

Consider a simple helical spring that has one end attached to some fixed object, while the free end is being pulled by a force whose magnitude is F. Suppose that the spring has reached a state of equilibrium, where its length is not changing anymore. Let X be the amount by which the free end of the spring was displaced from its "relaxed" position (when it is not being stretched). Hooke's law states that

$$F = k\,X \tag{5.2}$$

Where; k is a positive real number, characteristic of the spring.

Moreover, the same formula holds when the spring is compressed, with F and X both negative in that case. According to this formula, the graph of the applied force F as a function of the displacement X will be a straight line passing through the origin, whose slope is k.

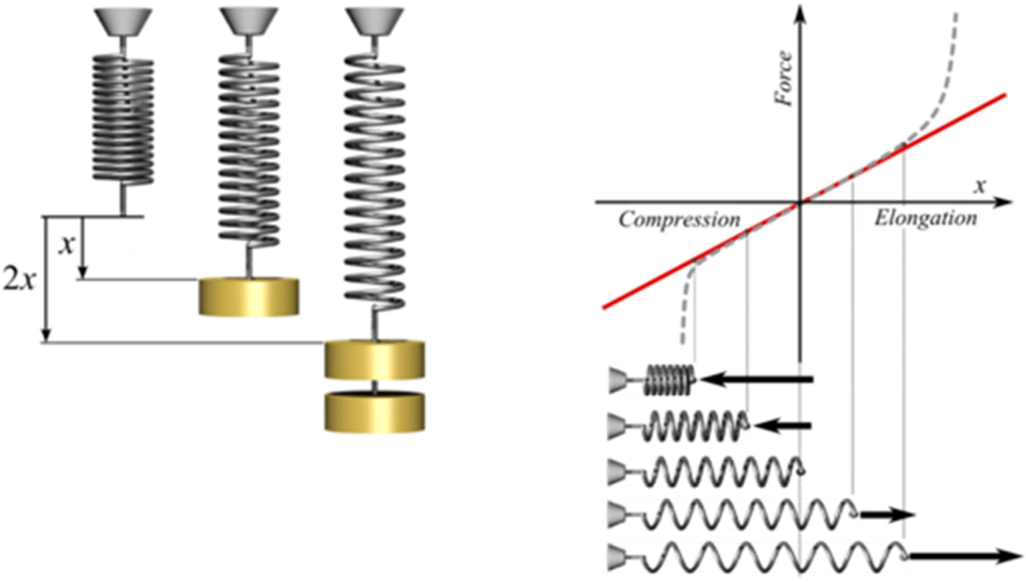


Figure 5.3: Hooke's law

Hooke's law for a spring is often stated under the convention that F is the restoring force exerted by the spring on whatever is pulling its free end. In that case, the equation becomes

$$F = -k\,X \tag{5.3}$$

Since the direction of the restoring force is opposite to that of the displacement.

5.2.2. Proving Ring

A proving ring consists of an elastic ring in which the deflection of the ring when loaded along a diameter is measured by means of a micrometer screw and a vibrating reed. The proving ring consists of two main elements, the ring itself and the diameter-measuring system. Forces are applied to the ring through the external bosses. The resulting change in diameter, referred to as the deflection of the ring, is measured with a micrometer screw and the vibrating reed mounted diametrically within the ring.

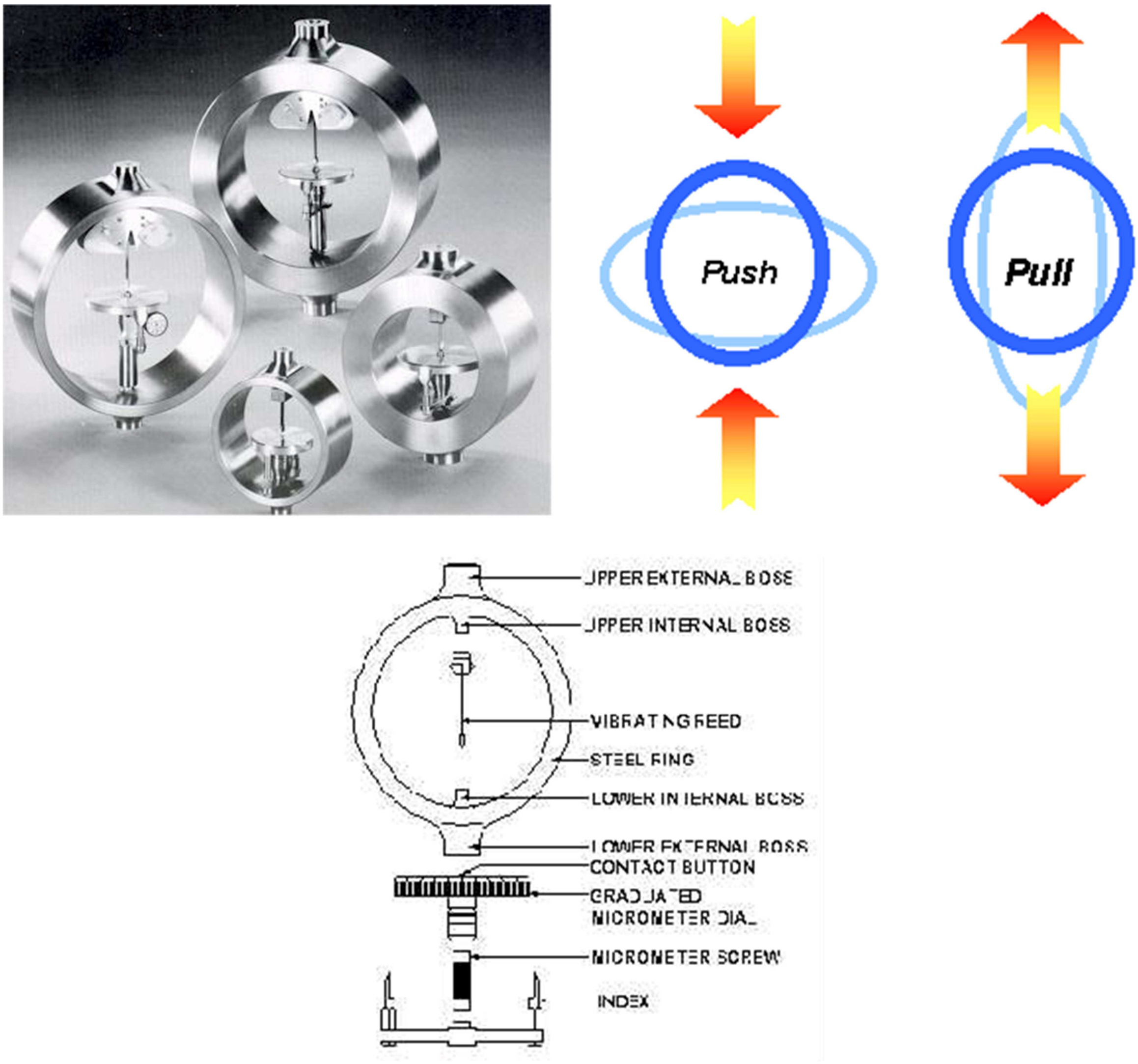


Figure 5.4: Proving ring

To read the diameter of the ring, the vibrating reed is set in motion by gently tapping it with a pencil. As the reed is vibrating, the micrometer screw on the spindle is adjusted until the button on the spindle just contacts the vibrating reed, dampening out its vibrations. When this occurs a characteristic buzzing sound is produced. At this point a reading of the micrometer dial indicates the diameter of the ring.

5.2.3. Load Cell

A load cell is an electronic device (transducer) that is used to convert a force into an electrical signal whose magnitude is directly proportional to the force being measured. The various load cell types include hydraulic, pneumatic, and strain gauge. It happens in 2stages as follows: mechanical force is sensed using a strain gauge and the strain gauge converts the deformation (strain) to electrical signals. A load cell usually consists of four strain gauges in a Wheatstone bridge configuration. The output of the transducer is plugged into an algorithm to calculate the force applied to the transducer.

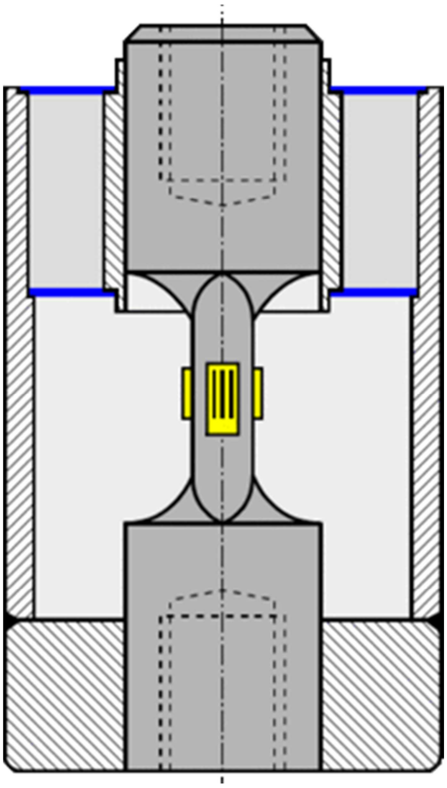


Figure 5.5: Push-pull rod load cell spring element

Strain gauge load cells are the most common in industry. These load cells are particularly stiff, have very good resonance values, and tend to have long life cycles in application. Strain gauge load cells work on the principle that the strain gauge (a planar resistor) deforms when the material of the load cells deforms appropriately. Deformation of the strain gauge changes its electrical resistance, by an amount that is proportional to the strain. The change in resistance of the strain gauge provides an electrical value change that is calibrated to the load placed on the load cell.

There are several common shapes of load cells:

1. Shear beam, a straight block of material fixed on one end and loaded on the other
2. Double-ended shear beam, a straight block of material fixed at both ends and loaded in the center
3. Compression load cell, a block of material designed to be loaded at one point or area in compression
4. S-type load cell, a S-shaped block of material that can be used in both compression and tension (load links and tension load cells are designed for tension only)
5. Rope clamp, an assembly attached to a rope and measures its tension. Rope clamps are popular in hoist, crane and elevator applications due to the ease of their installation; they have to be designed for a large range of loads, including dynamic peak loads, so their output for the rated load tends to be lower than of the other types
6. Loadpin, used for sensing loads on e.g. axles.

Common issues

1. Mechanical mounting: the cells have to be properly mounted. All the load force has to go through the part of the load cell where its deformation is sensed. Friction may induce offset or hysteresis. Wrong mounting may result in the cell reporting forces along undesired axis, which still may somewhat correlate to the sensed load, confusing the technician.
2. Overload: Within its rating, the load cell deforms elastically and returns to its shape after being unloaded. If subjected to loads above its maximum rating, the material of the load cell may plastically deform; this may result in a signal offset, loss of linearity, difficulty with or impossibility of calibration, or even mechanical damage to the sensing element (e.g. delamination, rupture).

3. Wiring issues: the wires to the cell may develop high resistance, e.g. due to corrosion. Alternatively, parallel current paths can be formed by ingress of moisture. In both cases the signal develops offset (unless all wires are affected equally) and accuracy is lost.
4. Electrical damage: the load cells can be damaged by induced or conducted current. Lightning hitting the construction, or arc welding performed near the cells, can overstress the fine resistors of the strain gauges and cause their damage or destruction. For welding nearby, it is suggested to disconnect the load cell and short all its pins to the ground, nearby the cell itself. High voltages can break through the insulation between the substrate and the strain gauges.
5. Nonlinearity: at the low end of their scale, the load cells tend to be nonlinear. This becomes important for cells sensing very large ranges, or with large surplus of load capability to withstand temporary overloads or shocks (e.g. the rope clamps). More points may be needed for the calibration curve.
6. The correct selection of a load cell for the application it is to be used in is a critical factor to realise accuracy and reliability. So what parameters need to be considered when selecting a load cell

5.2.4. Strain Gauge

When external forces are applied to a stationary object, stress and strain are the result. Stress is defined as the object's internal resisting forces, and strain is defined as the displacement and deformation that occur.

Strain may be compressive or tensile and is typically measured by strain gages.

It was Lord Kelvin who first reported in 1856 that metallic conductors subjected to mechanical strain exhibit a change in their electrical resistance.

- A strain gauge is a device used to measure deformation (strain) of an object.
- The most common type of strain gauge consists of an insulating flexible backing which supports a metallic foil pattern.
- The gauge is attached to the object by a suitable adhesive.
- As the object is deformed, the foil is deformed, causing its electrical resistance to change.

Chapter.6

6.0 Torque Measurement

6.1. Torque Transduce

Torque is measured by either sensing the actual shaft deflection caused by a twisting force, or by detecting the effects of this deflection. The surface of a shaft under torque will experience compression and tension, as shown.

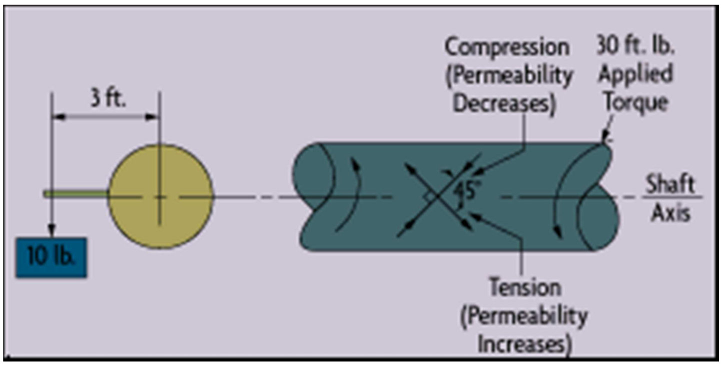


Figure 6.1: Torque measurement system.

To measure torque, strain gauge elements usually are mounted in pairs on the shaft, one gauge measuring the increase in length, the other measuring the decrease in length in the other direction. The torque sensor can be connected to its power source and signal conditioning electronics via a slip ring.

Another method is through induction coupling. Excitation voltage for the strain gauge is inductively coupled, and the strain gauge output is converted to a modulated pulse frequency. Maximum speed of such an arrangement is 15,000 rpm.

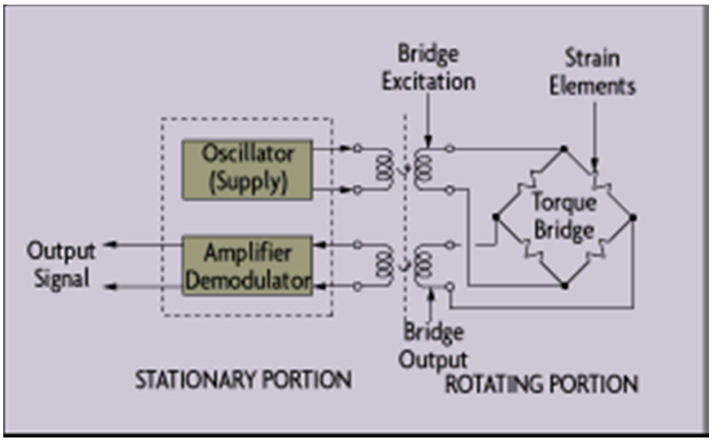


Figure 6.2: Torque measurement using strain gauge.

6.1.2. Angular Displacement

Proximity and displacement sensors also can detect torque by measuring the angular displacement between a shaft's two ends. By fixing two identical toothed wheels to the shaft at some distance apart, the angular displacement caused by the torque can be measured.

6.3. Measurement of Power

Measurement of torque is related to measurement of mechanical power such as power to drive a machine and power produced by a machine. Equipment used to measure power is dynamometer as shown in Figure 6.3. A dynamometer is a device used for measuring the torque and brake power required to operate a driven machine. They are: Three is types of dynamometer as follows:

- transmission dynamometer
- driving dynamometer
- absorption dynamometer

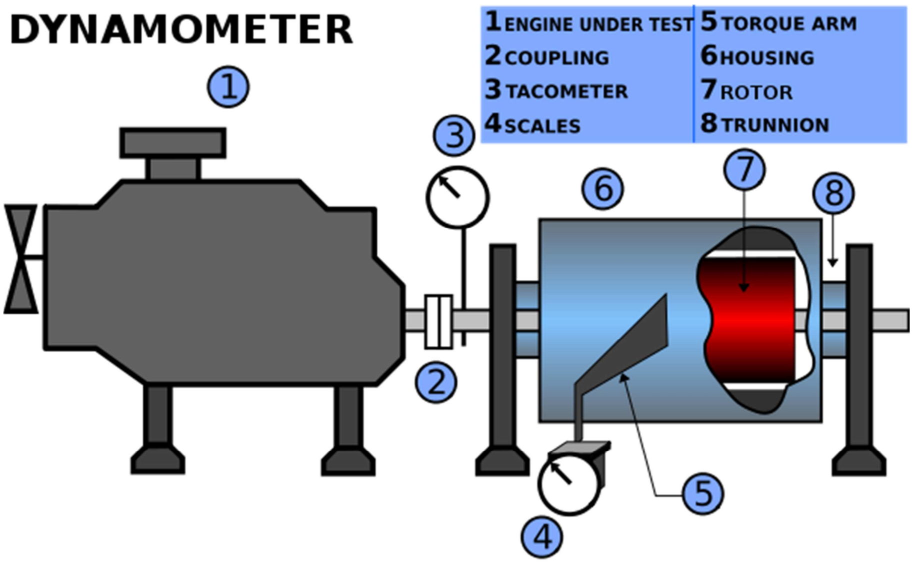


Figure 6.3: Electrical dynamometer setup showing engine, torque measurement arrangement and tachometer.

6.3.1. Transmission Dynamometer

A dynamometer is power measurement without being absorbed or used up, during transmission. The transmission dynamometer transmits the force while measuring the elastic twist of the output shaft as shown in Figure 6.4. Also called torsion meter as it measure the torque on a shaft, and hence the horse power of an engine, esp. of a marine engine of high power, by measuring the amount of twist of a given length of the shaft. A dynamometer can also be used to determine the torque and power required to operate a driven machine such as a pump. In that case, motoring or driving dynamometer is used.

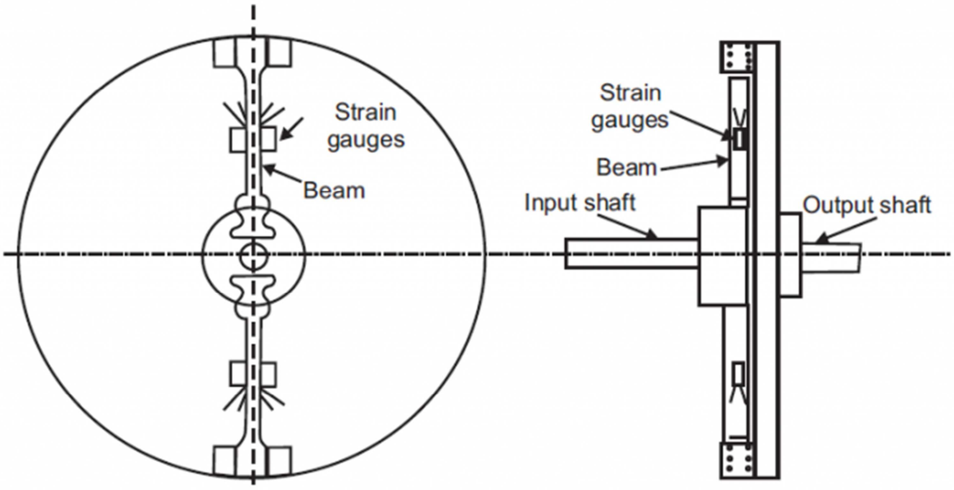


Figure 6.4: Transmission Dynamometer

Above figure shows the transmission dynamometer which employs beams and strain gauges for a sensing torque. Transmission dynamometers measure brake power very accurately and are used where continuous transmission of the load is necessary. These are mainly used in automatic units.

6.3.2. Absorption Dynamometer

Absorption Dynamometer consists of an absorption unit, plus a means to measure torque and rotational speed. It has some type of rotor in housing. The rotor is coupled to the engine under test and is free to rotate. They mostly consist of a set of strain-gauges fixed on the rotating shaft and the torque is measured by the angular deformation of the shaft which is indicated as the strain gauge. A four arm bridge is used to reduce the effect of temperature, and the gauges are arranged in pairs such that the effect of axial or transverse load on the strain gauges is avoided.

Some means is provided to develop a braking torque between dynamometer's rotor and housing. The means for developing torque can be frictional, hydraulic, electromagnetic etc. according to the type of absorption/driver unit. Three types of absorption dynamometer:

1. Mechanical
2. Eddy Current
3. Hydraulic

Absorption dynamometers produce the torque that they measure by creating a constant restraint to the turning of a shaft by either mechanical friction and fluid friction, or electromagnetic induction.

6.3.2.1. The Prony Brake

The Prony Brake is a simple device to measure the torque produced by an engine based on mechanical friction. Prony brake develops mechanical friction on the periphery of a rotating pulley by means of brake blocks that are squeezed against the wheel by tightening the bolts. Essentially the measurement is made by wrapping a cord or belt around the output shaft of the engine and measuring the force transferred to the belt through friction. The friction is increased by tightening the belt until the frequency of rotation of the shaft is reduced. In practice more engine power can then be applied until the limit of the engine is reached.

