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ENGINEERING METROLOGY AND MEASUREMENTS

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Dedicated to our revered guru and mentor,
Dr T.R. Seetharam

Preface

The origin of metrology can be traced to the Industrial Revolution, which began in Western Europe and the United States in the beginning of the 19th century. This period saw a transition from manual to mechanized production and the setting up of factories to manufacture iron and textiles. There was a paradigm shift from artisan-oriented production methods to mass production. An artisan produced an article the same way a storage shelf is built in a closet—by trial and error till the parts fit. Mass production called for division of labour and precise definition of production tasks. Tasks became specialized, requiring skilled people who worked on only a portion of the job, but completed it quickly and efficiently. The workers' wages were determined by a 'piece-rate' system. They were only paid for the good parts; thus it became necessary to define what a good part was. This led to the design of inspection gauges and the need for an inspector who could decide whether a part was good or not. In 1913, Henry Ford, an American idustrialist, perfected the assembly line system to produce cars. In order to ensure quality as well as high production rates, new methods of inspection and quality control were initiated, which perhaps formed the basis of modern metrology.

Engineering metrology deals with the applications of measurement science in manufacturing processes. It provides a means of assessing the suitability of measuring instruments, their calibration, and the quality control of manufactured components. A product that is not manufactured according to metrological specifications will have to incur heavy costs to comply with the specifications later. Any compromise in quality creates rapid negative sentiments in the market and the cost of recovering the original market position would be quite high. Today, metrological error has a far greater impact on cost than in the past. Hence, an organization should strive towards a *zero-defect* regime in order to survive in a highly competitive market. Ensuring this aspect of manufacturing is the responsibility of a quality control engineer, who must be completely familiar with the basics of measurement, standards and systems of measurement, tolerances, measuring instruments, and their limitations.

The science of mechanical measurements has its roots in physics. It is an independent domain of knowledge dealing with the measurement of various physical quantities such as pressure, temperature, force, and flow.

ABOUT THE BOOK

Engineering Metrology and Measurements is a core subject for mechanical, production, and allied disciplines in all the major universities in India. Although there are a few good books available on metrology, the coverage of topics on mechanical measurements is either scanty or superficial, necessitating students to refer to different books on mechanical measurements. This book provides a comprehensive coverage of both metrology and mechanical measurements.

Divided into three parts, the first part of the book comprising Chapters 1–11, begins with a comprehensive outline of the field of engineering metrology and its importance in mechanical engineering design and manufacturing. The basic concepts of engineering standards, limits, fits, and tolerances, for ensuring interchangeability of machine components are then discussed.

This is followed by a discussion on metrology of linear and angular measurements. Later in the book, comparators, followed by the metrology of gears, screw threads, and surface finish metrology are discussed. The chapter on miscellaneous metrology talks about laser-based instrumentation and coordinate measuring machines. The last chapter in this section features inspection methods and quality control.

The second part of the book comprising Chapters 12–16 focuses on mechanical measurements. The coverage is restricted to measurement techniques and systems that are complementary to engineering metrology. The topics covered are the basics of transducers and the measurement of force, torque, strain, temperature, and pressure.

The third part of the book comprising Chapter 17 details nanometrology techniques and instrumentation. Nanotechnology has opened a new world of scientific research and applications. India has also joined the bandwagon and today, we see a phenomenal investment in the research and development of this discipline, both in the government and private sectors. There is abundant scope for pursuing higher studies both in India and abroad. We hope this section on nanometrology will further stimulate the curiosity of the students and motivate them to take up higher studies in this new and interesting field.

The book is designed to meet the needs of undergraduate students of mechanical engineering and allied disciplines. The contents of this book have been chosen after careful perusal of the syllabi of the undergraduate (B.E./B. Tech) and diploma programmes in India. The topics are explained lucidly and are supported by self-explanatory illustrations and sketches. The following are a few key features of the book.

