



# Metrology and Instrumentation

Practical Applications for Engineering and Manufacturing

Samir Mekid



## Metrology and Instrumentation

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# Metrology and Instrumentation

Practical Applications for Engineering and Manufacturing

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**WILEY**

This edition first published 2022

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John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, USA

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111 River Street, Hoboken, NJ 07030, USA

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*Library of Congress Cataloging-in-Publication Data*

Names: Mekid, Samir, author.

Title: Metrology and instrumentation : practical applications for engineering and manufacturing / Samir Mekid.

Description: Hoboken, NJ : Wiley, 2021. | Series: Wiley-ASME Press series | Includes index.

Identifiers: LCCN 2021034345 (print) | LCCN 2021034346 (ebook) | ISBN 9781119721734 (hardback) | ISBN 9781119721727 (adobe pdf) | ISBN 9781119721710 (epub)

Subjects: LCSH: Metrology. | Measuring instruments.

Classification: LCC QC88 .M38 2021 (print) | LCC QC88 (ebook) | DDC 620.0028/4—dc23

LC record available at <https://lcn.loc.gov/2021034345>

LC ebook record available at <https://lcn.loc.gov/2021034346>

Cover image: Courtesy of Abderrahman Mekid

Cover design: Wiley

Set in 9.5/12.5pt STIXTwoText by Straive, Chennai, India

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## Preface

This book is conceived for engineers and technicians operating in various industrial fields. It is also for students of mechanical, production, and other related disciplines in engineering to facilitate understanding of fundamentals of measurements, instruments and governing rules followed by learning various shop-floor required measurement techniques.

The book introduces basic needs from math, statistics, and measurement principles. It discusses errors and their sources in manufacturing while describing the various measurement instruments. Simple physical parameters such as force, torque, strain, temperature, and pressure are explained. The subsequent chapters cover tolerance stack-ups, GD&T, calibration principles in various aspects of manufacturing, and quality standards. ASME and ISO are cited according to needs and to corresponding knowledge throughout the book. Each chapter ends with a set of MCQs with answer tables to help prepare technicians and engineers for various qualification diplomas and certificates. The book adopts an illustrative approach to explain the concepts with solved examples to support understanding.

Chapter 1 of the book introduces the fundamental units and constants needed in metrology supported by the international vocabulary of metrology and international standards.

Chapter 2 emphasizes metrology that covers all scales, starting from nanoscale to large scale. Differences and relationships between scales are introduced to understand the differences and possible complementarity, while Chapter 3 introduces basic math and science background mainly to refresh memories and be a reference in case there is a need to check information. Math and science are of great importance when dealing with measurement since the inception of humanity.

Chapter 4 defines the error and its various possible sources: how error propagates in measurement, errors associated with motion, error classification, and error elimination. An estimation of error, or uncertainty analysis, is a tool for determining the performance capability of machine tools and highlighting potential areas for performance and cost improvement.

In Chapter 5, the measurement and quantification are the fundamental concepts of metrology, including the measurement system characteristics. This considers explicit and internationally accepted definitions, principles, and standards. The purpose of any measurement system is to provide the user with a numerical value corresponding to the variable being measured by the system. What are the international related standards? Examples of length measurement, parts, and machine inspection with reverse engineering are provided.

One of the most significant chapters is Chapter 6 as it introduces the tolerance stacks analysis methods. This chapter establishes uniform practices for stating and interpreting dimensioning, tolerancing, and related requirements for use on engineering drawings and in related documents under ASME Y14.5.1. A brief introduction to geometric dimension and tolerancing is followed by

tolerance stacks. This is to assign the right tolerances and to make sure that no unnecessary tight tolerance is selected, leading to costly manufacturing.

Chapter 7 introduces the principles and fundamentals of calibration under the international standards definitions and agreements. It tackles real calibration of machines and instruments in detail for understanding of the process.

Chapter 8 discusses the uncertainty based on the international standards and recent developments followed by the propagation of error with real-world examples. The doubt surrounding this measurement is the uncertainty of measurement. The background and fundamental definition of uncertainty and error will be discussed later based on international standards with all aspects in general practice.

Mechanical measurement for length and others are discussed in two chapters.