In its simplest form an engine is connected to a rotating drum by means of an output shaft. A friction band is wrapped around half the drum's circumference and each end attached to a separate spring balance. A substantial pre-load is then applied to the ends of the band, so that each spring balance has an initial and identical reading. When the engine is running, the frictional force between the drum and the band will increase the force reading on one balance and decrease it on the other. The difference between the two readings multiplied by the radius of the driven drum is equal to the torque.

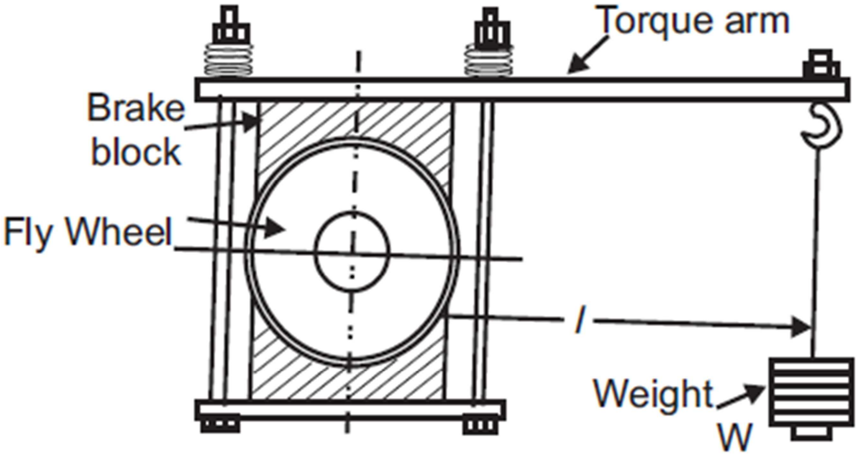


Figure 6.5: Prony Brake

$$BHP = Tx\omega = Tx2\pi N \quad (5.1)$$

But, $T = mgL$

$$BHP = mgLx2\pi N \quad (5.2)$$

6.3.2.2. Rope Brake

The rope brake as shown in below figure is another device for measuring brake power of an engine. It consists of some turns of rope wound around the rotating drum attached to the output shaft. One side of the rope is connected to a spring balance and the other side to a loading device. The power is absorbed in friction between the rope and the drum. Therefore drum in rope brake requires cooling.

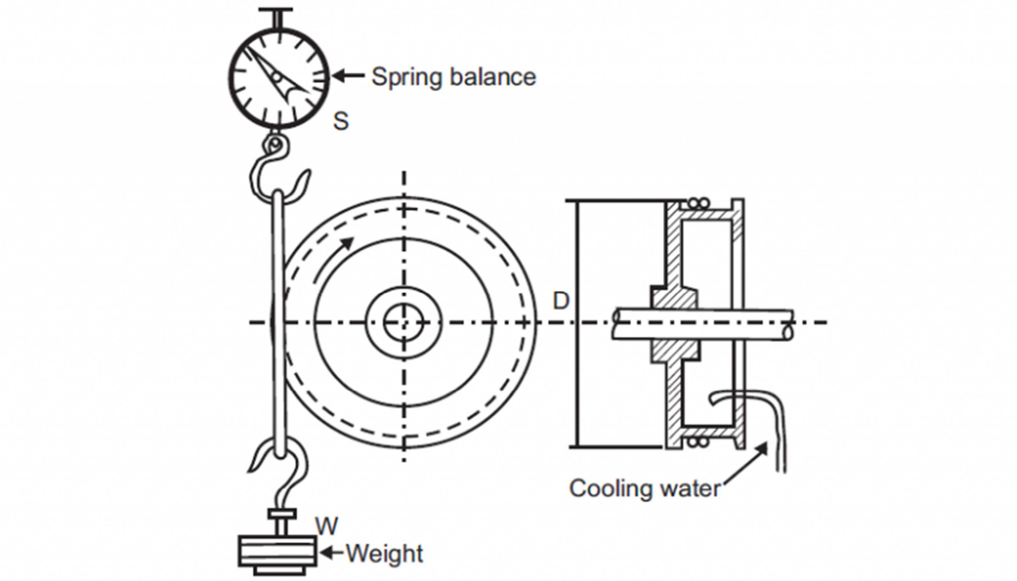


Figure 6.6: Rope Brake

Rope brake dynamometers are cheap and can be constructed quickly but brake power can't be measured accurately because of change in the friction coefficient of the rope with a change in temperature. The brake power is given by the formula

$$BHP = \pi\, DN\, (W - S) \quad (5.3)$$

Where; D is the brake drum diameter, W is the weight of the load and S is the spring balance reading.

6.3.2.3. Eddy Current

The working principle of eddy current dynamometer is shown in the figure below. It consists of a stator on which are fitted some electromagnets and a rotor disc made of copper or steel and coupled to the output shaft of the engine. When the rotor rotates, eddy currents are produced in the stator due to magnetic flux set up by the passage of field current in the electromagnets. These eddy currents are dissipated in producing heat so that this type of dynamometer requires some cooling arrangement. The torque is measured exactly as in other types of absorption dynamometers, i.e., with the help of a moment arm. The load in internal combustion engine testing is controlled by regulating the current in the electromagnets.

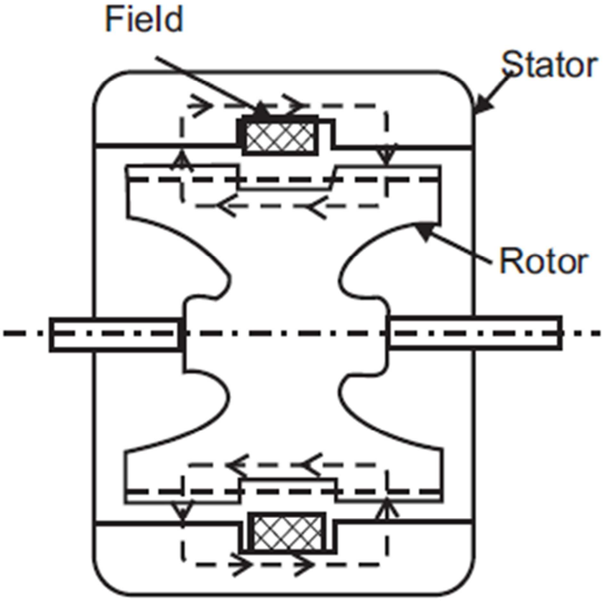


Figure 6.7: Eddy Current Dynamometer

The following are the main advantages of eddy current dynamometers:

1. High brake power per unit weight of dynamometer.
2. They offer the highest ratio of constant power speed range (up to 5:1).
3. Level of field excitation is below 1% of total power being handled by the dynamometer. Thus, they are easy to control and operate.
4. Development of eddy current is smooth hence the torque is also smooth and continuous under all conditions.
5. Relatively higher torque under low-speed conditions.
6. It has no intricate rotating parts except shaft bearing.
7. No natural limit to size, either small or large.

6.3.2.4. Hydraulic

A hydraulic dynamometer as shown in the figure below works on the principle of dissipating the power in fluid friction rather than in dry friction.

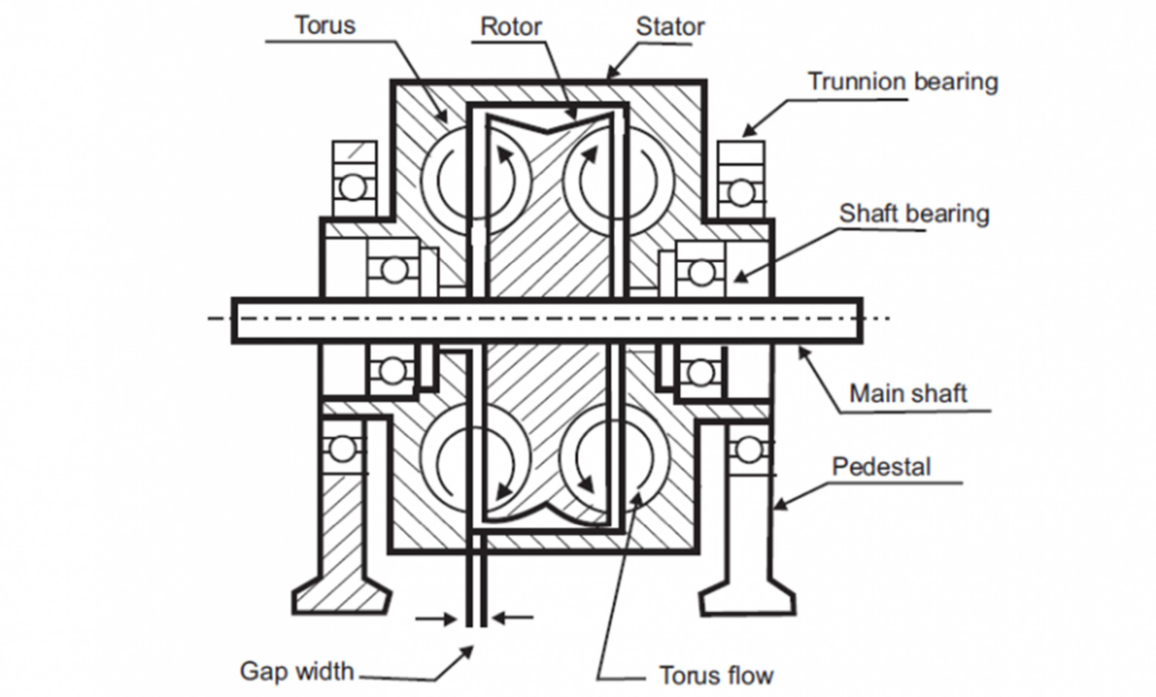


Figure 6.8: Hydraulic Dynamometer.

- In principle, hydraulic dynamometer construction is similar to that of a fluid flywheel.
- Hydraulic dynamometer consists of an impeller or inner rotating member coupled to the output shaft of the engine.
- The impeller in this dynamometer rotates in a casing filled with a fluid.
- Due to the centrifugal force developed in the outer casing, tends to revolve with the impeller, but is resisted by a torque arm supporting the balance weight.
- The frictional forces generated between the impeller and the fluid are measured by the spring balance fitted on the casing.
- The heat developed due to the dissipation of power in Hydraulic dynamometer is carried away by a continuous supply of the working fluid.
- The output power can be controlled by regulating the sluice gates which can be moved in and out to partially or wholly obstruct the flow of water between the casing and the impeller.

Chapter.7

7.0 Pressure Measurement

7.1. Pressure

Pressure is the amount of force (F) applied perpendicular to the surface of an object per unit area (A). It exerts pressure on that surface equal to the ratio of F to A, where F is the force and A is the surface area The symbol for it is p or P.

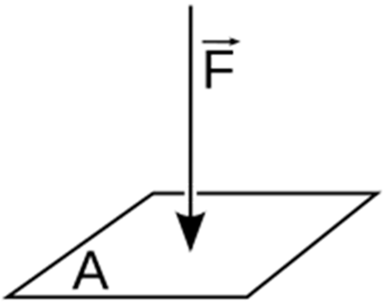


Figure 7.1: Force acting on area A

The formula for pressure (P) is

$$P = F/A. \tag{7.1}$$

Where: p is the pressure, F is the magnitude of the normal force and A is the area of the surface on contact. The principle SI unit is called a Pascal (Pa), or N/m^2. Other units used: lbf/in^2, kgf/cm^2, $tonf/in^2$, kp/cm2, inH2O, inHg, dyne/cm2, torr

Pressure is a scalar quantity. It relates the vector surface element (a vector normal to the surface) with the normal force acting on it. The pressure is the scalar proportionality constant that relates the two normal vectors:

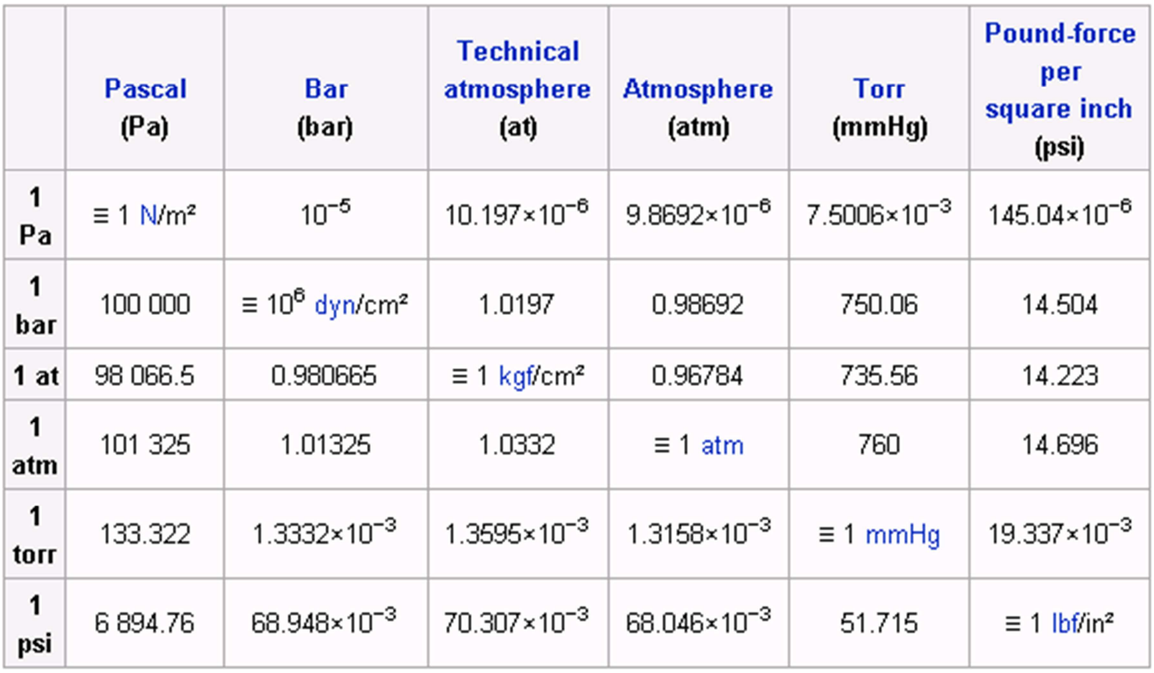
$$dF = -p\,dA = -pndA \tag{7.2}$$

The minus sign comes from the fact that the force is considered towards the surface element, while the normal vector points outward. The equation has meaning in that, for any surface S in contact with the fluid, the total force exerted by the fluid on that surface is the surface integral over S of the right-hand side of the above equation.

7.2. Units for Pressure

There are also two other specialized units of pressure measurement in the SI system: the bar, equal to 10^5 Pa, and the torr, equal to 133 Pa. The torr, once known as the "millimeter of mercury, "is equal to the pressure required to raise a column of mercury (chemical symbol Hg) 1 mm. It is named for the Italian physicist Evangelista Torricelli (1608-1647), who invented the barometer.

Table 6.1: Units for pressure



	Pascal (Pa)	Bar (bar)	Technical atmosphere (at)	Atmosphere (atm)	Torr (mmHg)	Pound-force per square inch (psi)
1 Pa	≡ 1 N/m²	10^{-5}	10.197×10^{-6}	9.8692×10^{-6}	7.5006×10^{-3}	145.04×10^{-6}
1 bar	100 000	≡ 10^6 dyn/cm²	1.0197	0.98692	750.06	14.504
1 at	98 066.5	0.980665	≡ 1 kgf/cm²	0.96784	735.56	14.223
1 atm	101 325	1.01325	1.0332	≡ 1 atm	760	14.696
1 torr	133.322	1.3332×10^{-3}	1.3595×10^{-3}	1.3158×10^{-3}	≡ 1 mmHg	19.337×10^{-3}
1 psi	6 894.76	68.948×10^{-3}	70.307×10^{-3}	68.046×10^{-3}	51.715	≡ 1 lbf/in²

7.2.1. Atmospheric Pressure

Atmospheric pressure is pressure caused by the weight of air in the atmosphere of earth. At sea level it has a mean value of one atmosphere (1atm) = 760 mm of mercury = 14.70 lbs per square in. = 101.35 kPa = 100 kN/m2 = 1 bar Pressure reduces with increasing altitude.

7.2.2. Pressure Change

This plastic bottle was closed at approximately 2000m altitude, then brought back to sea level. As a result, air pressure crushes it.

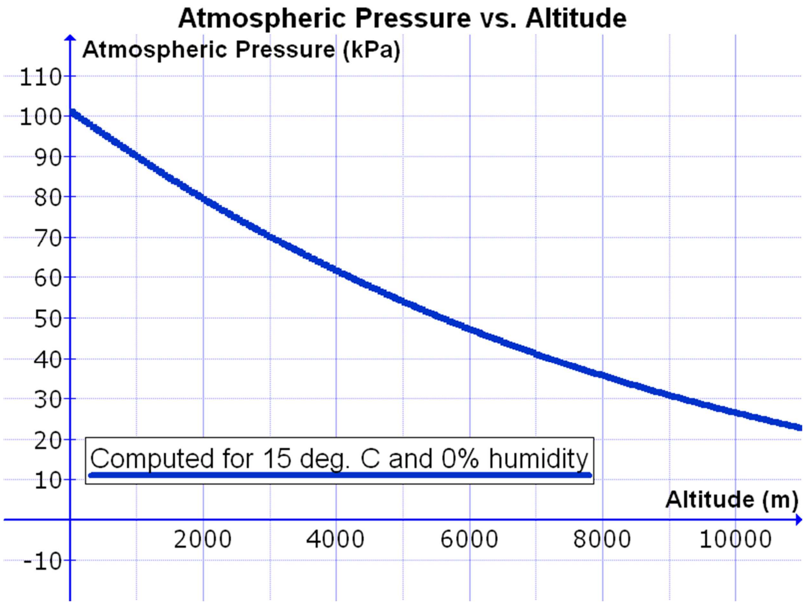


Figure 7.2: Pressure change with altitude

7.2.3. Vacuum

An outer-space in which there is no matter or in which the pressure is so low that any particles in the space do not affect any processes being carried on there. It is a condition well below normal atmospheric pressure. The most nearly perfect vacuum exists in intergalactic space, where it is estimated that on the average there is less than one molecule per cubic meter

7.2.4. Absolute Pressure

Absolute pressure of a fluid is zero-referenced against a perfect vacuum

7.2.5. Gauge Pressure

Gauge pressure (e.g. as read by barometer) is referenced against ambient air pressure, so it is equal to absolute pressure minus atmospheric pressure.

7.2.6. Differential Pressure

Differential pressure is the difference in pressure between 2 points.

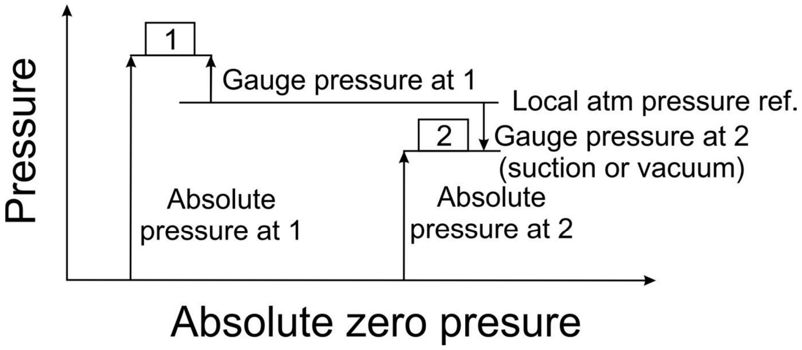


Figure 7.3: Pressure diagram

7.3 Method to Measure

7.3.1. Elastic Deformation

Pressure creates force which in turn deforms the elastic material

7.3.1.1. Bourdon Tube

A Bourdon gauge uses a coiled tube which as it expands due to pressure increase causes a rotation of an arm connected to the tube.

Coiled tube made of copper

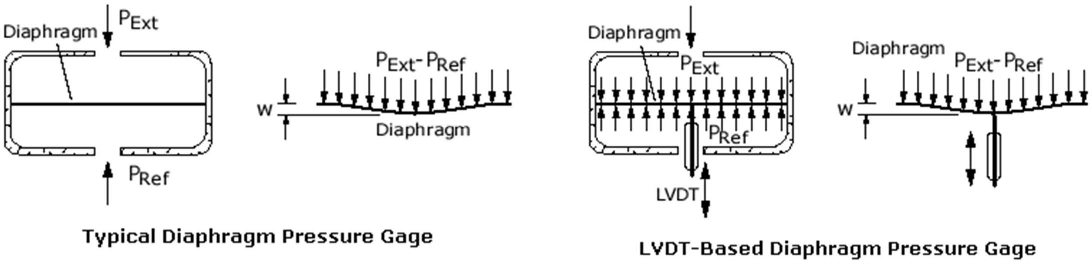
Mechanical movement linked by rack and pinion

Range = 100kN/m2 – 300MN/m2

7.3.1.2. Diaphragm (membrane) Based

LVDT = linear variable displacement transducer. Spring can be used instead of LVDT and attached to force (F) measuring device

$$p = kx/A \tag{7.3}$$



Typical Diaphragm Pressure Gage

LVDT-Based Diaphragm Pressure Gage

Figure 7.4: Diaphragm pressure gage

Diaphragm Shape

- flat for low pressure measurement or
- Corrugated for high pressure measurement

Material = Copper-beryllium

7.3.1.3. Bellows Based

Bellows is a one-piece, collapsible, seamless metallic unit that has deep folds formed from very thin-walled tubing. As inlet pressure to the instrument varies, the bellows will expand or contract. The moving end of the bellows is connected to a mechanical linkage. As the bellows and linkage assembly moves, either an electrical signal is generated or a direct pressure indication is provided. For extremely low pressure measurement (0.5–75psig to a 1000psigmax) psig = pound per square inch gauge.