KEY FEATURES

- Covers both metrology and mechanical measurements in one volume
- Offers guidelines for the proper use and maintenance of important instruments, such as vernier callipers, autocollimators, slip gauges, and pyrometers
- Provides simple solved examples, numerical exercises in all relevant chapters, theoretical review questions, and multiple-choice questions with answers at the end of every chapter
- Introduces the principles of nanometrology, a topic that has emerged from the popular discipline of nanotechnology, in an exclusive chapter, highlighting its applications in the production processes
- Includes an appendix containing 20 laboratory experiments with comprehensive procedures, observation templates, and model characteristics, with select experiments presenting photographs of the actual instruments to gain a visual understanding of the equipment used

ONLINE RESOURCES

To aid the faculty and students using this book, the companion website of this book http://oupinheonline.com/book/raghavendra-engineering-metrology-measurements/9780198085492 provides the following resources:

For instructors

- A solutions manual for the numerical exercises given in the book

- A complete chapter-wise PowerPoint presentation to aid classroom teaching

For students

- Two sets of model question papers to test students' understanding of the subject, thereby preparing them for the end-semester examination.

CONTENTS AND COVERAGE

The book is divided into three parts: Engineering Metrology (Chapters 1–11), Mechanical Measurements (Chapters 12–16), and Nano Impact on Metrology (Chapter 17). A chapter-wise scheme of the book is presented here.

Chapter 1 deals with the basic principles of engineering metrology. It gives an overview of the subject along with its importance. It also talks about general measurement, methods of measurement, errors associated with any measurement, and the types of errors.

Chapter 2 sets the standards of measurement. These standards acts as a reference point for the dimensional measurements.

Chapter 3 presents the limits, fits, and tolerances in design and manufacturing. An understanding of these concepts helps in the interchangeability of manufactured components.

Chapter 4 discusses linear measurements that form one of the most important constituents of metrology. The chapter throws light on surface plates and V-blocks, over which the measurand is inspected. It discusses the scaled, vernier, and micrometer instruments in detail. The chapter ends with a detailed explanation of slip gauges.

Chapter 5 elaborates on angular measurements. The fact that not all measurands can be measured by linear methods stresses the significance of this topic. This chapter deals with devices such as protractors, sine bars, angle gauges, spirit levels, and other optical instruments used for angular measurements.

Chapter 6 aids in the comprehension of comparators. In several instances, a measurement may be carried out on the basis of a comparison with the existing standards of measurements. This chapter discusses the instruments that work on this common principle.

Chapter 7 explains optical measurements and interferometry. Optical measurement provides a simple, accurate, and reliable means of carrying out inspection and measurements in the industry. This chapter gives insights into some of the important instruments and techniques that are widely used. Interferometers, which use laser as a source, are also discussed in detail.

Chapter 8 focuses on the metrological inspection of gears and screw threads. Gears are the main elements in a transmission system. Misalignment and gear runout will result in vibrations, chatter, noise, and loss of power. Therefore, one cannot understate the importance of precise measurement and inspection techniques for gears. Similarly, the geometric aspects of screw threads are quite complex and hence, thread gauging is an integral part of a unified thread gauging system.

Chapter 9 analyses the metrology of surface finish. Two apparently flat contacting surfaces are assumed to be in perfect contact throughout the area of contact. However, in reality, there are peaks and valleys between surface contacts. Since mechanical engineering is primarily concerned with machines and moving parts that are designed to precisely fit with each other, surface metrology has become an important topic in engineering metrology.

Chapter 10 comprises miscellaneous metrology, which details certain measurement principles and techniques that cannot be classified under any of the aforementioned dimensional measurements. Coordinate measuring machines (CMM), machine tool test alignment, automated inspection, and machine vision form the core of this chapter.

Chapter 11 lays emphasis on inspection and quality control. Inspection is the scientific examination of work parts to ensure adherence to dimensional accuracy, surface texture, and other related attributes. This chapter encompasses the basic functions of inspection and statistical quality control—*total quality management* (TQM) and *six sigma*—the customer-centric approaches towards achieving high quality of products, processes, and delivery.