Chapter 9 covers some of the instruments used for displacement and length measurements. From length measurement and calibration of instruments such as micrometers, calipers, gages, or tape measures, to high-tech optics-based scales and comparators. The industrial leading dimensional instrument calibration capabilities are available and well designed to reduce risk and inaccuracy in measurements. Chapter 10 covers mechanical instruments measuring other than length measurements. The chapter discusses calibration-related techniques. These are fundamental basis instruments that may be needed by any engineer at any time.

Thermodynamic properties of any material or solution are treated in Chapter 11. They are valuable not only for estimating the usefulness of the material or the feasibility of reactions in solution, but they also provide one of the best methods for investigating theoretical aspects related to the material or solution structure. Thermal properties of materials can be measured directly or indirectly. This includes temperature, developed pressure, calorimetry, and thermal conductivity.

Chapter 12 covers quality management and metrology since they are important components in metrology labs and manufacturing enterprises. This chapter introduces the definition of most components of quality with the related international standards with an overall organization of the lab requirement.

Contemporary digital metrology is discussed in Chapter 13. Digital metrology and its relationship to manufacturing and I4.0 are introduced. This chapter covers the digitalization, automation, and measurements that are becoming extremely important in this era of digital manufacturing and digital twins metrology (DTM). The measurement system is a combination of real-time control system and system for data transmission. Digital computing is the tool for data processing. The technology readiness for most measurement instrumentation exists together with virtual instruments capable of building further the DTM. Since several apps for smart phones have been developed, the last appendix gives a short presentation of 38 apps.

## About the Website Materials

This book has an online appendices extension covering smart phone Apps related to various metrology aspects discussed in the book and found in Appendix A, and a technical terms glossary in Appendix B. The link is [www.wiley.com/go/mekid/metrologyandinstrumentation](http://www.wiley.com/go/mekid/metrologyandinstrumentation).



## Acknowledgments

This book is like a vessel of time and knowledge since much of it has been dedicated to compiling information and data, verifying and checking numerous experiments, and ensuring that knowledge is delivered in a simple manner that can be easily captured by readers.

Several specialist companies in the area of metrology and manufacturing have contributed directly or indirectly to this book; hence, I am very thankful to all of them.

I acknowledge the courtesy of Fotofab (Chicago, USA), Leica (UK), and Renishaw (UK) to use some of their materials.

I am thankful to Otila Prian and Nina Fernandez from CREAFORM (AMETEK) for their reverse engineering samples; Ross Snyder, Application Engineer from Sigmatrix (Michigan, USA) for his stack-up analysis contribution. I would also like to thank Mr. Nicolaus Spinner from SPINNER Werkzeugmaschinenfabrik GmbH in Sauerlach (Germany) for providing me with the calibration results of his machines.

My thanks are extended to my Managing Editors: Gabriella Robles and Sarah Lemoire from John Wiley & Sons, Inc.

I would also like to acknowledge my MSc student Usman Khan and our departmental secretary Mino Thankachan for the hard work of formatting the chapters. Not to forget Abderrahman Mekid and Khawla Mekid for their editing and revisions.

The author would like to acknowledge the support of King Fahd University of Petroleum and Minerals (KFUPM) through the Deanship of Research Oversight and Coordination (DROC) for their support in research and resources made available to this book under BW#191006.

October 1, 2021

*Professor Samir Mekid*



## About the Author

Samir Mekid is professor of mechanical engineering at KFUPM and chartered engineer registered with IMechE (UK) and ASME member. Prior to joining KFUPM, he was assistant professor at UMIST (UK) and The University of Manchester (UK). He has worked with Caterpillar in the design department and has been an expert EU evaluator for various countries to several European Framework Projects Programs, e.g., FP6, FP7. He was member of the Scientific Advisory Board of the Centre of Excellence in Metrology for Micro and Nanotechnology (CEMMNT) in the UK. His area of research includes machine design, manufacturing instrumentation, metrology, mechatronics, smart materials, and sensors design. He has published over 180 publications in professional journals and international conference proceedings and edited three books. He holds more than 30 patents.

During his ongoing career, he taught several courses for undergraduate and graduate students including: metrology, sensors and actuators, together with machine design. He has trained approximately one hundred engineers through short courses on tolerance stack-ups, GD&T, manufacturing systems, and materials selection. He is currently the Founding Director of the Interdisciplinary Research Center for Intelligent Manufacturing and Robotics at KFUPM.