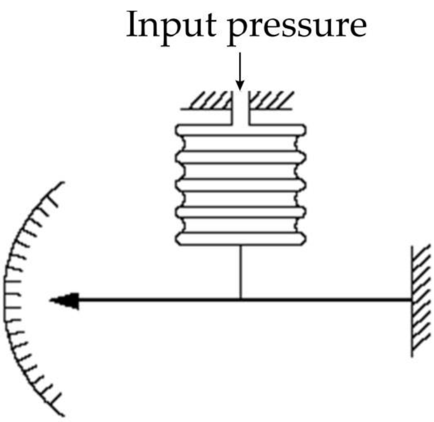


Figure 7.5: Bellows

7.3.1.4. Aneroid Gauge

An enclosed and sealed bellows chamber is called an aneroid, which means "without liquid". The important component is a sealed chamber made of thin metal in semi vacuum state. The chamber shrinks when atmospheric pressure increases, and expands when atmospheric pressure reduces.

Figure 7.6: Aneroid gauge

7.3.2. Liquid Column

Liquid column gauges consist of a vertical column of liquid in a tube whose ends are exposed to different pressures. The column will rise or fall until its weight is in equilibrium with the pressure differential between the two ends of the tube.

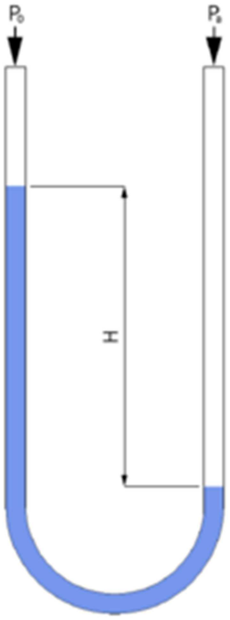


Figure 7.7: Liquid column gauge

7.3.2.1. Hydrostatic Pressure

Pressure at a given depth in a static liquid is a result the weight of the liquid acting on a unit area at that depth plus any pressure acting on the surface of the liquid

$$p = p_{atm} + \rho g h \tag{7.4}$$

Pressure due to liquid alone (i.e. the gauge pressure) at a given depth depends only upon the density of liquid ρ and the distance below surface of the liquid, h

$$p = \rho g h \tag{7.5}$$

7.3.2.1.1. U-tube Manometer

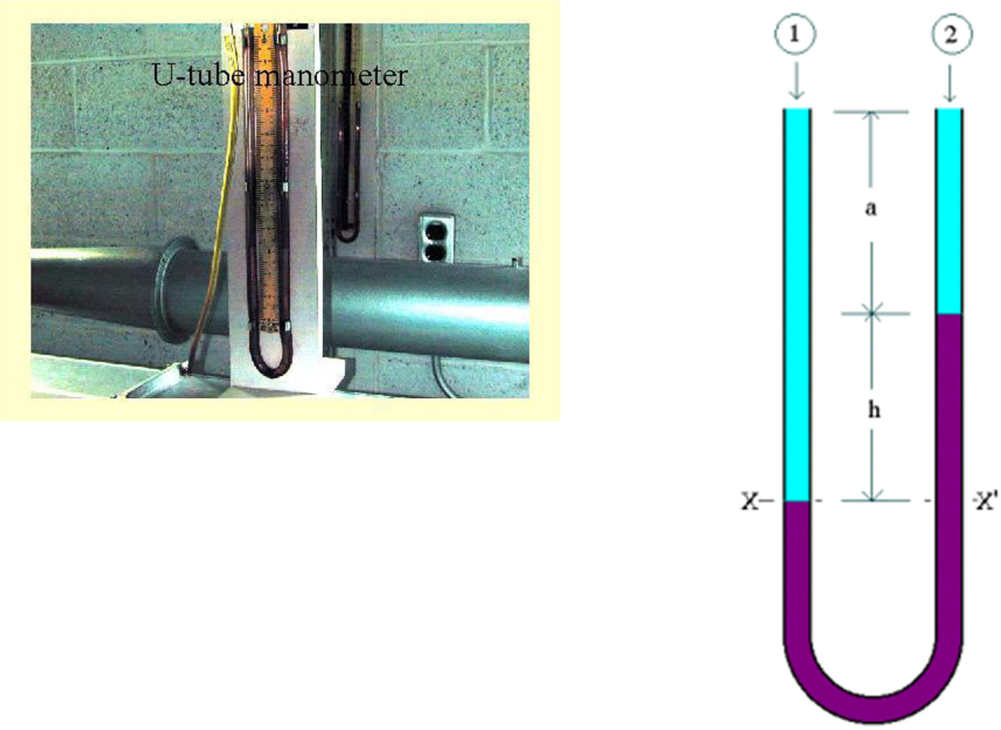


Figure 7.8: U-tube Manometer

Equating the pressure at the level X' (pressure at the same level in a continuous body of fluid is equal)

LHS; $P_x = P_1 + \rho g(a+h)$

RHS; $P_{x\prime} = P_2 + \rho g a + \rho_m g h$

Since $P_x = P_{x\prime}$

$$P_1 + \rho g(a+h) = P_2 + \rho g a + \rho_m g h$$

$$P_1 - P_2 = (\rho_m - \rho) g h \qquad (7.6)$$

7.3.2.1.2. Well-Type Manometer

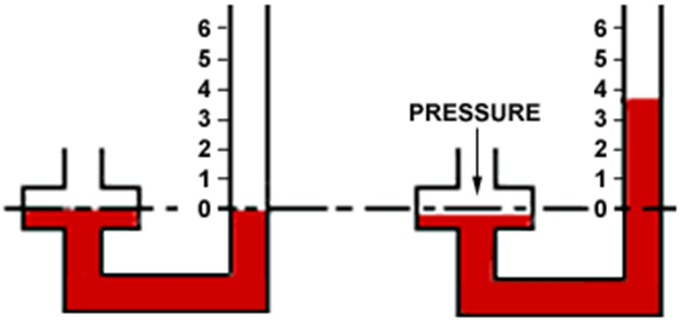


Figure 7.9: Well-Type Manometer

LHS: $P_1 - \rho g h_w$

RHS: $P_2 - \rho g h_c$

LHS = RHS

$$P_1 - \rho g h_w = P_2 - \rho g h_c$$

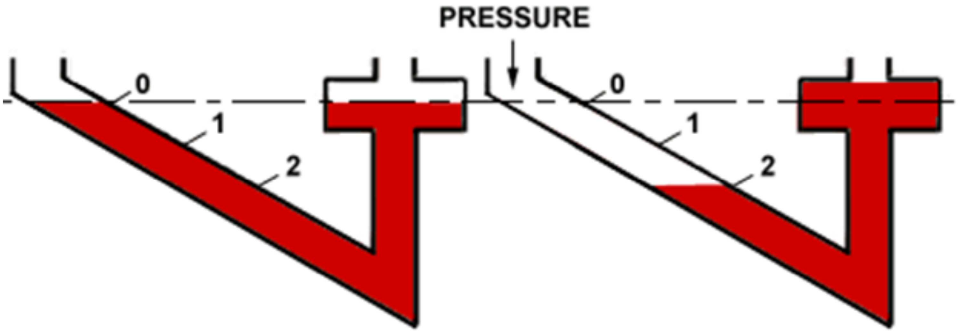
$$P_1 - P_2 = \rho g h_w - \rho g h_c$$

By constant volume, $h_w A_w = h_c A_c \rightarrow h_w / h_c = A_c / A_w$

Therefore, $p_1 - p_2 = \rho g h_c \, (1 + A_c / A_w)$

$$p_1 - p_2 = \rho g h_c \text{ when } A_w \gg A_c \tag{7.7}$$

7.3.2.1.3. Inclined Manometer



The inclined version is used for better sensitivity. Measuring range = 0.1bar – 30mbar.

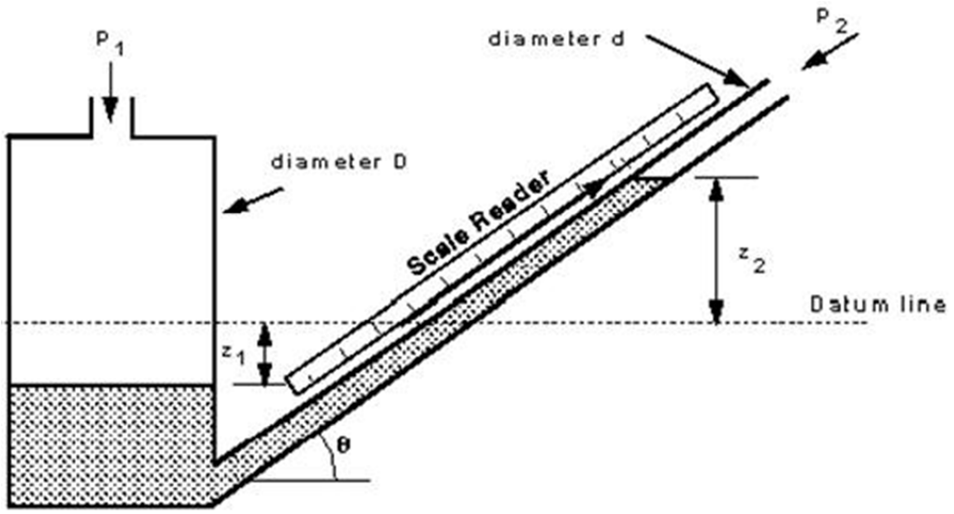


Figure 7.10: Inclined Manometer

$$p_1 + \ p_2 = \rho g z_z = \rho g x \sin\theta \tag{7.8}$$

7.3.2.1.4. Piezometer

The pressure at any point in the liquid is indicated by the height of the liquid in the tube above that point

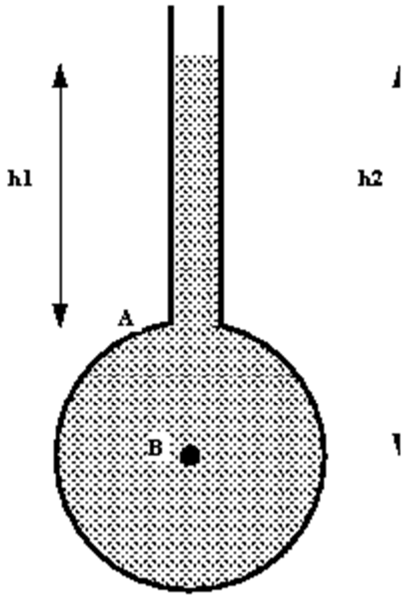


Figure 7.11: Piezometer

Pressure at A = pressure due to column of liquid above A

Pressure at B = pressure due to column of liquid above B

7.3.2.1.5. Mercury Barometer

A barometer is an instrument used to measure atmospheric pressure. A standard mercury barometer has a glass column of about 30 inches (about 76 cm) in height, closed at one end, with an open mercury-filled reservoir at the base.

Mercury in the tube adjusts until the weight of the mercury column balances the atmospheric force exerted on the reservoir. High atmospheric pressure places more force on the reservoir, forcing mercury higher in the column. Low pressure allows the mercury to drop to a lower level in the column by lowering the force placed on the reservoir

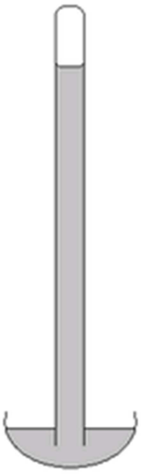


Figure 7.12: Mercury Barometer

7.3.2.1.6. Manometer Liquid Selection

1. Low viscosity
2. Low coefficient of expansion
3. Low vapor pressure
4. Low cohesiveness
5. Non corrosive

7.3.2.1.7. Manometer Liquid in Use

1. Mercury

2. Water
3. Kerosene
4. Alcohol
5. Ethyl
6. Benzene

Chapter.8

8.0 Temperature Measurement

8.1. Temperature

Temperature is a physical quantity related to heat which is expressing hot and cold. Temperature is measured with a thermometer using the concept of heat equilibrium, historically calibrated in various temperature scales and units of measurement. The most commonly used scales are the Celsius scale, denoted in °C (informally, degrees centigrade), the Fahrenheit scale (°F), and the Kelvin scale. The kelvin (K) is the unit of temperature in the International System of Units (SI), in which temperature is one of the seven fundamental base quantities. There are 6 types of equipment:

1. Thermocouples
2. Resistive temperature devices (RTDs) and thermistors
3. Infrared radiators
4. Bimetallic devices
5. Liquid expansion devices
6. Change-of-state devices

8.1.1. Temperature Scale

The 2 scales commonly in use today dated back from the eighteenth century and are named after Gabriel Daniel Fahrenheit and the Swedish astronomy professor Anders Celsius. Fahrenheit designed his scale to have two reference points that could be set up in his workshop. He originally chose the melting point of pure ice and the temperature of a normal human body, which he took as being 32° and 96° respectively.

8.1.1.1. Fahrenheit

These conveniently gave positive values for all the temperatures he encountered. Later he changed to using the boiling point of water (212°) as the upper fixed point of the scale

8.1.1.2. Celsius

Celsius also used the ice and steam points, but took them to be 0 °C and 100 °C respectively. Although the Celsius scale has taken precedence over the Fahrenheit scale, the latter is still familiar in weather reports in the United Kingdom: a summer’s day temperature of 75 °F seems much more pleasant than one of 24 °C

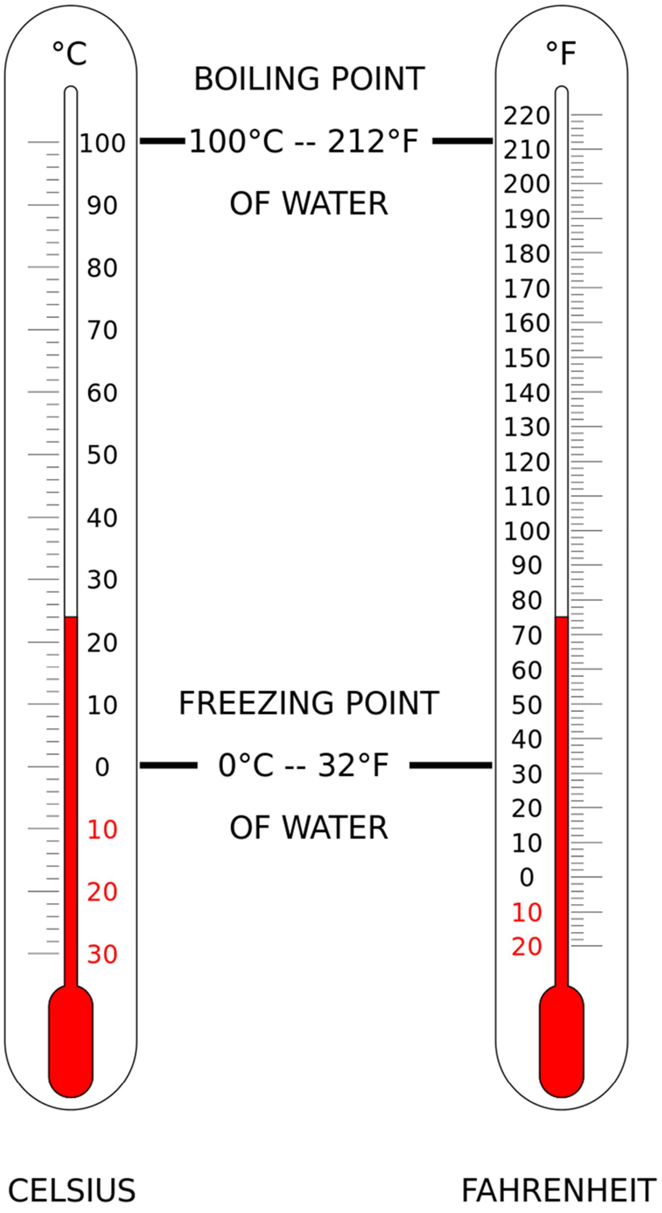


Figure 8.1: Comparison of the Celsius and Fahrenheit scales

8.1.1.3. Kelvin

A third, fundamental, temperature scale was proposed in 1854 by the Scottish physicist William Thomson, Lord Kelvin. It is based on the idea of the absolute zero, the point of no discernible energy, which is independent of any particular material substance. The Kelvin scale is widely used by physicists and engineers to determine and apply fundamental laws of thermodynamics. The international temperature scale of 1990 (ITS-90) Since 1954, the unit of (thermodynamics) temperature has been defined as kelvin and is the fraction of 1/273.16 of the thermodynamics temperature of the triple point of water. This is the unique temperature and pressure, which 3 phases of water (solid, liquid and vapor) co-exist in equilibrium. It is fractionally higher than the melting point, being 0.01°C or 273.16K. From this single point, it is possible to generate a thermodynamics temperature scale using gas thermometers and radiation thermometers, which accurately obey known law.

8.2. Temperature Measurement

A thermometer is a device that measures temperature or a temperature gradient. Thermometers are widely used in industry to monitor processes, in meteorology, in medicine, and in scientific research. A thermometer has two important elements:

1. A temperature sensor (e.g. the bulb of a mercury-in-glass thermometer or the digital sensor in an infrared thermometer) in which some change occurs with a change in temperature, and
2. Some means of converting this change into a numerical value (e.g. the visible scale that is marked on a mercury-in-glass thermometer or the digital readout on an infrared model).

8.2.1. Thermocouple

Thermocouple consists of two strips of wires made of different metals and joined at one end. Changes in the temperature at that juncture induce a change in electromotive force (emf) between the other ends. As temperature goes up, this output emf of the thermocouple rises, though not necessarily linearly. Thermocouples are the most common sensors in industry. They have a long history, the original paper on thermoelectricity by Seebeck being publish in 1822. The thermocouple consists of 2 dissimilar metallic conductor joined at the point of measurement. When the conductors are heated, a voltage is generated in the circuit and this can be used to determine the temperature.

The standard configuration for thermocouple usage is shown in the figure. Briefly, the desired temperature T_{sense} is obtained using three inputs—the characteristic function $E(T)$ of the thermocouple, the measured voltage (V), and the reference junctions' temperature T_{ref}. The solution to the equation $E(T_{sense}) = V + E(T_{ref})$ yields Tsense. These details are often hidden from the user since the reference junction block (with T_{ref} thermometer), voltmeter, and equation solver are combined into a single product

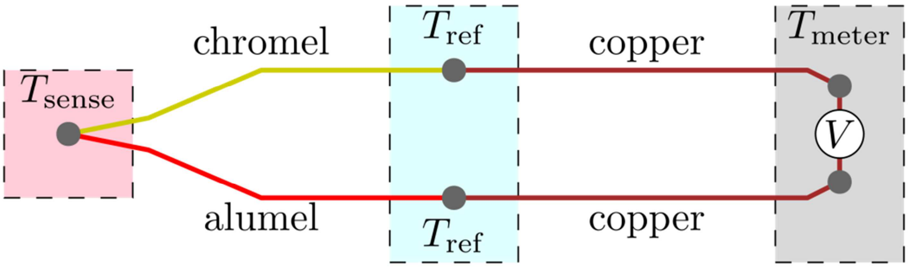
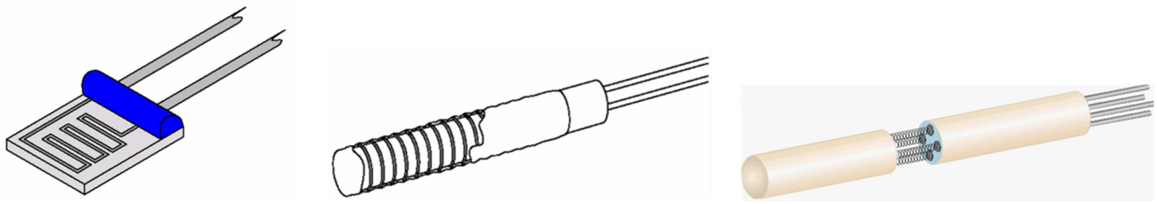


Figure 8.2: K-type thermocouple in the standard thermocouple measurement configuration.

8.2.2. Resistance Temperature Devices

Resistance thermometers also called Resistive Temperature Devices (RTD) are sensors used to measure temperature by capitalizing on the fact that electrical resistance of a material changes as its temperature changes. There are two types which is the metallic devices and thermistors. As their name indicates, RTDs rely on resistance change in a metal, with the resistance rising more or less linearly with temperature. Thermistors are based on resistance change in a ceramic semiconductor; resistance drops nonlinearly with temperature rise.

In the modern world, mercury and spirit-filled thermometers have largely given way to electrical devices, which can be digitized and automated. The RTD wire is a pure material, typically platinum, nickel, or copper. Platinum resistance thermometers are electrical thermometers, which make use of the variation of resistance of high-purity platinum wire with temperature. This variation is predictable, enabling accurate measurements to be performed. They are sensitive and with sophisticated equipment, measurements can routinely be made to be better than a thousand part of 1°C. The three main categories of RTD sensors are thin-film, wire-wound, and coiled elements.


Thin-film PRT

Wire-wound PRT

Coil-element PRT

Figure 8.3: Three types of RTD sensors.

8.2.3. Infrared Temperature Devices

An infrared thermometer is a thermometer which infers temperature from a portion of the thermal radiation sometimes called blackbody radiation emitted by the object being measured. Infrared sensors are non-contacting devices or temperature guns to describe the device's ability to measure temperature from a distance. They infer temperature by measuring the thermal radiation emitted by a material.