Chapter 12 helps in understanding mechanical measurements. Mechanical measurements are (physical) quantity measurements unlike the dimensional measurements discussed in Chapters 1–11.

Chapter 13 explains the principle and working of transducers. Transducers are generally defined as devices that transform physical quantities in the form of input signals into corresponding electrical output signals. Since many of the measurement principles learnt in earlier chapters require a transducer to transmit the obtained signal into an electrical form, the study of transducers is inevitable.

Chapter 14 elucidates the physical quantities of measurement: force, torque, and strain.

Chapter 15 illustrates the concept of temperature measurements—the principles involved in temperature measurement and devices such as resistance temperature detector (RTD), thermocouple, liquid in glass thermometer, bimetallic strip thermometers, and pyrometers.

Chapter 16 defines yet another important physical quantity, pressure. It helps us in getting acquainted with instruments such as manometers, elastic transducers, and vacuum and high pressure measurement systems.

Chapter 17 helps us appreciate the applications of nanotechnology in metrology. It explains the basic principles of nanotechnology and its application in the manufacturing of nanoscale elements that are made to perfection.

Appendix A introduces the universal measuring machine.

Appendix B simplifies the theory of flow measurement. Although a broader subset of mechanical measurements, flow measurement is an independent field of study. Students are introduced to this field in a typical course on fluid mechanics. Here we have tried to present only the basics of flow measurement with a synopsis of measurement devices such as the orifice meter, venturi meter, pitot tube, and rotameter.

Appendix C comprises 20 laboratory experiments with photographs of some of the equipment used in measurement. The appendix also provides a step-by-step procedure to conduct the experiments and an observation of results.

Appendix D presents the control chart associated with statistical quality control. These values help understand certain problems discussed in Chapter 11.

ACKNOWLEDGEMENTS

We attribute our efforts for completing this book to Dr T.R. Seetharam and Dr G.L. Shekar, who have inspired us and shaped our careers. Dr. Seetharam, Professor (retired) in Mechanical Engineering and former Principal, National Institute of Engineering (NIE), Mysore, is an embodiment of scholarship and simplicity. He has motivated thousands of students, who are now in noteworthy positions in organizations all over the world. He mentored us during our formative years at the NIE and instilled in us the spirit to strive for excellence. Dr G.L. Shekar, the present Principal of NIE has been a friend, philosopher, and guide. He is a bundle of unlimited energy and has initiated a large number of research and industry-related projects at the NIE. We are happy to be associated with many of these projects, which have broadened our horizon of knowledge and provided a highly stimulating work environment.

We thank our college management, colleagues, and students, who encouraged us to work on this book. Special thanks to our esteemed colleagues, Dr B.K. Sridhara, Dr T.N. Shridhar, and Dr M.V. Achutha, for their valuable suggestions and continuous encouragement. We acknowledge the contributions of our former colleagues, Mr Manil Raj and Mr N.S. Prasad, in the preparation of the laboratory experiments provided as an appendix in the book. Special thanks to Mr K. Chandrashekar, Scientist B, Centre for Nanotechnology, NIE, for sourcing a large number of e-books on nanotechnology. Ms Pooja K., Software Engineer, Delphi Automotive Systems Pvt. Ltd, Bangalore, provided useful inputs for key chapters in Part II of the book and we thank her for the same.

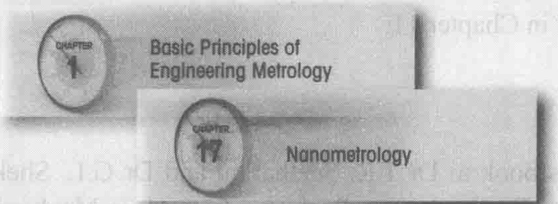
We are extremely grateful to our families, who graciously accepted our inability to attend to family chores during the course of writing this book, and especially for their extended warmth and encouragement. Without their support, we would not have been able to venture into writing this book.