Figure 8.4: An infrared thermometer.

- Pyrometer or radiation thermometers make use of the fact that all objects emit thermal radiation, as seen when looking at the bars of an electric lamp or light bulb.
- The amount of radiation emitted can be measured and related to temperature using the Planck law of radiation.

- Temperature can be measured remotely using this technique, with the sensor situated some distance away from the object.
- Hence it is useful for objects that are very hot, moving or in hazardous environments.

8.2.4. Bimetallic Devices

A bimetallic strip is used to convert a temperature change into mechanical displacement. The strip consists of two strips of different metals which expand at different rates as they are heated, usually steel and copper, or in some cases steel and brass. Bimetallic devices take advantage of the difference in rate of thermal expansion between different metals. Strips of two metals are bonded together. When heated, one side will expand more than the other, and the resulting bending is translated into a temperature reading by mechanical linkage to a pointer. Figure 7.4 shows a diagram of a bimetallic strip showing how the difference in thermal expansion in the two metals leads to a much larger sideways displacement of the strip.

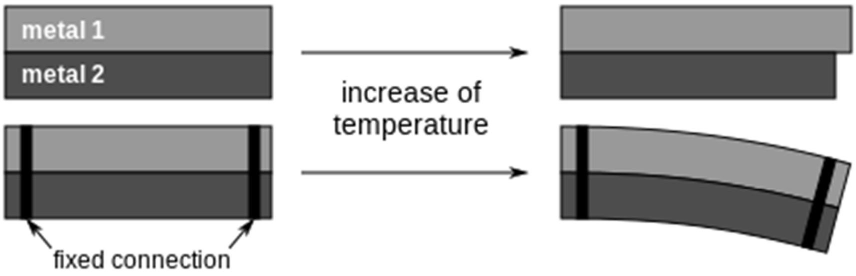


Figure 8.5: Bimetallic strip.

8.2.5. Fluid Expansion Devices

Fluid-expansion devices, typified by the household thermometer, generally come in two main classifications: mercury type and organic-liquid type. Versions employing gas instead of liquid are also available. Mercury is considered an environmental hazard, so there are regulations governing the shipment of devices that contain it. Fluid-expansion sensors do not require electric power, do not pose explosion hazards, and are stable even after repeated cycling. On the other hand, they do not generate data that is easily recorded or transmitted, and they cannot make spot or point measurements.

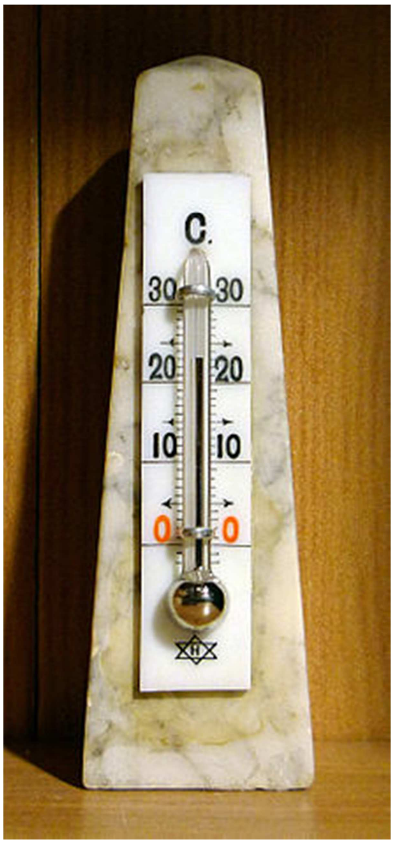


Figure 8.6: Mercury thermometer.

8.2.6. Change-of-State Temperature

Change-of-state temperature sensors measure a change in a material’s state brought on by a temperature change. Change-of-state temperature sensors consist of labels, pellets, crayons, lacquers or liquid crystals whose appearance changes once a certain temperature is reached. They are used, for instance, with steam traps - when a trap exceeds a certain temperature, a white dot on a sensor label attached to the trap will turn black. Response time typically slow, so these devices often do not respond to transient temperature changes. And accuracy is lower than with other types of sensors. Furthermore, the change in state is irreversible, except in the case of liquid-crystal displays. Even so, change-of-state sensors can be handy when one needs confirmation that the temperature of a piece of equipment or a material has not exceeded a certain level, for instance for technical or legal reasons during product shipment.

Figure 8.7: Change-of-state temperature sensors.

8.2.7. Silicon Diode

The silicon diode sensor is a device that has been developed specifically for the cryogenic temperature range. Essentially, they are linear devices where the conductivity of the diode increases linearly in the low cryogenic regions. The conductivity of a silicon diode increases linearly in the low cryogenic regions

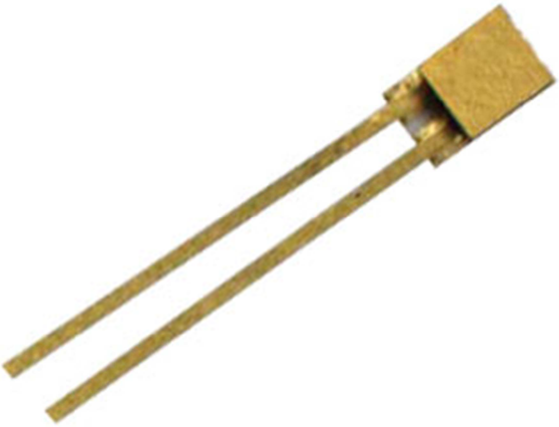


Figure 8.8: Silicon diode temperature.

8.3. Exercise

1. Which of the following pairs of temperatures measuring devices work by basically the same principle?
   - A. Thermocouple and RTD
   - B. Bimetallic strip and thermistor
   - C. Infrared pyrometer and thermocouple
   - D. Thermistor and RTD

2. What is the current international temperature scale of 1990 (the ITS-90)?
   - A. Kelvin
   - B. Fahrenheit
   - C. Celsius
   - D. Rankine

3. Which of the following is **WRONG** about temperature?
   - A. Temperature is related to heat
   - B. Measuring temperature means measuring heat
   - C. Temperature is fixed and do not move
   - D. Heat is measure using the concept of heat equilibrium

4. Which of the following is **NOT** the equipment to measure the temperature?
   - A. Bimetallic devices
   - B. Liquid expansion devices
   - C. Infrared resistance
   - D. Change of state devices

5. The following are related to the thermocouple **EXCEPT**
   - A. Consists of three strips of wires
   - B. Wire made of different metals
   - C. Wires joined at one end
   - D. Changes in the temperature will induces a change in electric force

6. Which of the following is **NOT** related to the infrared temperature device?
   - A. Infrared sensor are contacting devices
   - B. Infer temperature by measuring the thermal radiation
   - C. Useful for objects that are very hot moving
   - D. Temperature can be measured remotely

7. What is the measureable property that changers with temperature in a thermocouple?
   - A. expansion
   - B. electrical resistance
   - C. thermal radiation
   - D. voltage

8. Which contact type thermometer has a temperature range of -250^{o}C to 2000^{o}C?
   - A. Radiation thermometer
   - B. Liquid-in-glass thermometer
   - C. electrical resistance thermometer
   - D. Thermocouple thermometer.

9. The Celsius unit is based on;

A. The interval of 100^{o}C between the triple point of water and the boiling point of water at the atmospheric pressure.

B. The interval of 100^{o}C between the melting point of ice and boiling point of water at the water vapour pressure

C. The difference between ambient temperature and the boiling point of water at the one atmospheric pressure.

D. The interval of 100^{o}C between the melting point of ice and the boiling point of water at one atmospheric pressure.

10. All of the following are related to the bimetallic device **EXCEPT**
    - A. Take advantage of the different in rate of thermal expansion
    - B. Strips of three metals are bounded together
    - C. Thermal expansion between different metal
    - D. When heated, one side of the strip will expand more than the other

,

Chapter.9

9.0 Experimental Uncertainties

9.1. Introduction

In statistics, propagation of uncertainty (error) is the effect of variables' uncertainties on the uncertainty of a function based on them. When the variables are the values of experimental measurements they have uncertainties due to measurement limitations (e.g., instrument precision) which propagate to the combination of variables in the function.

The knowledge we have of the physical world is obtained by doing experiments and making measurements. It is important to understand how to express such data and how to analyze and draw meaningful conclusions from it. It is crucial to understand that all measurements of physical quantities are subject to uncertainties. In order to draw valid conclusions, the uncertainties must be indicated and dealt with properly.

9.2. Uncertainty of Measurement

Many instrumental, physical and human limitations cause measurements to deviate from the true values of the quantities being measured. No measurement is perfectly accurate or exact. We can reduce the deviations but regardless of the gap between advanced instrument or simple instrument or different techniques of measurement, we can never hope to measure true values. These deviations are called experimental uncertainties, but more commonly the shorter word error is used. Result of a measurement cannot consist of the measured value alone. An indication of how accurate the result is must be included. The result of any physical measurement has two essential components:

1. A numerical value (in a specified system of units) giving the best estimate possible of the quantity measured, and
2. The degree of uncertainty associated with this estimated value.

For example, a measurement of the width of a table would yield a result such as 95.3 +/- 0.1 cm.

9.2.1. Importance of Estimation Uncertainty

When we specify the error in a quantity or result, we are giving an estimate of how much that measurement is likely to deviate from the true value of the quantity. This estimate is far more than a guess. It is based on a physical analysis of the measurement process and a mathematical analysis of the equations which apply to the instruments and to the physical process being studied. A measurement or experimental result is of little use if nothing is known about the probable size of its error. We know nothing about the reliability of a result unless we can estimate the probable sizes of the errors and uncertainties in the data which were used to obtain that result. That is why it is important for students to learn

- how to determine quantitative estimates of the nature and size of experimental errors
- to predict how these errors affect the reliability of the final result

9.2.2. Relative and Absolute Uncertainty

The uncertainty u can be expressed in a number of ways. It may be defined by the absolute error (Δx). Uncertainties can also be defined by the relative error ($\Delta x/x$) is called the relative error or fractional uncertainty, which is usually written as a percentage. Most commonly, the uncertainty on a quantity is quantified in terms of the standard deviation (σ), the positive square root of variance (σ^2).

The quantity z is called the absolute error. The value of a quantity and its error are then expressed as an interval $x \pm u$. If the statistical probability distribution of the variable is known or can be assumed, it is possible to derive confidence limits to describe the region within which the true value of the variable may be found.

9.3. Classification of Uncertainty

9.3.1. Systematic Uncertainty

- Systematic means that when the measurement of a quantity is repeated several times, the error has the same size and algebraic sign for every measurement.

- Systematic errors tend to shift all measurements in a systematic way so their mean value is displaced
- Systematic errors are usually caused by the following factors:
    1. Calibration error
    2. Certain consistently recurring human error
    3. Certain error caused by defective equipment
    4. External effect (Loading error)
    5. Limitation of system resolution

9.3.1.1. Calibration Uncertainty

Calibration error occurs when an instrument's scale has not been adjusted to read the measured value properly. Zero-offset error is caused all reading to be offset by a constant amount. If a scale give a measurement of 100g without load (zero error), then 100g must be minus from every reading. Scale error is an error in the slope of the output relative to the input which causes all readings to error by a fixed percentage. When an instrument is calibrated, it is done in a specific room with standard/specific environment. But when the instrument used in different environment, a correction must be made on the reading.

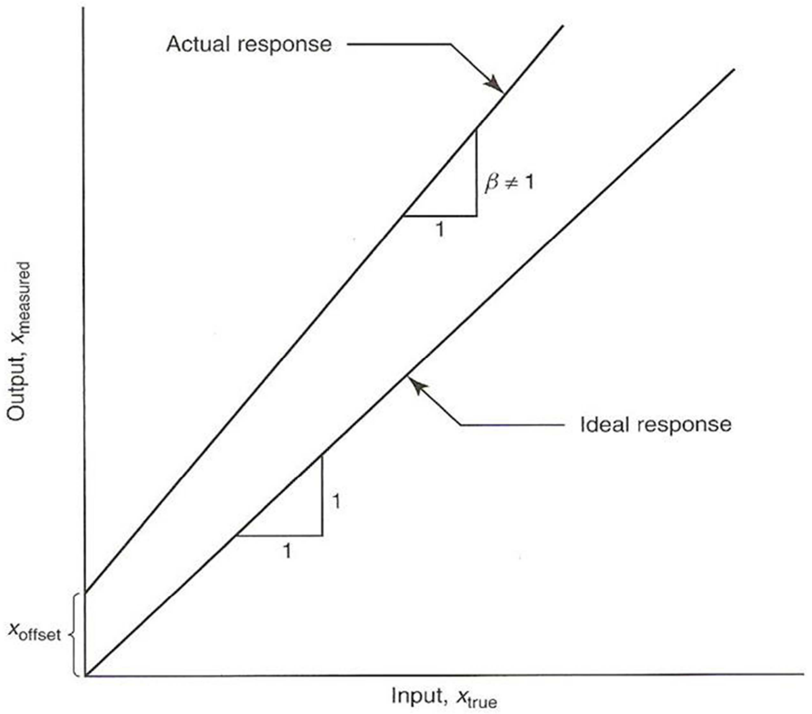


Figure 9.1: Calibration Error

For ideal response, $x_{measured} = x_{true}$. Actual response may include zero-offset error (xoffset) and scale error ($\beta \neq 1$) so that $x_{measured} = \beta x_{true} + x_{offset}$. Calibration procedures normally attempt to identify and eliminate these error by comparing with a standard.

- Standards themselves also have uncertainties
- The impreciseness of any calibration procedure guarantees that some calibration-related bias error is present in all measuring system.

9.3.1.2. Certain consistently recurring human error

- May well be systematic error
- When an individual consistently tend to read high
    - Eg. reading a scale incorrectly (parallax effect)

9.3.1.3. Defective Equipment

- Built-in errors resulting from incorrect design/fabrication or maintenance
    - Defective mechanical/electrical component
    - Incorrect scale graduations
- These type of errors are often consistent in sign and magnitude
- Sometimes can be corrected by calibration

9.3.1.4. External Factor

- Refer to the influence of the measurement procedure on the system being tested
    - The sound-pressure level sensed by a microphone is not the same as the sound-pressure level that would exist at that location if the microphone were not present.
- Minimizing the influence of the measuring instrument on a measured variable is a major objective in designing any experiment

9.3.1.5. Resolution

9.3.2. Random Uncertainty

- Random errors are present in all experimental measurements.
- The name “random" indicates that there's no way to determine the size or sign of the error in any individual measurement.
- Random errors cause a measuring process to give different values when that measurement is repeated many times (assuming all other conditions are held constant to the best of the experimenter's ability).
- Error caused by disturbances to the equipment
    - Temperature variations
    - Mechanical vibration
    - Noises
- Error caused by fluctuating experimental condition
    - Temperature/pressure variation
- Error derived from insufficient measuring-system sensitivity
- The effect of random errors can be reduced by taking repeated measurements, then calculating their average.
- The average is generally considered to be a "better" representation of the "true value" than any single measurement, because errors of positive and negative sign tend to compensate each other in the averaging process.

9.3.3. Illegitimate Uncertainty

- Errors that would not be expected
- Blunders and outright mistake during an experiment
    - Misunderstanding what you are doing
    - Elbowing your lab partner's measuring apparatus
    - Failure to turn on the instrument
- Computational error after an experiment
    - using an incorrect value of a constant in the equations
    - using the wrong units
    - Miscalculating during data reduction
- Can be eliminated through exercise of care or repetition of the measurement

9.3.4. Propagation of uncertainty

Often several quantities are measured, and the results of those measurements are used to calculate a desired result. Each measurement includes some uncertainty, and these uncertainties will create an uncertainty in the calculated result.

9.3.4.1. Uncertainty in a single measurement

In general, the uncertainty in a single measurement from a single instrument is half the least count of the instrument.

Example 1:

Koto measures his weight as closest to the 142-pound mark. He knows his weight must be larger than 141.5 pounds (or else it would be closer to the 141-pound mark), but smaller than 142.5 pounds. So Koto's weight must be $weight\ =\ 142\ +/-\ 0.5\ pounds$

What is the fractional uncertainty in Koto's weight?

$$fractional\ uncertainty = \frac{\text{uncertainty in weight}}{\text{value for weight}} = \frac{0.5\text{ pounds}}{142\text{ pounds}} = \ 0.0035$$

What is the uncertainty in Bob's weight, expressed as a percentage of his weight?

$$percentage\ uncertainty = \frac{\text{uncertainty in weight}}{\text{value for weight}} 100\% = \frac{0.5\text{ pounds}}{142\text{ pounds}} 100\% = \ 0.35\%$$

9.3.4.2. Addition and Subtraction:

When one adds or subtracts several measurements together, one simply adds together the uncertainties to find the uncertainty in the sum. The addition and subtraction uncertainties are written as

$$z\ =\ x\ +\ y,\ z\ =\ x - y \tag{9.1}$$

- Derivation: We will assume that the uncertainties are arranged so as to make z as far from its true value as possible. The average deviations can be written as $\varDelta z\ =\ |\varDelta x|\ +\ |\varDelta y|$, for both cases

- With more than 2 numbers added or subtracted we continue to add the uncertainties.

Using simpler average errors, the average deviations can be written as

$\Delta z = |\Delta x| + |\Delta y| + |\Delta w| + \cdots$

Using standard deviations, the average deviations can be written as

$\Delta z = \sqrt{(\Delta x)^2 + (\Delta y)^2 + (\Delta w)^2 + \cdots}$

Example 1:

$x = (2.0 \pm 0.2), y = (3.0 \pm 0.6)$ and $w = (4.50 \pm 0.02)$. Find z and its uncertainty when, z = x + y – w.

Answer

$z = x + y - w = 2.0 + 3.0 - 4.5 = 0.5$

Using standard deviations errors:

$\Delta z = \Delta x + \Delta y + \Delta w = 0.2 + 0.6 + 0.02 = 0.82$ rounding to 0.8,

$z = (\mathbf{0.5} \pm \mathbf{0.8})$

Using standard deviations errors:

$\Delta z = \sqrt{(0.2)^2 + (0.6)^2 + (0.02)^2} = 0.633$, rounding to 0.6 cm $z = (0.5 \pm 0.6)$

Example 2:

The radius of a circle (r) is (3.0 ± 0.2) cm. Calculate the circumference and its uncertainty.

Answer

Circumference, $C = 2\pi r = 18.849 \ldots = 18.8$ cm

$\Delta C = 2\pi \Delta r = 1.257$ cm (The factors of 2 and π are exact)

$C = (18.8 \pm 1.3)$ cm

Example 3:

If $x = (2.0 \pm 0.2)$ cm, $y = (3.0 \pm 0.6)$ cm. Calculate $z = x - 2y$ and its uncertainty.

Answer

$z = x - 2y = 2.0 - 2(3.0) = -4.0$ cm

Using simpler average errors:

$\Delta z = \Delta x + 2\,\Delta y = 0.2 + 1.2 = 1.4$ cm

$z = (-4.0 \pm 1.4)$ cm.

Using standard deviations errors:

$\Delta z = \sqrt{(0.2)^2 + 2(0.6)^2} = 0.8718$

$z = (-4.0 \pm 0.9)$ cm

9.3.4.3. Multiplication and Division

The multiplication and division uncertainties are written as

$$z = xy, \; z = x/y \tag{9.2}$$

Derivation:

$z + \Delta z = (x + \Delta x)(y + \Delta y)$

$z + \Delta z = xy + x\,\Delta y + y\,\Delta x + \Delta x\,\Delta y$

The last term is much smaller and can be neglected.

Since, $z = xy$, $\Delta z = y\,\Delta x + x\,\Delta y$, Using simpler average errors

$$\frac{\Delta z}{z} = \frac{\Delta x}{x} + \frac{\Delta y}{y} + \cdots, \; \Delta z = z\left(\frac{\Delta x}{x} + \frac{\Delta y}{y}\right)$$

Using standard deviations, the average deviations can be written as

$$\Delta z = \sqrt{\left(\frac{\Delta x}{x}\right)^2 + \left(\frac{\Delta y}{y}\right)^2 + \left(\frac{\Delta w}{w}\right)^2 + \cdots}$$

Example 1:

Length (x) of a box is (4.52 ± 0.02) mm, and width (y) is (2.0 ± 0.2) mm. Calculate the area (z) and uncertainty of the box.

Answer

$z = xy = (4.52)\,(2.0) = 9.04$ which we round to 9.0

Using simpler average errors:

$\Delta z = z\left(\frac{\Delta x}{x} + \frac{\Delta y}{y}\right) = 9.0\left(\frac{0.02}{4.52} + \frac{0.2}{2.0}\right) = 0.9396$, which can be rounded to 0.9,

$z = (9.0 \pm 0.9)\ mm^2$

Using standard deviations errors:

$\Delta z = \sqrt{\left(\frac{0.02}{4.52}\right)^2 + \left(\frac{0.2}{2.0}\right)^2} = 0.905,\ z = (9.0 \pm 0.9)\ mm^2$

Example 2:

If $x = (2.0 \pm 0.2)$ cm and $y = (3.0 \pm 0.6)$ sec, calculate $z = x/y$.

Answer

$z = 2.0/3.0 = 0.6667$ cm/s.

So $\Delta z = (0.3)\,(0.6667)$ cm/sec = 0.2 cm/sec

$z = (0.7 \pm 0.2)$ cm/sec

Using standard deviations errors:

$z = (0.7 \pm 0.2)$ cm/sec

9.3.4.4. Products of powers

The Products of powers uncertainties are written as

$$z = x^m y^n \tag{9.3}$$

Using simpler average errors

$$\frac{\Delta z}{z} = |m|\frac{\Delta x}{x} + |n|\frac{\Delta y}{y} + \cdots$$

Using standard deviations

$$\Delta z = \sqrt{\left(\frac{m\Delta x}{x}\right)^2 + \left(\frac{n\Delta y}{y}\right)^2 + \left(\frac{k\Delta w}{w}\right)^2 + \cdots}$$

Example 1:

$w = (4.50 \pm 0.02)\ cm, A = (2.0 \pm 0.2)\ , y = (3.0 \pm 0.6)\ cm$, calculate $z = wy^2/\sqrt{A}$

Answer

$$z = \frac{5.63.0^2}{\sqrt{2.0}} = 28.638\ cm^2$$

$$\frac{\Delta z}{28.638} = \frac{0.02}{4.5} + 2\frac{0.6}{3.0} + 0.5\frac{0.2}{2.0} = 0.49$$

$$\Delta\ z = (0.49)\ (28.638\ ) = 14.03$$

z = (28 ± 14)

Exercise:

$w = (4.52 \pm 0.02)\ cm, x = (2.0 \pm 0.2)\ cm, y = (3.0 \pm 0.6)\ cm$. Calculate $z = w\ x + y2$

9.3.4.5. Partial Derivatives

The general method of getting formulas for propagating errors involves the total differential of a function. Suppose that $z = f(w, x, y, \ldots)$ where the variables w, x, y, etc. must be independent variables. The total differential is then

$$dz = \left(\frac{\partial f}{\partial x}\right) dx + \left(\frac{\partial f}{\partial y}\right) dy + \left(\frac{\partial f}{\partial w}\right) dw \qquad (9.4)$$

Using simpler average errors

$$\Delta z = \left|\frac{\partial f}{\partial x}\right| \Delta x + \left|\frac{\partial f}{\partial y}\right| \Delta y + \left|\frac{\partial f}{\partial w}\right| \Delta w + \cdots$$

Using standard deviations

$$\Delta z^2 = \left(\frac{\partial f}{\partial x}\right) \Delta x^2 + \left(\frac{\partial f}{\partial y}\right) \Delta y^2 + \left(\frac{\partial f}{\partial w}\right) \Delta w^2$$

Example 1:

Consider $S = x\,cos\,(q)$ for $x = (2.0 \pm 0.2)\,cm$ and $q = (53 \pm 0.2)° =$ (0.9250 ± 0.0035) rad. Calculate S and its uncertainty.

Answer

$S = 2.0\,cm\,cos53° = 1.204\,cm$

$dS = \cos\theta\,dx - x\sin\theta\,d\theta$

We take the absolute value of each term

$\Delta S = \cos\theta\,\Delta x - x\sin\theta\,\Delta\theta$

$\Delta S = \cos 53\;0.2 - 2\sin 53\;0.0035 = 0.126$

For standard deviation approach

$\Delta S = \sqrt{(\cos\theta\,\Delta x)^2 + (-x\sin\theta\,\Delta\theta)^2} = 0.120$

S = (1.20 ± 0.13) cm (using average deviation approach) or

S = (1.20 ± 0.12) cm (using standard deviation approach.)

9.3.4.6. The uncertainty of a Slope on a Graph

If a graph has more than a few points as shown in Figure 9.2, the uncertainty in the slope can be calculated. The data points are shown by small, filled, black circles; each datum has error bars to indicate the uncertainty in each measurement. It appears that current is measured to +/- 2.5 milliamps, and voltage to about +/- 0.1 volts. The hollow triangles represent points used to calculate slopes.

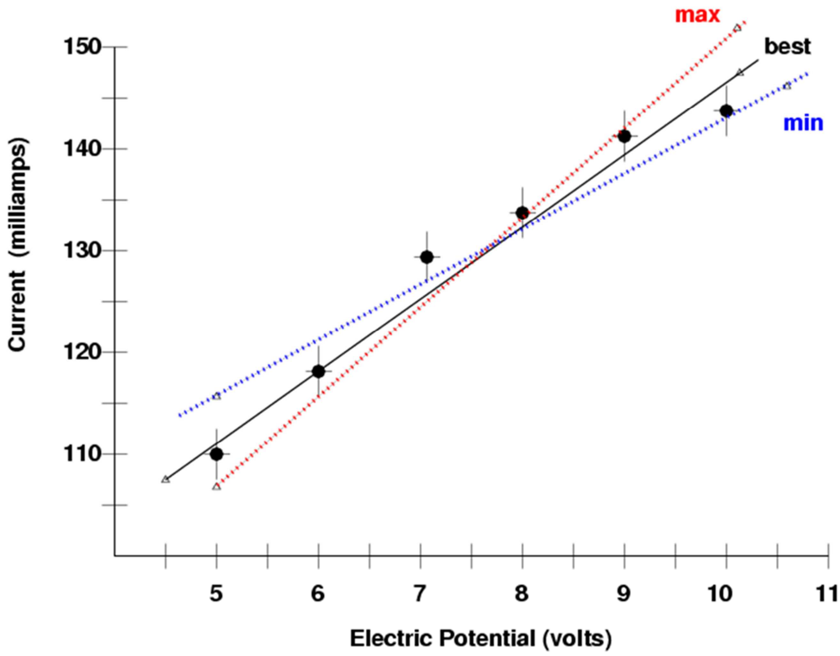


Figure 9.2: Electrical potential versus current

1. Draw the "best" line through all the points, taking into account the error bars. Measure the slope of this line.
2. Draw the "min" line -- the one with as small a slope as you think reasonable (taking into account error bars), while still doing a fair job of representing all the data. Measure the slope of this line.
3. Draw the "max" line -- the one with as large a slope as you think reasonable (taking into account error bars), while still doing a fair job of representing all the data. Measure the slope of this line.
4. Calculate the uncertainty in the slope as one-half of the difference between max and min slopes.

It is founded

$$bestslope \;=\; \frac{147\text{ mA} - 107\text{ mA}}{10\text{ V } - 4.5\text{ V}} = 7.27\, {}^{mA}\!/_{V}$$

$$Minslope \;=\; \frac{145\text{ mA} - 115\text{ mA}}{10.5\text{ V} - 5.0\text{ V}} = 5.45\, {}^{mA}\!/_{V}$$

$$Maxslope \;=\; \frac{152\text{ mA} - 106\text{ mA}}{10\text{ V } - 5.0\text{ V}} = 9.20\, {}^{mA}\!/_{V}$$

$$Uncertainty\ in\ slope\ is\ \ 0.5 * (9.20 - 5.45) = 1.875\ {}^{mA}\!/_{V}$$

There are at most two significant digits in the slope, based on the uncertainty.

$$slope \;=\; 7.3\ +/-\ 1.9\ {}^{mA}\!/_{V}$$

Chapter.10

10.0 Experiment & Data Analysis

10.1. Experiment in Mechanical Engineering

Experimental data in science are data produced by a measurement, test method, experimental design or quasi-experimental design. Experimental data may be qualitative or quantitative, each being appropriate for different investigations. The data from the experiment when it wants to be shared or presented to other people must use a standard measurement system such as dimension and unit that is easily understood by everyone.

10.1.1. Dimensions

Any of a set of basic kinds of quantity, as mass, length, and time, in terms of which all other kinds of quantity can be expressed; usually denoted by capital letters, with appropriate exponents, placed in brackets. Physical parameters are distinguished by their dimensions, for instance:

- Distance is expressed in length (L).
- Mass is expressed by M,
- Time by T,
- Temperature by θ
- Diameter of a pipe or cylinder by D

All above basic dimensions are called as Primary or Fundamental Dimensions.

Others dimension such as area (A) is expressed by (L^2), velocity (V) expressed by (L/T), and Force (F) expressed by (ML/T^2) which are called Secondary Dimensions

10.1.2. Units

The magnitudes assigned to the dimensions are called units.

Table 10.1: Fundamental quantity and units

Quantity	Unit	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric Current	ampere	A
Temperature	Kelvin	K
Luminous Intensity	candela	cd
Amount of Matter	mole	mole

Table 10.2: Engineering Units

Unit	Symbol
Radian	rad
Hertz	Hz
Newton	N
Pascal	Pa
Coulomb	C
Henry	H
Hectare	ha
Tonne	t
Liter	l
Volt	V
Ampere	A
Farad	F
Joule	J
Watt	W
Weber	Wb
Degree	○
Minute	m

10.1.3. Equilibrium of Static Force

When all the forces that act upon an object are balanced, then the object is said to be in a state of equilibrium. The forces are considered to be balanced if the rightward forces are balanced by the leftward forces and the upward forces are balanced by the downward forces as expressed below:

$$\sum F = 0 \tag{10.1}$$

Static means an object is stationary or at rest. A common physics lab is to hang an object by two or more strings and to measure the forces that are exerted at angles upon the object to support its weight.

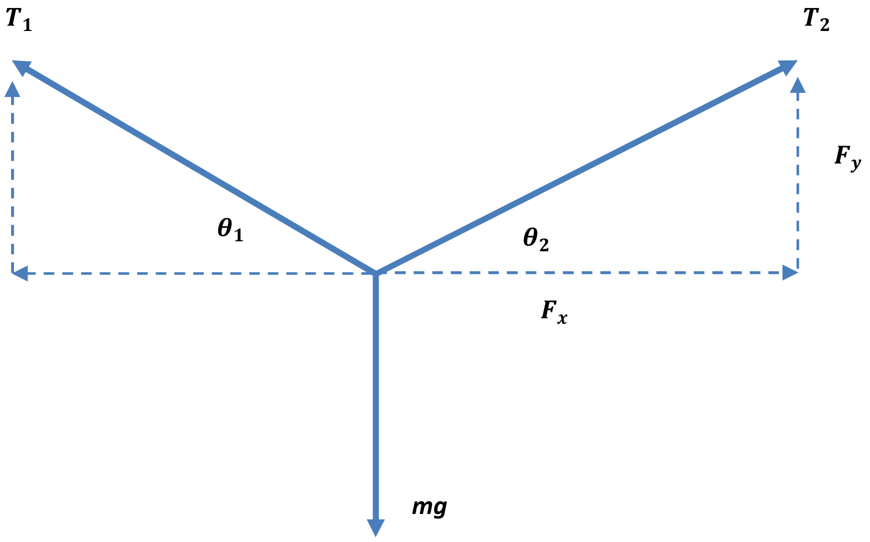


Figure 10.1: Equilibrium of static force.

Using Figure 10.1, summation of forces must zero, so the total force on x-axis and y-axis can be written as

$$T_1 \cos\theta_1 = T_2 \cos\theta_2$$

$$T_1 = T_2 \frac{\cos\theta_2}{\cos\theta_1} \tag{10.2}$$

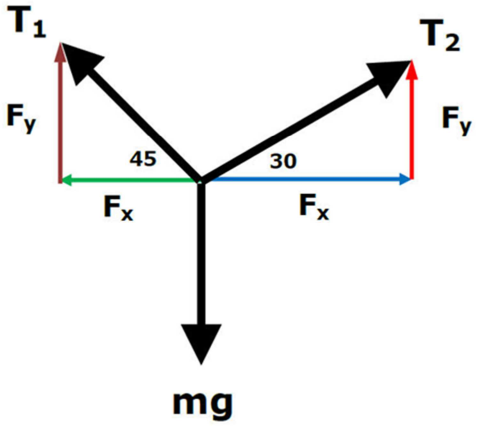
$$T_1 \sin\theta_1 + T_2 \sin\theta_2 = mg \tag{10.3}$$

By substitution Eq.10.2 into Eq.q0.3, then the solution can be written as

$$T_2\left[\frac{\cos\theta_2}{\cos\theta_1}\sin\theta_1+\sin\theta_2\right]=mg \qquad (10.4)$$

Example 1

Using figure below, calculate T1 and T2 when mg = 100 N



By using eqs.10.2 ~ 10.4, then T_1 and T_2 can be calculate

$T_1\cos 45=T_2\cos 30$ and $T_1=1.2247\,T_2$

$1.2247\,T_2\sin 45+T_2\sin 30=100$ then, $T_2(0.866025404\;+0.5\,)=100$

$T_2={}^{100}/_{1.366025404}$ = 73.2050 and $T_1=1.2247\,x\,73.2050=\;89.6575$

10.1.3.1. Experiment of Equilibrium of Static Force

Figure below shows experimental set up of equilibrium of static force. In the experiment, measure distance between the two pulleys (L).

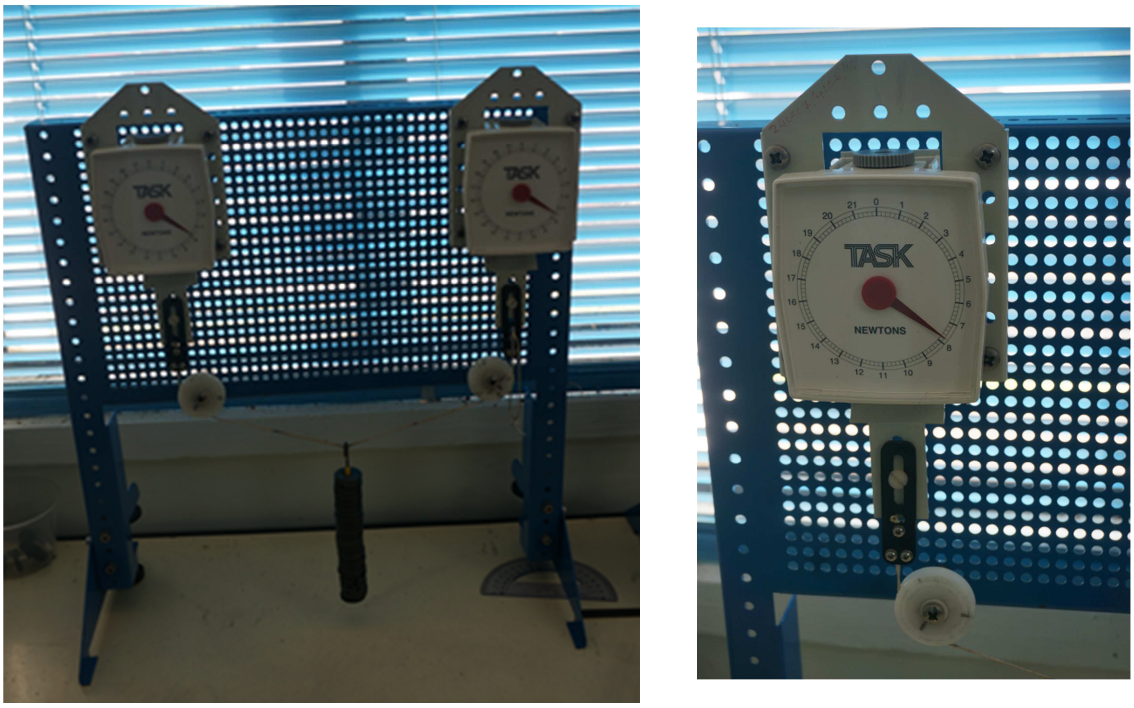


Figure 10.2: Experimental set up of equilibrium of static force.

Exercise.1

Complete the table below

Load (N)	Load cell 1 (N)	Load cell 2 (N)	Angle (θ_1)	Angle (θ_2)	T_1	T_2
1	2.0	1.9	15	11		
2	3.6	3.4	15	15		
3	5.0	4.9	16	19		
4	6.2	6.0	18	20		
5	7.3	7.2	19	19		

Exercise.2

Complete the table below

Load (N)	Load cell 1 (N)	Load cell 2 (N)	Angle (θ_1)	Angle (θ_2)	T_1	T_2
1	1.9	1.7	15	5		
2	3.4	3.1	25	10		
3	4.8	4.3	25	10		
4	6.0	5.3	27	10		
5	7.3	6.3	30	10		

10.1.4. Elastic Modulus

10.1.4.1. Cantilever

A cantilever is a rigid structural element, such as a beam or a plate, anchored at one end to a support from which it protrudes. It is y a horizontal beam that is firm at only one end while the other end is left free to carry some vertical loads. The beam's fixed end has a reaction force and moment created by the load acting at the free end. The intention of cantilever beam is to create a bending effect to certain limit. Diving board at swimming pool and cantilever bridge are a perfect example for cantilever beam. Aircraft wing that carries wind force is another good example for cantilever beam.

Figure 10.3: Cantilever bridge.

The below figure depicts a cantilever beam fixed to a vertical plane.

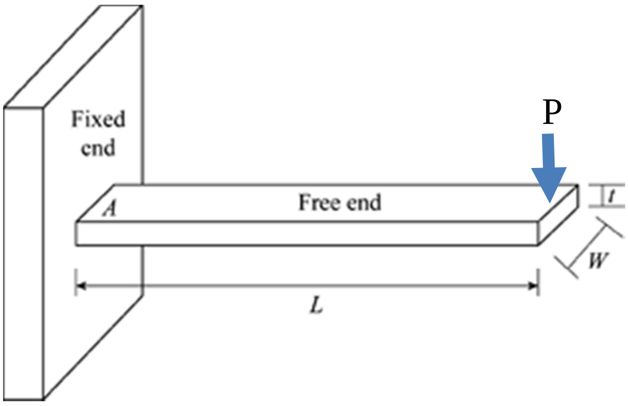


Figure 10.4: Cantilever beam.

We can write the expressions for reactions, deflections and maximum moment for a cantilever beam of length (l) that is acted by various types of loads.

1. Point load P (N) at free end.

   Reaction force (N) at A$R_A = P$:

   Maximum bending moment (Nm): $M_A = -Pl$

   Maximum deflection/ displacement (m), $\delta_{max} = \frac{Pl^3}{3EI}$

   Slope at free end, $\theta = \frac{pl^2}{2EI}$

2. Uniformly distributed load with magnitude P over the entire beam length

   Reaction force at A (N): $R_A = P$

   Maximum bending moment (Nm): $M_A = -\frac{Pl^2}{2}$

   Maximum deflection/displacement (m): $\delta_{max} = \frac{Pl^4}{8EI}$

   Slope at free end: $\theta = \frac{pl^3}{6EI}$

Where: E is the elastic modulus and I is second moment of inertia for beam's cross section which can be written as $= \frac{bt^3}{12}$.

Example 1

Using Figure 10.3, calculate I when width (b) and thickness (t) of beam 13.2 mm and 4.4 mm, respectively and length is 130 mm

$$I = \frac{13.2\ 4.4^3}{12} = 9.37E^{-11}$$

Example 2

Using example 1, calculate E when deflection 0.16 mm and load 0.981 N

$$E = \frac{Pl^3}{3\delta I} = \frac{0.981x130^3}{3x0.16x9.37E^{-11}} = 4.79\text{E}+10$$

10.1.4.2. Experimental Set up of Cantilever

Figure below shows experimental set up of cantilever.

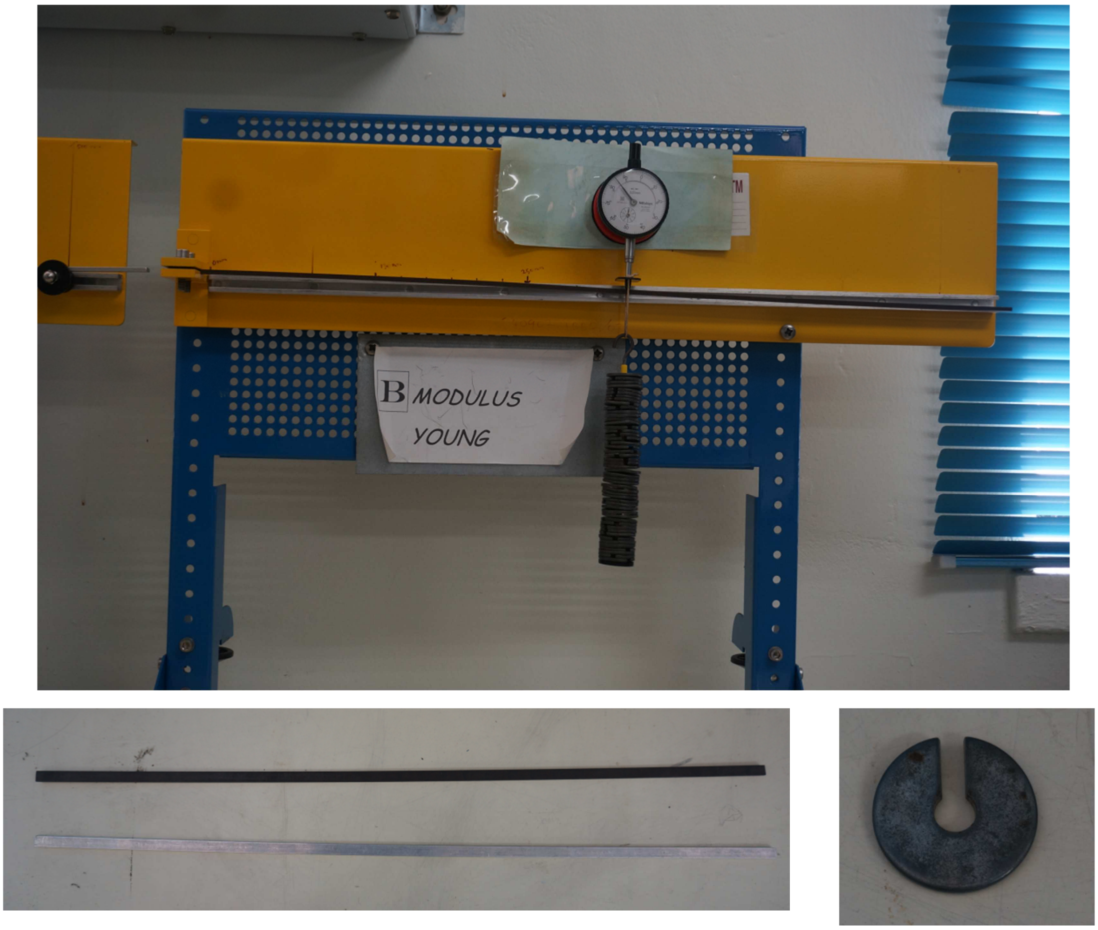


Figure 10.5: Experimental set up of cantilever.