Last, but not the least, we express our heartfelt thanks to the editorial team at the Oxford University Press, who guided us through this project.

We eagerly look forward to your feedback. You can reach us by e-mail at raghu62.nie@gmail.com and kitty_nie@yahoo.co.in

N.V. Raghavendra
L. Krishnamurthy

Features of the Book



Metrology and Mechanical Measurements

One of the very few textbooks that lay equal emphasis on both metrology and mechanical measurements.

Illustrative Schematics

The figures have been drawn in such a way so as to aid in the quick understanding of the concepts described in the ensuing text.

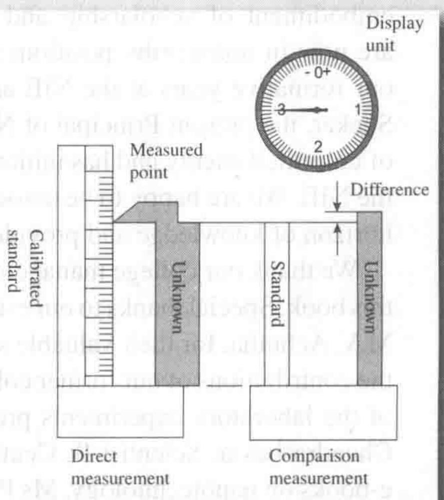
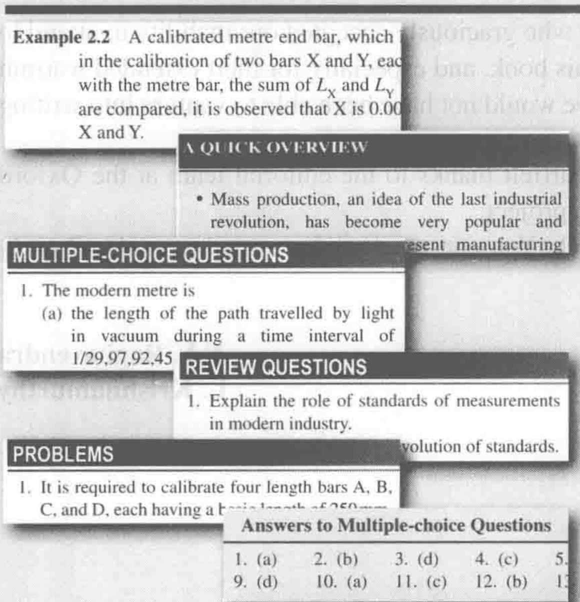


Fig. 6.1 Direct measurement versus comparison measurement



Example 2.2 A calibrated metre end bar, which
in the calibration of two bars X and Y, eac
with the metre bar, the sum of L_X and L_Y
are compared, it is observed that X is 0.00
X and Y.

A QUICK OVERVIEW

• Mass production, an idea of the last industrial revolution, has become very popular and
...esent manufacturing

MULTIPLE-CHOICE QUESTIONS

1. The modern metre is
   (a) the length of the path travelled by light in vacuum during a time interval of 1/29,97,92,45

REVIEW QUESTIONS

1. Explain the role of standards of measurements in modern industry.
...volution of standards.

PROBLEMS

1. It is required to calibrate four length bars A, B, C, and D, each having a b...

Answers to Multiple-choice Questions

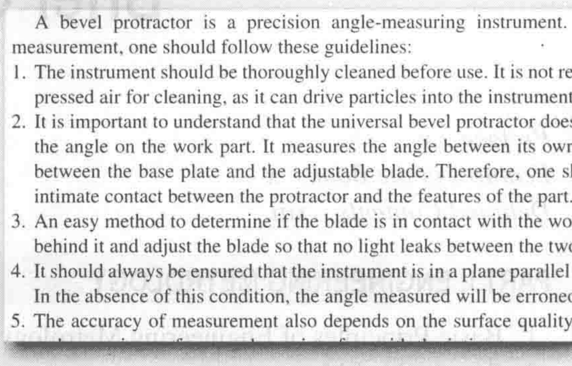
1. (a)	2. (b)	3. (d)	4. (c)	5.
9. (d)	10. (a)	11. (c)	12. (b)	1

Pedagogy

Provides numerical examples, exercises, end-chapter review questions, and multiple-choice questions with answers.

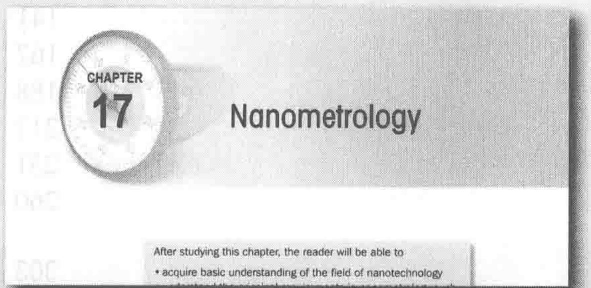
Instrument Guidelines

Provides step-by-step guidelines for the use and maintenance of select instruments.



A bevel protractor is a precision angle-measuring instrument. measurement, one should follow these guidelines:

1. The instrument should be thoroughly cleaned before use. It is not re pressed air for cleaning, as it can drive particles into the instrument
2. It is important to understand that the universal bevel protractor does the angle on the work part. It measures the angle between its own between the base plate and the adjustable blade. Therefore, one sh intimate contact between the protractor and the features of the part.
3. An easy method to determine if the blade is in contact with the wo behind it and adjust the blade so that no light leaks between the two
4. It should always be ensured that the instrument is in a plane parallel In the absence of this condition, the angle measured will be erroned
5. The accuracy of measurement also depends on the surface quality

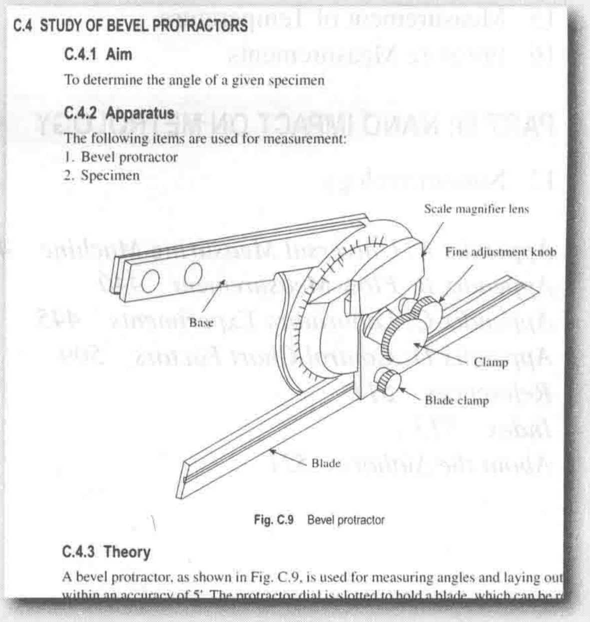


Chapter on Nanometrology

With the field of nanotechnology having an impact on almost every discipline of science and technology, this is the only Indian textbook to discuss this topic.

Laboratory Experiments

Appendix C contains 20 experiments usually demonstrated in a typical laboratory course on the subject. Select experiments also feature photographs of the devices used for experimentation. It contains procedures, observation templates, and model characteristics of all relevant experiments.



C.4 STUDY OF BEVEL PROTRACTORS

C.4.1 Aim

To determine the angle of a given specimen

C.4.2 Apparatus

The following items are used for measurement:
1. Bevel protractor
2. Specimen

Fig. C.9 Bevel protractor

C.4.3 Theory

A bevel protractor, as shown in Fig. C.9, is used for measuring angles and laying out within an accuracy of 5'. The protractor dial is slotted to hold a blade, which can be r

Brief Contents

Detailed Contents