Exercise.1

a) If steel beam has width (b) and thickness (t) of beam 13.2 mm and 4.4 mm and length is 130 mm, complete the table below

b) Plot graph between displacements versus load

Load (N)	Displacement (mm)				E (N/m^2)
	Reading 1	Reading 2	Reading 3	Average	
0.981	0.18	0.14	0.16		
1.962	0.37	0.35	0.33		
2.943	0.56	0.53	0.57		
3.924	0.76	0.72	0.74		
4.905	0.96	0.91	0.90		

Exercise.2

a) If the aluminum beam has width (b) and thickness (t) of beam 7.7 mm and 1.3 mm, respectively and load is 1 N, complete the table below.

b) Plot graph between displacements versus L^3

Length (m)	Displacement (mm)				E (N/m^2)
	Reading 1	Reading 2	Reading 3	Average	
0.130	0.56	0.54	0.54	0.547	
0.150	0.74	0.73	0.75	0.740	
0.170	1.08	1.05	1.04	1.057	
0.190	1.33	1.35	1.36	1.347	
0.210	1.81	1.81	1.83	1.817	
0.230	2.38	2.35	2.35	2.360	
0.250	2.74	2.72	2.75	2.737	

10.1.4.3. Simply Supported Beam

Figure 10.4 shows a simply supported beam with a concentrated load at its center. We need to determine the deflection under the load. It is assumed that the loading are all symmetric about the center. That means the deflection curve of the beam as shown in green.

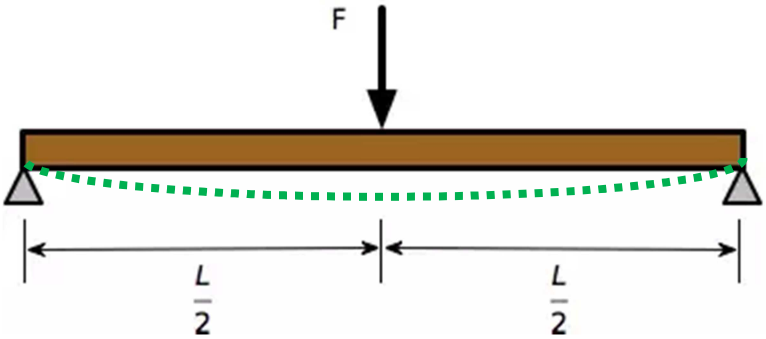


Figure 10.6: Simply supported beam.

Each of these conceptual cantilever beams is of length L/2 and the upward loads at their tips are equal to the reaction forces at the supports of the original problem, P/2. The maximum deflection/ displacement (δ_{max}), at the center of the original beam is equal to the tip deflection of either conceptual cantilever as written as below

$$\delta_{max} = \frac{({}^{P}/_{2})({}^{l}/_{2})^3}{3EI} = \frac{Pl^3}{48EI}$$

Example 1

If steel beam has width (b) and thickness (t) of beam 13.2 mm and 4.4 mm, respectively and length is 500 mm, calculate E when deflection 0.16 mm and load 0.981 N.

$$E = \frac{Pl^3}{48\delta I} = \frac{0.981x500^3}{48x0.16x9.37E^{-11}} = 1.70E + 11$$

10.1.4.4. Experimental Set up of Simply Supported Beam

Figure below shows experimental set up of simply supported beam.

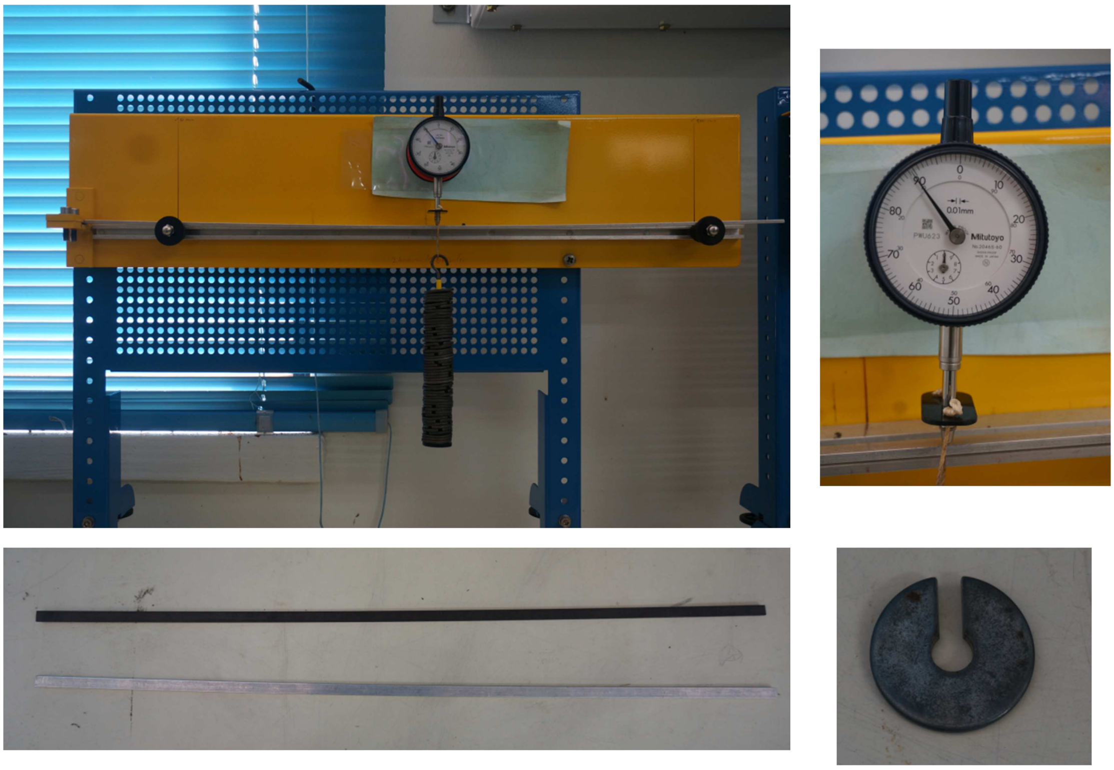


Figure 10.7: Experimental set up of simply supported beam.

Exercise.1

If steel beam has width (b) and thickness (t) of beam 7.7 mm and 1.3 mm, respectively and length is 500 mm, complete the table below

Load (N)	y (mm)	y (m)	E (N/m^2)
0.981	0.460	0.0005	
1.962	0.900	0.0009	
2.943	1.350	0.0014	
3.924	1.900	0.0019	
4.905	2.400	0.0024	

Exercise.2

a) If aluminum beam has width (b) and thickness (t) of beam 13.2 mm and 4.4 mm, respectively and length is 500 mm, complete the table below

Load (N)	y (mm)	y (m)	E (N/m^2)
0.981	1.12	0.0011	
1.962	2.29	0.0023	
2.943	3.38	0.0034	
3.924	4.53	0.0045	
4.905	5.70	0.0057	

b) If table below show calculated value, compare the elastic modulus from experiment with the calculated value

Material	E (GPa)	E (N/m2)	Area (m2)	I (m4)
Steel Beam	207	2.07E+11	3.05E-05	2.60E-11
Aluminium Beam	69	6.90E+10	3.05E-05	2.60E-11
Square ABS plastic beam	2.8	2.80E+09	4.54E-05	5.10E-11
I-Shape ABS Plastic Beam	2.8	2.80E+09	4.54E-05	5.00E-11

10.3. Statistical Analysis

It’s the science of collecting, exploring and presenting large amounts of data to discover underlying patterns and trends. Traditional methods for statistical analysis are used from sampling data to interpreting results which have been used by scientists and engineers for many years.

In a secondary analysis, the statistical analyst further examines the data to suggest other questions and to help plan future experiments. In engineering applications, the goal is often to optimize a process or product, rather than to subject a scientific hypothesis to test of its predictive adequacy. The use of optimal (or near optimal) designs reduces the cost of experimentation

- Manufacturers use statistics to weave quality into beautiful fabrics, to bring lift to the airline industry and to help guitarists make beautiful music.
- Researchers keep children healthy by using statistics to analyze data from the production of viral vaccines, which ensures consistency and safety.
- Communication companies use statistics to optimize network resources, improve service and reduce customer churn by gaining greater insight into subscriber requirements.
- Government agencies around the world rely on statistics for a clear understanding of their countries, their businesses and their people.
- Quality control and process control use statistics as a tool to manage conformance to specifications of manufacturing processes and their products.
- Reliability engineering which measures the ability of a system to perform for its intended function (and time) and has tools for improving performance.
- Probabilistic design involving the use of probability in product and system design
- System identification uses statistical methods to build mathematical models of dynamical systems from measured data

10.3.1. Median

The median is the value separating the higher half of a data sample, a population, or a probability distribution, from the lower half as shown Figure 9.1. For example, in the data set {1, 3, 3, 6, 7, 8, 9}, the median is 6. For a continuous probability distribution, the median is the value such that a number is equally likely to fall above or below it.

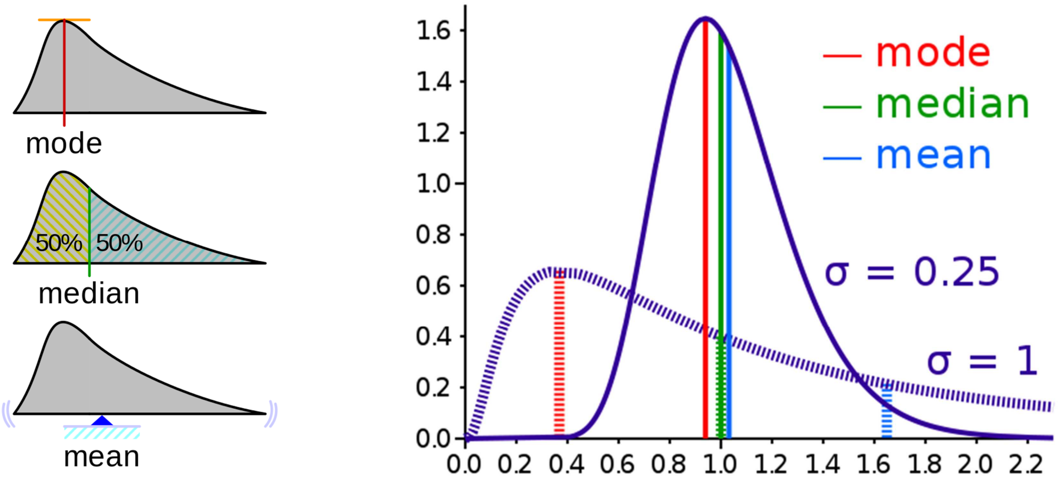


Figure 10.8: Geometric visualisation of the mode, median and mean of an arbitrary probability density function.

10.3.2. Mod

The mode of a set of data values is the value that appears most often. It is the value x at which its probability mass function takes its maximum value as shown in Figure 9.1. The mode is a way of expressing, in a (usually) single number, important information about a random variable or a population.

For example, the mode of the sample [1, 3, 6, 6, 6, 6, 7, 8, 11, 12, 17] is 6. Given the list of data [1, 1, 2, 4, 4] the mode is not unique, the dataset may be said to be bimodal: 1 and 4, while a set with more than two modes may be described as multimodal.

10.3.3. Mean

The statistical mean refers to the mean or average that is used to derive the central tendency of the data in question as shown in Figure 9.1. The mean is determined by adding all the data points in a population and then dividing the total by the number of points. The resulting number is known as the mean or the average which can be written as:

.

$$X = (x_1 + x_2 + x_3 + \cdots + x_n)/n \qquad (10.1)$$

10.3.4. Deviation

In mathematics and statistics, deviation is a measure of difference between the observed value of a variable and some other value, often that variable's mean. The sign of the deviation (positive or negative), reports the direction of that difference (the deviation is positive when the observed value exceeds the reference value). The magnitude of the value indicates the size of the difference.

$$d_i = |x_i - x| \tag{10.2}$$

Where; d_i is the absolute deviation, x_i is the data element and x is the chosen measure of central tendency of the data set—sometimes the mean, but most often the median.

10.3.5. Variance

In probability theory and statistics, the variance combines all the values in a data set to produce a measure of spread. The variance is the expectation of the squared deviation of a random variable from its mean. Informally, it measures how far a set of (random) numbers are spread out from their average value. The mean square of the difference between the random variable and its mean is the variance or second central moment of the distribution. The equation of variance is

$$\sigma^2 = \frac{\Sigma(xi - x)^2}{n} \tag{10.3}$$

For example, for the numbers [1, 2, 3] the mean is 2 and the variance is 0.667. [(1 - 2)2 + (2 - 2)2 + (3 - 2)2] ÷ 3 = 0.667

Calculating variance involves squaring deviations, so it does not have the same unit of measurement as the original observations. For example, lengths measured in metres (m) have a variance measured in metres squared (m^2)

10.3.6. Standard deviation

Standard deviation is the measure of spread most commonly used in statistical practice when the mean is used to calculate central tendency. Thus, it measures spread around the mean. The standard deviation is numerically equal to the square root of the variance:

$$\sigma = \sqrt{\frac{\Sigma(xi - x)^2}{n}} \tag{10.4}$$

Standard deviation is also influenced by outliers one value could contribute largely to the results of the standard deviation. In that sense, the standard deviation is a good indicator of the presence of outliers. This makes standard deviation a very useful measure of spread for symmetrical distributions with no outliers.

Standard deviation is also useful when comparing the spread of two separate data sets that have approximately the same mean. The data set with the smaller standard deviation has a narrower spread of measurements around the mean and therefore usually has comparatively fewer high or low values.

For example, for the numbers [1, 2, 3] the mean is 2 and the variance is 0.667. [(1 - 2)2 + (2 - 2)2 + (3 - 2)2] ÷ 3 = 0.667 and the Standard deviation is 0.8167. When using standard deviation keep in mind the following properties.

- Standard deviation is only used to measure spread or dispersion around the mean of a data set.
- Standard deviation is never negative.
- Standard deviation is sensitive to outliers. A single outlier can raise the standard deviation and in turn, distort the picture of spread.
- For data with approximately the same mean, the greater the spread, the greater the standard deviation.
- If all values of a data set are the same, the standard deviation is zero (because each value is equal to the mean).

When analysing normally distributed data, standard deviation can be used in conjunction with the mean in order to calculate data intervals.

Example 1 – Standard deviation

A hen lays eight eggs. Each egg was weighed and recorded as follows:

60 g, 56 g, 61 g, 68 g, 51 g, 53 g, 69 g, 54 g

First, calculate the mean:

$$x = \frac{\sum x}{n} = \frac{472}{8} = 59$$

Now, find the standard deviation.

Table 1. Weight of eggs, in grams

Weight (x)	$(x - \bar{x})$	$(x - \bar{x})^2$
60	1	1
56	-3	9
61	2	4
68	9	81
51	-8	64
53	-6	36
69	10	100
54	-5	25
472		**320**

Example 2 – Standard deviation calculated using a frequency table

Thirty farmers were asked how many farm workers they hire during a typical harvest season. Their responses were:

4, 5, 6, 5, 3, 2, 8, 0, 4, 6, 7, 8, 4, 5, 7, 9, 8, 6, 7, 5, 5, 4, 2, 1, 9, 3, 3, 4, 6, 4

Workers (x)	Tally	Frequency (f)	(xf)	$(x - \bar{x})$	$(x - \bar{x})^2$	$(x - \bar{x})^2f$
0	I	1	0	-5	25	25
1	I	1	1	-4	16	16
2	II	2	4	-3	9	18
3	III	3	9	-2	4	12
4	𝍸 I	6	24	-1	1	6
5	𝍸	5	25	0	0	0
6	IIII	4	24	1	1	4
7	III	3	21	2	4	12
8	III	3	24	3	9	27
9	II	2	18	4	16	32
		30	**150**			**152**

To calculate the mean:

$$x = \frac{\sum xf}{f} = \frac{150}{30} = 5$$

To calculate the standard deviation:

$$\sigma = \sqrt{\frac{\Sigma(xi - x)^2 f}{}} = \sqrt{\frac{152}{30}} = 2.25$$

10.4. Graphic Analysis

- Practically everything measurable may be presented graphically.
- Plotted on coordinate paper as points that represent values of variables.
- Line graph can show the relation between variables by using straight line, curve line or both.
- The most commonly used graph is the 2-D graph drawn on Cartesian coordinate (x, y).
- Usually to investigate the relationship between two parameters on two different axis – horizontal axis (abscissa) and vertical axis (ordinate).
- To make a graph effective, certain considerations must be observed:
  1. Choosing the coordinate scales
     - The scale of the independent variables is usually plotted along the x-axis (horizontal).
  2. Labelling the coordinate scales
  3. Plotting the data
  4. Fitting the curve to the plotted points
  5. Labelling the curves
  6. Preparing the title properly

When plotting on x-y graph,

- If y is a function of x, then y is plotted on vertical axis, and x is plotted on horizontal axis

- If parameter Q is influenced by changes in parameter P, then Q is plotted on vertical axis, and P is plotted on horizontal axis

10.4.1. Graph x – y

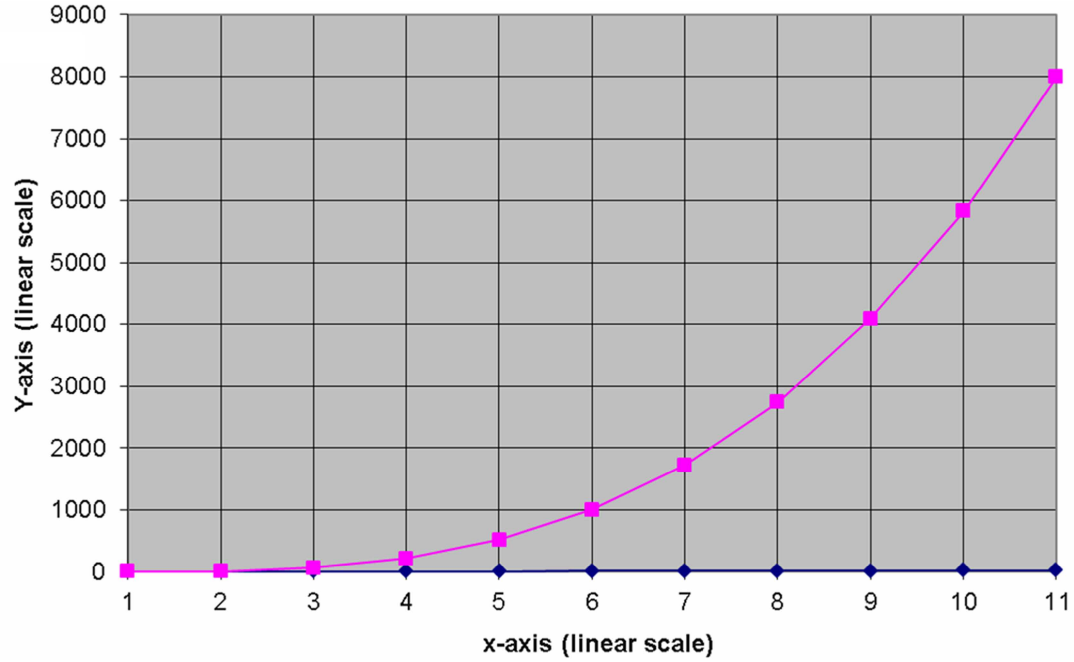


Figure 10.9: An example of graph x-y

10.4.2. Semi Log

In science and engineering, a semi-log graph or semi-log plot is a way of visualizing data that are related according to an exponential relationship. One axis is plotted on a logarithmic scale. This kind of plotting method is useful when one of the variables being plotted covers a large range of values and the other has only a restricted range – the advantage being that it can bring out features in the data that would not easily be seen if both variables had been plotted linearly.

Semi log graph is used whenever:

Range of y value is too big, several magnitude (multiple power of 10)

Exponential equation, $= ae^{bx}$ *, looks like a straight line when plotted on semi log graph*

- The basic equation is $y = ae^{bx}$
- It can be written in log form
  - ➢ $log\ y = log\ a + bx\ log\ e = log\ a + 0.434294bx$

- It can also be written in ln form
    - $\ln y = \ln a + bx \ln e = \ln a + bx\ (because\ \ln e = 1)$

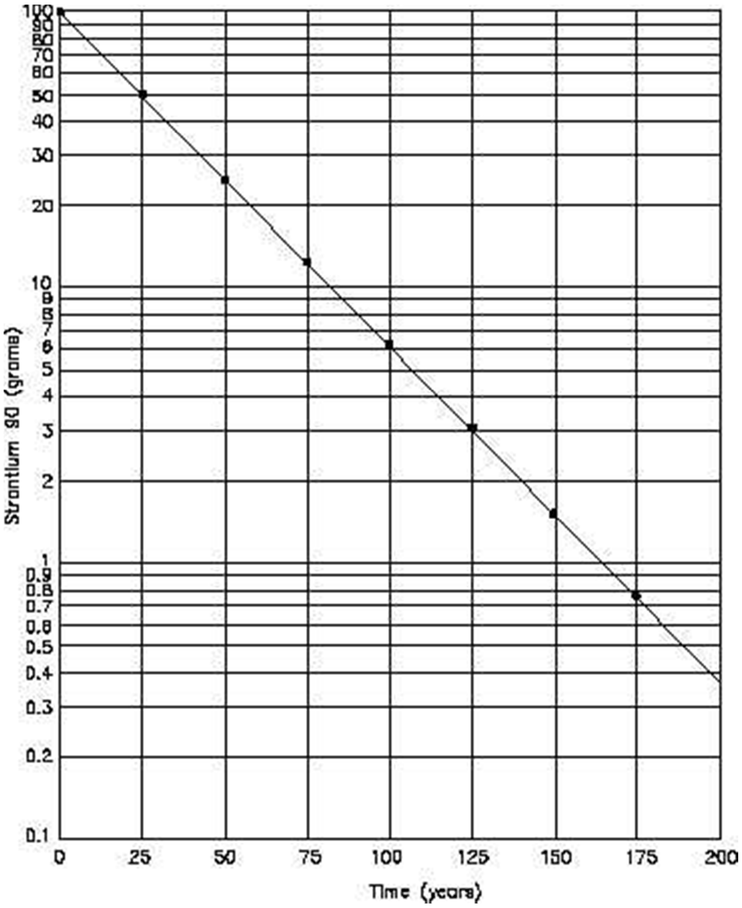


Figure 10.10: An example of Semi-log.

We can define a general equation for a straight line on a graph as ;

ordinate = (slope x abscissa) + constant

We can define the exponential equation mentioned before as

$\log y = ordinate$

$0.434294\ b = slope$

$x = abscissa$

$\log a = constant$

Or, we can also define the exponential equation mentioned before as

$\ln y = ordinate$

$b = slope$

$x = abscissa$

ln a = constant

10.4.3. Log-Log

In science and engineering, a log–log graph or log–log plot is a two-dimensional graph of numerical data that uses logarithmic scales on both the horizontal and vertical axes. Monomials – relationships of the form $y = ax^b$ – appear as straight lines in a log–log graph, with the power and constant term corresponding to slope and intercept of the line, and thus these graphs are very useful for recognizing these relationships and estimating parameters.

- Log-log graph has log coordinates along both axes.
- It is a plot of log y versus log x .
- plotted as a straight line on a log-log paper
- Log-log graph does not have log 0 because log 0 is not defined

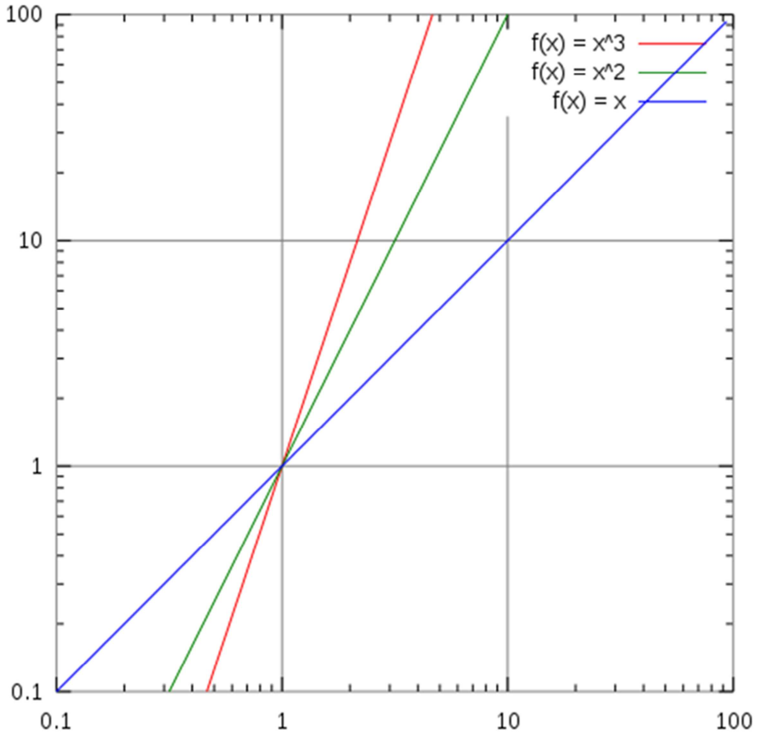


Figure 10.11: A log–log plot of $y = x$ (blue), $y = x^2$ (green), and $y = x^3$ (red).

- This type of graph is suitable for data that can be represented by power equation $y = ax^b$
- It can be written in log form
- $log\, y = log\, a + b\, log\, x$
- It can also be written in ln form
- $ln\, y = ln\, a + b\, ln\, x$

We can define power equation mentioned before as

$log\ y$ = ordinate

b = slope

$log\ x$ = abscissa

$log\ a$ = constant

We can define power equation mentioned before as

$ln\ y$ = ordinate

b = slope

$ln\ x$ = abscissa

$ln\ a$ = constant

Chapter.11

11.0 Occupational Health and Safety Act

11.1. Introduction

The Occupational Health and Safety Act (OHSA) is legislation for workplace health and safety. The main purpose of the Act is to protect workers from health and safety hazards on the job. It sets out duties for all workplace parties and rights for workers. It establishes procedures for dealing with workplace hazards and provides for enforcement of the law where compliance has not been achieved voluntarily. OHSA applies to almost every worker, supervisor, employer and workplace, including workplace owners, constructors and suppliers of equipment or materials to workplaces covered by the Act. There are some definitions related to OHSA as follows:

1. Accidents:

   Accidents is undesirable, unplanned, uncontrolled and unexpected event that can cause injury to workers and damage to properties
2. Injury:

   Injury is harmful condition sustained by the body as a result of an accident
3. Fatal injury:

   Fatal injury is death occurring up to a year after accident
4. Major injury:

   Major injury is type of harm which causes permanent or prolonged impairment of the body

11.2. Hazard and Risk

A hazard is something that can cause harm, e.g. electricity, chemicals, working up a ladder, noise, a keyboard, a bully at work, stress, etc. The hazard presented by a substance is its potential to cause harm. Hazard is associated with degrees of danger, and is quantifiable.

A risk is the chance, high or low, that any hazard will actually cause somebody harm. For example, working alone away from your office can be a hazard. The risk from a substance (or machines, methods of work, or other aspects of work organization) is the likelihood that it will cause harm in the actual circumstance of use. Risk should be thought of in terms of “chance-taking”. Link between hazard and risk must be understood – poor control can create substantial risk even from a substance with low hazard, but with proper control, the risk of being harmed by even the most hazardous substance is greatly reduced.

11.3. Preventing Industrial Accidents

It is important for all employees to be aware of the dangers that may accompany their work. And, of course, some jobs present more risks than others. The concept of risk assessment and risk management is essential for the prevention and control of risks to occupational safety and health. Key aspects of risk assessment include ensuring that all relevant risks are taken into account, checking the efficiency of the adopted safety measures, documenting assessment results and reviewing the assessment regularly.

Japanese Central Council on Preventing Industrial Accidents lists 7 leading unsafe acts as

1. violation or neglect of rules and regulations
2. sloppy liaison procedures
3. mishandling and/or misjudgment by equipment operators
4. carelessness
5. abuse or neglect of safety devices
6. irrational behavior
7. unsafe job performance due to physical handicap

7 leading causes of accidents

1. physiological causes
2. psychological causes
3. management errors
4. poor training

5. unsafe equipment or work environment
6. insufficient skill
7. socio-cultural factors

Successful safety programs depend on:

- Leadership by the management
- Safe and healthy working conditions
- Safe work practices by employees

Management must:

- Be willing to accept the responsibility of occupational safety and health as an integral part of their jobs
- Establish safety policies
- Stimulate awareness of safety in others
- Show their own interests

Front line supervisor:

- Bears the greatest responsibility for implementing safety and health programs
- Must be given appropriate training' support, assistance and authority

Key To Accident Prevention

- Determining The Cause
- Preventing recurrences

The Anatomy of an Accident

- Contributing Causes
- Immediate Causes
- The Accident
- The Results Of The Accidents

11.4. Contributing Causes of Accidents

The cause of an accident or incident has many aspects. Causes are actions, omissions, events, conditions, or a combination thereof, that lead to an accident or incident.

Examples:

a) Inadequate codes or standards
b) Failure by management to enforce safety rules

c) Faulty design or lack of maintenance
d) Inadequate personal protective equipment

Strong management team and a cooperative safety minded workforce to control the contributing factors.

Supervisory safety performance

a) safety instructions inadequate
b) safety rules not enforced
c) safety not planned into the job
d) infrequent employee safety contacts
e) hazards left uncorrected
f) safety devices and equipment not provided

Mental Condition of Worker

a) Lack of safety awareness and training
b) Lack of coordination
c) Improper attitude
d) Slow mental reaction
e) Inattention
f) Lack of emotional stability
g) Nervousness
h) Temperament

Physical condition of worker

a) Extreme fatigue
b) Deafness
c) C. Poor eyesight
d) Heart condition
e) High blood pressure
f) Lack of physical qualifications for the job

11.5. Immediate Causes of Accidents

Accidents arise from unsafe behavior and unsafe conditions. An important factor is the safety climate or safety culture of an organization. Safety culture concerns how workplace safety is managed which is consisting of the shared attitudes, beliefs, perceptions, and values among employees.

11.5.1. Unsafe Acts

a) Protective equipment or safety equipment provided but not used
b) Hazardous method of handling materials (wrong lifting method, loose grip etc.)
c) Improper use of tools or equipment although proper tools were available
d) Hazardous movement (running, jumping, throwing, etc.)
e) Horseplay

Any acts on the part of a person which will increase his or her chances of having an accident. Many workers take unnecessary risks on the job because they believe they will not have an accident.

Negative reinforcement

E.g. Drivers who violate traffic rules

They have been 'rewarded' for unsafe driving behavior in 2 ways

1. They have achieved whatever their goal was
2. They have had no accidents and are thus still alive

The more reinforcement they have succeeded in careless methods, the more reinforcement they seem to have received.

To determine unsafe act:

a) What did someone do or fail to do
b) Was the injured employee following procedure
c) What specific task needed to be eliminated or added to prevent a recurrence?

Most commonly found unsafe acts:

1. Using broken or defective hand tools
2. Not wearing the prescribed personal protective equipment
3. Not following safety procedures or obeying the safety rules
4. Poor housekeeping practices on the part of the worker around the work place
5. Careless attitudes and ignorance

Many unsafe acts occur because workers were not properly trained or motivated by their supervisors·
Certain actions in some situations will increase chances of accidental injuries

11.5.2. Unsafe Conditions

a) Ineffective safety device
b) Safety device required but not provided
c) Poor housekeeping (material on floor, stacking, storage, congestion on aisles)
d) Defective equipment, tools, machines and electrical systems.
e) Improper dress or apparel for job
f) Improper or inadequate illumination, ventilation

Faulty equipment can also cause serious personal injuries, a common example being accidents from faulty ladders. If the rubber feet are absent, the base of the aluminum stile can slip suddenly on a hard floor and the user fall.

Greatest contributors of unsafe conditions are the actions of the employees themselves
Unsafe condition:

1. Mechanical and physical condition of the equipment (unguarded moving machine parts)
2. Condition of walking and working surfaces (defective floors and aisles)
3. Illumination, ventilation, sound, vibration, toxic fumes,

Categories of unsafe conditions:

1. Action or inaction of the workers at the workplace
2. Deterioration of tools, machines and equipment due to normal wear and tear
3. Poor or inadequately designed tools, machines and operating equipment.
4. Omission of safety features during the engineering or maintenance of the equipment.

11.6. The Accident

Occupational accidents and diseases cause great human suffering and loss and the economic cost is also high. An accident at work is a discrete occurrence in the course of work" leading to physical or mental occupational injury. According to the International Labor Organization (ILO), more than 337 million accidents happen on the job each year, resulting, together with occupational diseases, in more than 2.3 million deaths annually [ILO]. There are several types of accidents as follows:

a. Struck by
b. Struck against
c. Caught in, on or between
d. Fall from above
e. Electrical contact
f. Burn

11.6.1. Results of the Accidents

a. Annoyance
b. Production delays
c. Reduced quality
d. Spoilage
e. Minor injury
f. Disabling injury
g. Fatality

11.6.2. Accident Control Steps

Accident is an indicator that the management system is not functioning accident prevention program.

Control steps to be taken:

Supervisory Safety Performance

a. Job-hazard analysis
b. Enforcement of safety rules
c. Adequate safety knowledge
d. Promotion of employee participation in the safety program
e. Proper job placement

   f. Development of safety working condition

Mental Working Condition of Worker

a. Daily safety contacts by the supervisor
b. Adequate safety indoctrination and on the job safety training
c. Safety promotion and publicity
d. Regularly schedule safety meetings
e. Employee participation in the safety program
f. Adequate supervisor - employee communication on all matters concerning safety on the job

Physical Condition of The Worker

a. Pre-placement physical examinations
b. Periodic examinations
c. Proper job placements
d. Adequate medical systems
e. Recognition of physical limitations of workers newly placed on the job

Exercises

Test 1 2015, UTM

SECTION A (60% - 40 minutes)

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1. An experiment has to be divided into various stages systematically. Which of the following order of stages is correct,

   i. Clearly stated the experiment objective
   ii. Proper preparation and planning
   iii. Repeatability and repetition of experiment
   iv. Experiment and measurement execution
   v. Data analysis & report writing

   A. i, ii, iv, v and iii
   B. i, ii, iii iv and v
   C. ii, i, v, iii, and iv
   D. i, ii, iv, iii and v

2. Which of the following is a correct sequence of contents in a report?

   i. Appendices
   ii. Abstract
   iii. Theory
   iv. Reference

   A. ii, iii, i, iv
   B. ii, iii, iv, i
   C. iii, ii, i, iv
   D. iii, iv, ii, i

3. The following reports are expected from engineering students EXCEPT,

   A. Industrial report
   B. Field report
   C. Financial report
   D. Laboratory report

4. There might be differences of aims between experiments conducted by a student compared to an experience researcher. But, regardless of who's conducting the

research the *scientific method* used should be the same. Which sentence is **WRONG** in describing this method?

A. Change only one variable at a time
B. Used a new experimental procedure only
C. Test the reliability of that experiment by proving that the result is repeatable
D. Test the experimental procedure to make sure it is valid and suitable

5. *Pilot experiment* is needed in certain cases. Below are some reasons of having pilot test. Which one is **NOT TRUE**?

A. To make sure that suitable experimental method is applied
B. To make sure that suitable apparatus is used
C. If pilot test is success then there is no need to do other experiment as the result is already valid. This will cut cost and time
D. To choose the best within various available apparatus that can be used

6. Choose the **BEST** combination that describes the log book.

i. As an important tool that help in report writing
ii. As the main record for patent law
iii. To note down the processes activities remarks and result of experiment
iv. As a record of success or failure for any research

The best combination is,

A. i, ii, & iii
B. i, ii, & iv
C. ii, iii, & iv
D. All above.

7. The log book of engineering student must include the following.

i. Date and objectives of the experiment
ii. Main apparatus to be used and set-up
iii. Table of results and remarks on error/ result of experiment.
iv. Literature review or any research from previous study

The best combination is,

A. i, ii, & iii
B. i, ii, & iv
C. ii, iii, & iv
D. All above.

8. The following should be included in the Conclusion section of a report EXCEPT,

A. Figures and explanation of figures
B. Summary of the main points
C. The limitation and advantages of the findings
D. The application of the results

9. In which section of the report the following words can be found?

"Effect of particle angularity on frictional coefficients was investigated. The particles used were silica sand and garnet with drag and stop mode test using the spike parameter quadratic fit (SPQ) method to characterize the particles angularity. Results showed that particles angularity exhibited ………."

A. Abstract
B. Introduction
C. Theory
D. Discussion

10. The Abstract of the laboratory report should include all these elements, **except**

A. Problem background
B. Report outline
C. Major conclusion
D. Important results finding

11. To design and apply measurement systems, we need two kinds of information;

i. *accepted methods* of specifying the *accuracy* of any measurement system.
ii. the different devices available for measuring specific variables such as temperature and pressure, so that we can *choose the most appropriate* apparatus
iii. the material specification
iv. the cost of material and equipment

A. i & ii
B. i &iii
C. i & iv
D. iii & iv

12. Important section for those who must act on the findings, it may involve strategies to solve the problem in the current work and further work to be completed;

A. Conclusions
B. References
C. Recommendations
D. Appendices

13. Choose the right concept of mechanical measurement below in order to minimize errors in the experiment;

    i. if several parameters need to be controlled, the number of influencing parameters should be reduced.
    ii. the variable being measured is the only dependent variable during the measurement.
    iii. measuring detector must not be sensitive enough to detect any changes in the variable being measured
    iv. signal path of a measurement system must be so designed that effects of foreign or external variables can be minimized

    A. i, ii & iii
    B. ii, iii & iv
    C. i, iii, & iv
    D. i, ii, & iv

14. Which definition is not true;

    A. Population: collection of raw data
    B. True value: actual magnitude of measured entity
    C. Resolution: the biggest scale readable from the equipment
    D. True error: difference between the measured and the true value

15. Calibration procedures involve a comparison of the particular instrument with either of the two references;

    i. a *primary standard*
    ii. a *secondary standard* with a higher accuracy than the instrument to be calibrated
    iii. an un*known input* source
    iv. a known output source

    A. i & ii
    B. i & iii
    C. ii & iv
    D. ii & iii

16. Which of the following statements related to force measurement is not true?

    A. The change in dimension and shape of an elastic body is proportional to the applied stress.
    B. If the stress goes beyond the elastic limit of a body, the body does not return to its original state after the stress is removed.

C. The Hooke's law states that strain and the relative change in dimension is proportional to stress.
D. The Hooke's law can be applied to the region above the elastic limit of a body.

17. The order of hierarchy of standards are:

i. Primary standard
ii. Local standard
iii. National standard / mobile standard
iv. Work instrument / measurement system

A. i, ii, iii & iv
B. i, iii, ii & iv
C. i, iv, ii & iiii
D. ii, i, iii & iv

18. Which of the following is not the function of a vernier calipers?

A. To measure radius of the edges
B. To measure outside diameter
C. To measure inside diameter
D. To measure depth

19. Calibration can be defined as an act of:

A. applying a known value to the input of a measuring instrument for the purpose of observing the output.
B. optimizing output result from two experiments
C. finding the best accuracy of the equipment
D. averaging the error from an experiment.

20. Which of the following statements is not true related to pressure measurement;

A. Absolute pressure is zero-referenced against a perfect vacuum, so it is equal to gauge pressure minus atmospheric pressure
B. Gauge pressure is zero-referenced against ambient air pressure
C. Gauge pressure is equal to absolute pressure minus atmospheric pressure.
D. Differential pressure is the difference in pressure between two points.

21. Which of the parameters below are used in a method of measurement:

i. Linear dimension
ii. Mass, weight, force and torque
iii. Pressure and temperature
iv. Concept and design

A. i, ii
B. i, ii, iii
C. i, ii, iv
D. ii, iii, iv

22. Which of the tools below are used to measure linear dimensions:

i. Ruler
ii. Caliper
iii. Screw gauges
iv. Dial gauges

A. i, ii, iii
B. i, ii, iv
C. i, iii, iv
D. All of the above

23. What is the reading shown by the vernier caliper Figure 1?

A. 556.3mm
B. 55.65mm
C. 55.43mm
D. 554.35mm

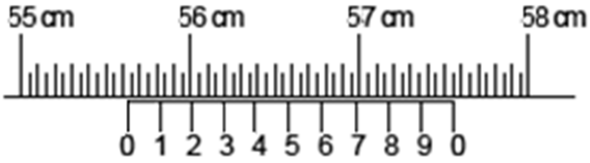


Figure 1

24. What will be the precision of the scale shown in Figure 2?

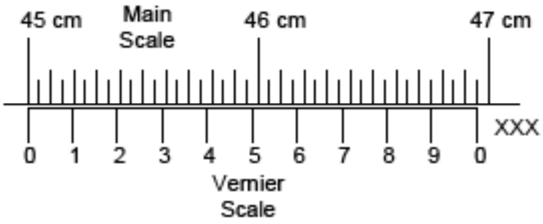


Figure 2

A. ± 1mm
B. ± 0.01mm
C. ± 0.05mm
D. ± 0.1mm

25. Which of the following mechanism are used in the pressure measurement instruments?

    i. By elastic deformation
    ii. By plastic expansion
    iii. By liquid column
    iv. By strain measurement

    A. i, ii, iii
    B. i & iii
    C. ii, iii, iv
    D. All of the above

26. Which of the following is the unit for Force?

    A. kg / (ms^{-2})
    B. kg / (ms)
    C. kg.m/ (s^2)
    D. kg / (ms^2)

27. In a manometer liquid selection, which is not true about the selection criteria of the liquid?

    A. Low viscosity
    B. Low coefficient of expansion
    C. Low vapour pressure
    D. Low corrosiveness

28. A **load cell** is an electronic device (transducer) that:

    i. convert force into electrical signal
    ii. use strain gauge to measure the force
    iii. consist four strain gauges to convert strain into electrical signals
    iv. convert electrical signal into pressure

    A. ii, iii, iv
    B. ii & iv
    C. i, ii, & iii
    D. All of the above

29. Which of the following is not suitable to measure power:

    A. Transmission dynamometer
    B. Prony brake
    C. Tachometer
    D. Hydraulic dynamometer

30. Which of the below is the absorption type of dynamometer:

    i. Mechanical
    ii. Electrical
    iii. Hydraulic
    iv. Pneumatic

    A. i, ii, iii
    B. i, ii, iv
    C. ii, iii, iv
    D. All of the above

Answer:

D, B, C, B, C, D, A, A, A, B

A, C, D, C, A, D, B, A, A, A

B, D, A, C, B, C, D, C, C, A

Test 1 2017, UTM

SECTION A (60% - 40 minutes)

1. During an experiment, why there is a need to record down the details of the equipment used?
   A. To reduce errors
   B. To ease the data analysis process
   C. To avoid in term of changes in arrangement in the experiment
   D. To be recorded into log book

2. Generally, scientific methods used to carry out an experiment are as follows,
   i. To change only one variable at one time
   ii. To prove that certain experiment is acceptable and reliable
   iii. To prove the repeatability of certain experiment
   iv. To fix the total costing in an experiment

A. i, ii, iii, iv	B. i, ii, iii
C. ii, iii, iv	D. ii and iv

3. What is the main focus of an engineer during an experiment
   A. To prove one theory or formula.
   B. To collect a set of data that can be used at any other time.
   C. To obtain the differences between theory orformula with the experiment result.
   D. To obtain an accurate method for certain experiment results.

4. Select the correct phrase about log book in any research activities

i. Storage of latest information.
ii. Space for data analysis.
iii. Procedures in the application of pattern law.
iv. Help in the preparation of report.

A. i, ii, iii, iv B. i, ii, iv
C. i, iii, iv D. ii, iii, iv

5. Relative accuracy can be defined as

A. $\frac{\text{(Measured value-True value)}}{\text{True Value}} \times 100$
B. (True value - Measured value) x Error
C. $\frac{\text{(True value - Measured value)/}}{\text{True value}}$
D. $\frac{\text{(True value - Measured value)}}{\text{Measured value}} \times 100$

6. Calibration process involves the comparison of output for an equipment or measuring system with

i. A main standard (exactness).
ii. Duplicate standard in which we are sure of having a better accuracy than the equipment to be calibrated.
iii. A measuring system purchased recently.
iv. A pre-determined value of input.
v. Measuring standard in a laboratory.

.

A. i, iii, v B. i, ii, iv
C. ii, iii, iv D. none of the above.

7. The agency that offering the equipment calibration services in Malaysia is

A. FRIM
B. SIRIM
C. PORIM
D. IKIM

8. Below is the component in standard hierarchy EXCEPT

A. Duplicate standard
B. National standard
C. Localized standard
D. Measuring system standard

9. In order to design a measuring system, what are the two (2) types of information that we need to know?

i. Available measuring equipment in the lab that is bought with high price.
ii. A widely accepted method to state the accurate specification in a measuring system.
iii. Making sure a measuring system is being tested repetitively before it is being used.
iv. Knowledge in organizing certain criteria to ease the equipment selection so to carry out various measuring, such as temperature, acceleration, pressure, and electric current.
v. Development of advance equipment with the flow of time.

A. i, v B. iii, v
C. ii, iv D. None of the above

10. An engineering report could consist of the following items as part of the report. Which of the following items could be part of the engineering report?

i. Data analysis
ii. Test result
iii. Corporate logo
iv. Recommendation

A. i, ii B. i, ii, iii
C. i, iv D. i, ii, iv

11. The main target group to whom an undergraduate laboratory report will be read is

A. Laboratory technician
B. Supervising lecturer
C. Fellow colleague
D. Dean of faculty

12. These items can be included in the introduction section of a report EXCEPT

A. Background
B. Main theoretical derivation
C. Limitation of the report
D. Report's approach

13. What do the conclusion section of a report should consist of?

A. A summary of the important findings that have been identified and placed in context.
B. A summary of results that have important values to the project.
C. A summary of discussion based on the experimental result.
D. None of the above.

14. Consider the layout of a complete report below. What is item f ?

a. Title
b. Abstract
c. Preliminary pages
d. Introduction
e. Theory
f. ____________
g. Discussion
h. Conclusion
i. References
j. Appendices

A. Project scope
B. Limitation
C. Experimental procedures
D. None of the above

15. The following statements about abstract are true Except:

A. Also know as synopsis.
B. Often written last
C. Never appear in separate page.
D. All material in the abstract will also be in the report

l6. Which is NOT experimental observation?

A. Test procedures.
B. Recorded data.
C. The difficulty in operating apparatus.
D. The uncertainty of measured data.

17. A conclusion may include

A. A clear and concise summary of the main point.
B. A reference to the original aims.
C. The application of the result.
D. All of the above.

18. The following statements are not true about report recommendation EXCEPT

A. Student may include a brief persuasive statement before presenting the recommendation.
B. All reports must have recommendation.
C. It is an optional section of the report to those who must act on the findings.
D. Cannot be worded in instructional language.

19. Which statement best describes the Figure 1.0?

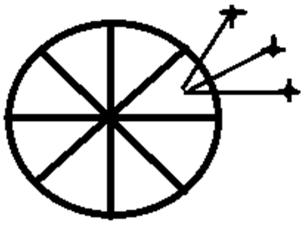


Figure 1.0

A. Accurate and precise.
B. Accurate but not precise.
C. Not accurate but precise.
D. Not accurate and not precise.

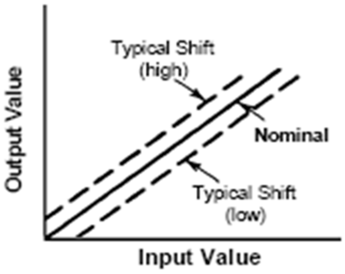
20. Which of the following is NOT adopted as international standard?

A. l/273.16 of thermodynamic triple point of water.
B. 1 650 763.73 wavelengths of orange-red light emitted from a krypton-86 lamp.
C. Cessium-133 atom that undergoes 9192 631770 vibrations.
D. Light that travels in vacuum in 3.335641 x 10-e second.

21. Sequence calibration is an effective diagnostic technique for quantifying?

A. Hysteresis error
B. Linear error
C. Zero error
D. Sensitivity error

22. What type of error is shown below?



A. Zero shift error
B. Sensitivity error
C. Repeatability error
D. Linearity error

23. What is the definition of calibration?

A. The relationship between an input of known dynamic behaviour and the measurement system output.
B. The act of formulating functional relationship between input and output
C. Applying a known value to the input of the measuring system for the purpose of observing the output.
D. The measurement of the changes in the indicated output associated with a given change in a static input.

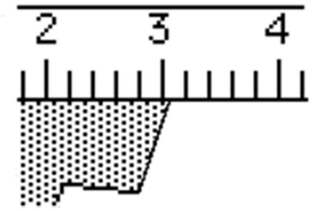
24. Which one is the characteristic that must be taken into consideration when determining a primary standard?

A. Accuracy
B. Continuous reliability
C. Linearity
D. Repeatability

25. Hysteresis effects can be minimized by

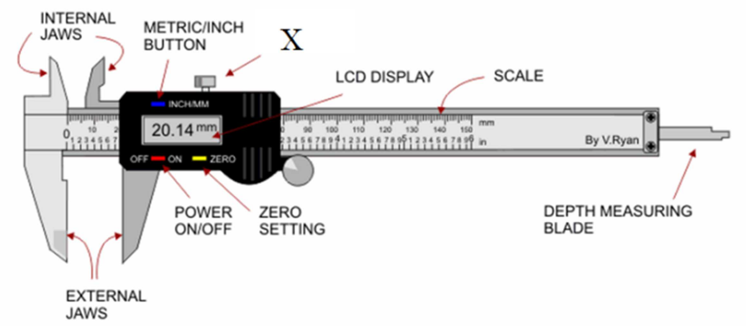
A. Static calibration
B. Random calibration
C. Dynamic calibration
D. Sequence calibr:ation

26. What should be the reading indicated by the ruler in the diagram below?



A. 3.00 + 0.03
B. 3.00 + 0.05
C. 3.07 + 0.05
D. 3.07 + 0.07

27. What is the designed function of the part marked with X ?



A. To indicate the middle of the vernier unit such that the width of the jaw opened to the estimated width.
B. To be pressed when sliding the vernier unit.
C. To lock the vernier unit when the set is to be stored.
D. To keep the vernier steady during use.

28. Which statement is NOT correct?

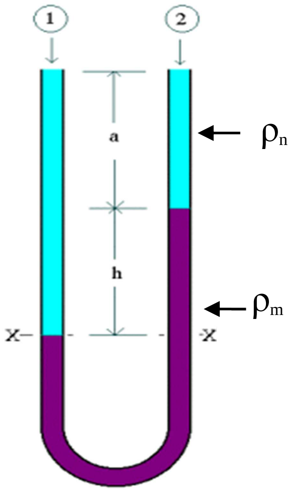
A. Steelyard balance can be made more accurate by ensuring that the fulcrum of the beam is friction-free.
B. One kilogram of mass on earth will weigh one sixth of its weight on earth because the moon gravity is acting on one sixth of its mass.
C. Spring balance should not be used for commercial applications unless their springs are-temperature compensated or used at a fairly constant temperature.
D. A load cell is an electronic device that is used to convert a force into an electrical signal.

29. Which statement is NOT correct?

A. 1 pascal (Pa) is l x l05 N/m^2
B. 1 torr is equal to 133 Pa
C. Gauge pressure is absolute pressure less atmospheric pressure
D. 1 atmosphere is 760mmHg at sea level

30. What is (P_1-P_2) for the manometer?

A. $\rho ga + \rho gh$ B. $\rho_m gh + \rho_n gh$
C. . $\rho_n gh - \rho_m gh$ D. $\rho_m gh - \rho_n gh$



SECTION B (40% - 20 minutes)

31. Briefly describe what are the elements to be included in the ABSTRACT section in a technical report or thesis? (10 *marks*)
32. Discuss, with the aid of a suitable graph, the concept of sensitivity error. (10 *marks*)
33. What is dynamometer? Briefly describe the three types of dynamometer and explain the working principle one of the dynamometers. (10 marks)
34. Describe the following terms of pressure:
    a. Absolute pressure of a fluid
    b. Gauge pressure
    c. Differential pressure

    Briefly describe the two methods used to measure pressure and give two examples of the pressure measuring equipment's. (10 marks)

Test 2 2017, UTM

SECTION A (60% - 40 minutes)

1. Which of the following pairs of temperatures measuring devices work by basically the same principle?
   A. Thermocouple and RTD
   B. Bimetallic strip and thermistor
   C. Infrared pyrometer and thermocouple
   D. Thermistor and RTD

2. What is the current international temperature scale of 1990 (the ITS-90)?
   A. Kelvin
   B. Fahrenheit

C. Celsius
D. Rankine

3. Which of the following is **WRONG** about temperature?
   A. Temperature is related to heat
   B. Measuring temperature means measuring heat
   C. Temperature is fixed and do not move
   D. Heat is measure using the concept of heat equilibrium

4. Which of the following is **NOT** the equipment to measure the temperature?
   A. Bimetallic devices
   B. Liquid expansion devices
   C. Infrared resistance
   D. Change of state devices

5. The following are related to the thermocouple **EXCEPT**
   A. Consists of three strips of wires
   B. Wire made of different metals
   C. Wires joined at one end
   D. Changes in the temperature will induces a change in electric force

6. Which of the following is **NOT** related to the infrared temperature device?
   A. Infrared sensor are contacting devices
   B. Infer temperature by measuring the thermal radiation
   C. Useful for objects that are very hot moving
   D. Temperature can be measured remotely

7. What is the measureable property that changers with temperature in a thermocouple?
   A. expansion
   B. electrical resistance
   C. thermal radiation
   D. voltage

8. Which contact type thermometer has a temperature range of -250^{o}C to 2000^{o}C?
   A. Radiation thermometer
   B. Liquid-in-glass thermometer
   C. electrical resistance thermometer
   D. Thermocouple thermometer.

9. The Celsius unit is based on;

A. The interval of 100^{o}C between the triple point of water and the boiling point of water at the atmospheric pressure.
B. The interval of 100^{o}C between the melting point of ice and boiling point of water at the water vapour pressure
C. The difference between ambient temperature and the boiling point of water at the one atmospheric pressure.
D. The interval of 100^{o}C between the melting point of ice and the boiling point of water at one atmospheric pressure.

10. All of the following are related to the bimetallic device **EXCEPT**
    A. Take advantage of the different in rate of thermal expansion
    B. Strips of three metals are bounded together
    C. Thermal expansion between different metal
    D. When heated, one side of the strip will expand more than the other

11. Which of the following characterizes the mean:
    A. The sum of all the measurements divided by the number of measurements
    B. The point in a distribution about which the summed deviations equal zero
    C. The point in a distribution about which the sum of the squared deviations is minimal
    D. The sum of all the measurements divided by the hundreds

12. In experimental measurement, systematic errors tend to shift all measurement in a systematic ways do their mean value is displaced. Which one of the following is **NOT** the source for systematic error?
    A. Calibration error
    B. Random error
    C. External effect such loading error
    D. Limitation od system resolution

The following text applies to questions 13-15:

A group of students performs a simple experiment to find the average acceleration of a falling object. They drop a baseball from a building and use a string and meter stick to measure the height the ball was dropped. Stopwatch is used to find an average time of fall for 3 trials from the same height and re-ports the following data:

$h = 5.25 \pm 0.15\, m, t = 1.14 \pm 0.06\, s.$

13. Use the equation, $a = 2h/t^2$ to determine the aver-age acceleration (a) and its uncertainty.
    A. 8.08 ± 0.1 m/s^2
    B. 8.08 ± 0.06 m/s^2
    C. 8.08 ± 0.88 m/s^2
    D. 8.08 ± 1.08 m/s^2

14. Comment on the accuracy of the acceleration result. Do you think they made any mistakes?
    A. The uncertainty is high; probably a mistake in height measurement or reaction time with stop-watch.
    B. Although a < g (9.8 m/s2), the result seems reasonably accurate since air resistance would reduce the ball’s acceleration.
    C. The result does not agree with 9.8 m/s2, so the student must have made a mistake.
    D. The result can only be as accurate as the measurements; cannot tell if a mistake was made

15. What is the suggestion to improve the accuracy of the experimental result?
    A. Measure height better use a long tape measure that does not stretch.

B. Improve the precision of the time with more trials
C. Get an assistant to time when the ball hits the ground.
D. Reduce or eliminate air resistance

The following text applies to questions 16-17:

A simple pendulum is known to have a period of oscillation, T = 1.55 s. Student A uses a digital stop-watch to measure the total time for 5 oscillations and calculates an average period T = 1.25 s. Student B uses an analogue wristwatch and the same procedure to calculate an average period for the 5 oscillations and finds T = 1.6 s.

16. Which period is more accurate?
    A. Student A’s period of 1.25 s because a digital stopwatch is more reliable.
    B. Student A’s period of 1.25 s because the stopwatch can measure to 0.01 s.
    C. Student B’s period of 1.6 s because it is closer to the known period than A’s value.
    D. There is not enough information to answer this question.
17. Which measurement is more precise?
    A. Student A’s period of 1.25s because a digital stopwatch is more reliable.
    B. Student A’s period of 1.25s because the stop-watch can measure to 0.01s.
    C. Student B’s period of 1.6s because it is closer to the known period than A’s value.
    D. There is not enough information to answer this question.

18. What is the most probable source of error that could explain the difference in the results?
    A. Human reaction time in starting and stopping the timing devices.
    B. The stopwatch may run too fast; not calibrated properly.
    C. The amplitude of oscillation may have been too large for one pendulum.
    D. Student A mistakenly measured 4 oscillations instead of the intended 5.

19. A group of students are told to use a meter stick to find the length of a hallway. They make 6 independent measurements: 4.402 m, 4.217 m, 4.345 m, 4.456 m, 4.372 m, 4.289 m. How should they report their best estimate of the length of the hallway in two significant digit?
    A. 4.30 m
    B. 4.346 m
    C. 4.35 m
    D. 4.300 m

20. Fluctuation of pressure or pressure variation often involves in experimental measurement and can be classified as:
    A. Random error
    B. Illegitimate error
    C. Systematic error
    D. Calibration error

21. Which of the following basic dimension in used to represent Pressure, p;
    A. M/(LT2)
    B. L/(MT2)

C. M/(LT3)
D. ML2 /T3

22. Which one the following is a correct for definition of the quantity Dz?
A. relative error
B. Percentage error
C. absolute error
D. Random error

23. When an even number of ungrouped scores are arranged according to magnitude, the median is the:
A. score with the greatest frequency
B. mean of the two middle scores
C. middle score
D. mean of the highest and lowest scores

24. Given that a collection of scores on a quiz leads to a mean of 40, a median of 38, and a mode of 36. If we added l0 points to each score what would be the new median?
A. 38
B. 48
C. 40
D. 50

25. Which one of the following is classified into errors?
A. Bias, random and illegitimate errors
B. Absolute, random and illegitimate errors
C. Relative, random and illegitimate errors
D. Percentage, random and illegitimate errors

26. According to the mental condition of worker, which one of the following does not contribute to accident?
A. Lack of safety awareness and training
B. Temperament
C. Nervousness
D. Proper attitude

27. According to the supervisory safety performance, which one of the following does not contribute to accident?
A. safety instructions inadequate
B. safety rules enforced
C. safety not planned into the job
D. infrequent employee safety contacts

28. The fluid expansion techniques are related to EXCEPT.
A. Fluid-expansion sensor do not require electric power
B. The mercury type and organic liquid type
C. Version employing gas are also available
D. Wires tensile measurement

29. The followings are the description of Fahrenheit, EXCEPT.
    A. Named after Gabriel Daniel Fahrenheit
    B. Melting point of pure ice and the temperature of a normal human body as reference
    C. Changed to using the boiling point of water (212°) as the upper fixed point of the scale
    D. Initially 0° and 96° being reference lower and upper scale

30. All below are the significant of using semi-log scale graph when plotting experimental function, EXCEPT.
    A. Reduce the scale range that too big
    B. Have log scale on both axes
    C. Produce linear trend
    D. Does not have log 0 on the log scale

SECTION B (40% - 20 minutes)

31. Describe the working principle of thermocouple and bimetallic device?
32. Write list of seven (7) leading unsafe acts according to Japanese Central Council on Preventing Industrial Accidents?
33. Determine the variance and standard deviation for the following data:

    5.30, 5.73, 6.77, 5.26, 4.33, 5.45, 6.09, 5.64, 5.81 and 5.75
34. Practically everything THAT IS measurable can be presented graphically. To make a graph more effective, certain considerations must be observed. List down the items that must be included when drawing a graph

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Autobiographies

Jaswar Koto was born on October, 1970. He is a descendant of the Prophet Rasullullah S.A.W through Husein R.A. He is a President of Ocean and Aerospace Research Institute, Indonesia. Professor on offshore engineering and also President of International Society of Ocean, Mechanical & Aerospace for scientist and engineers.

He has been invited as a Visiting Professor more than 16 times, received several international awards and supervised PhD, Master and Bachelor Students.

He received his bachelor degree in 1994 from Institut Teknologi Sepuluh Nopember (ITS), Indonesia, Curtin University in 1996 and Notre Dame University in 1999. In 2003 he has completed PhD with receiving award in engineering form Aerospace and Marine Engineering, Osaka Prefecture University, Japan.

He has started his researches since 1994 on structure analysis of fluid flow in subsea pipelines, subsea pipeline corrosion due to Carbon Monoxide, design and hydrodynamic analysis of AUV in Australia. Then, he joined Research and Development Institute, Sumitomo Heavy Industries -Marine Engineering-, Japan. In 2005, he joined ExxonMobil projects. Since 2010, he has a contract with Department of Aeronautical, Automotive, and Ocean Engineering, Faculty of Mechanical Engineering. He is also appointed as head of High Performance Computing, CICT, Universiti Teknologi Malaysia.

M. Nazri M. Nasir, PhD, is senior lecturer at Department of Aeronautics, Automotive and Ocean Engineering, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia since 2006. Currently, he is a project leader of the UTM's Unmanned Aerial System (UAS) also known as CAMAR which based at UTM Aeronautics Laboratory. He was conferred the Doktor-Ingenieurs from Technische Universität Darmstadt, Germany in 2017 and Master of Science in Aerospace Engineering from Delft University of Technology, The Netherlands in 2008. Besides, he is a chartered engineer of the Institution of Mechanical

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