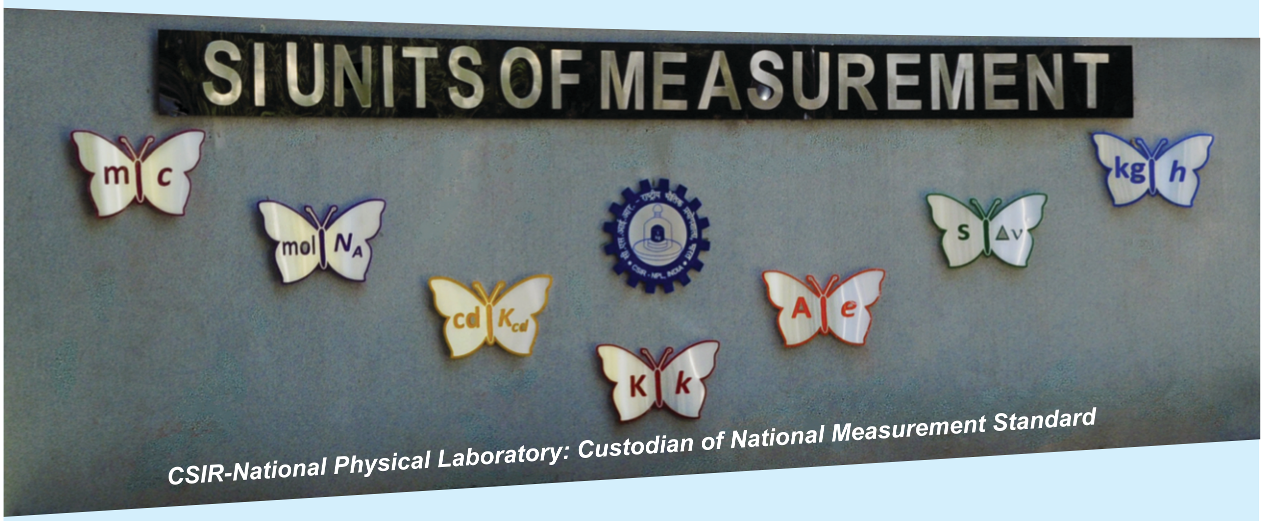
Recommendations for Revision of Syllabus for Metrology in Engineering Courses



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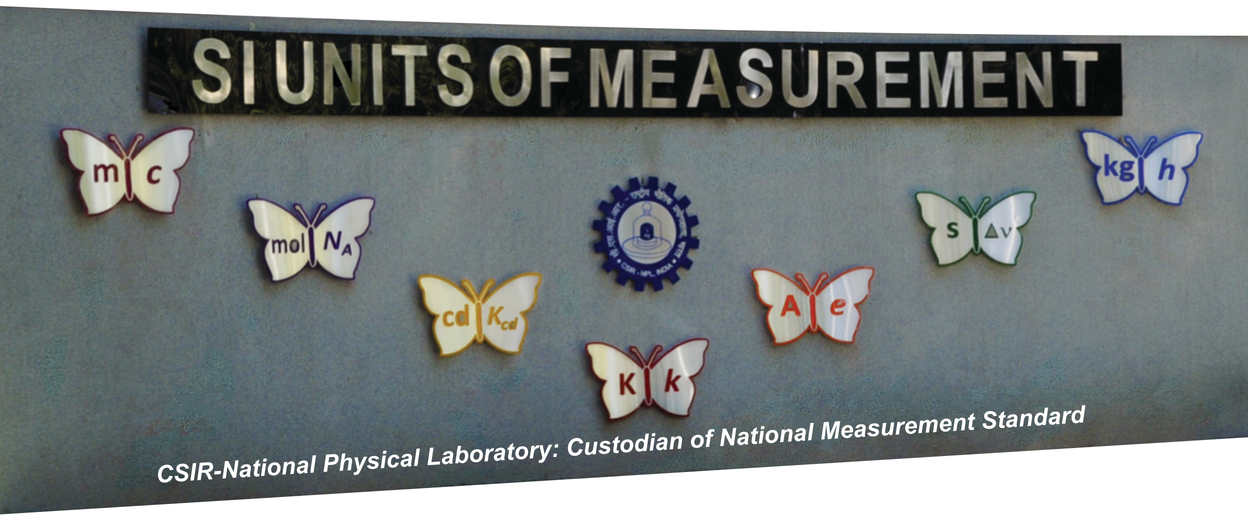

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Content

Foreword

This recommendation document is prepared by the National Metrology Institute of India (CSIR-National Physical Laboratory) to propose in the syllabus of metrology taught in engineering courses in India as a follow up of the worldwide revisions made in the definitions of SI units implemented from World Metrology Day (May 20, 2019). The recommendations made herein this document are purely suggestive and implementing agencies may / may not have their technical committee to enforce the revisions in full or partial, as the case may be, and fit for the purpose to impart contemporary educations to students as per global trends. The primary objective of the document is to foster the metrological perspectives in engineering education in India to equip the engineering students to face the growing technological challenges of Industries. The recommendations are elaborated with technical explanations to introduce their possible changes.

1. Introduction

1.1 Metrology and its Importance

Metrology defined as the science of measurement and its application, can be considered as the first step for all the sciences as it allows observer to quantify and express any desired parameter in a number. Accurate and precise description of a parameter is essential for the technological advancement in industrial and health sectors and contributes to the socio, economic and industrial growth of the country. For example, the parameter 'time' was measured very precisely by four Caesium atomic clocks aboard commercial airliners (Hafele-Keating experiment). This experiment proved that the gravity changes time (gravitational time dilation) which is very important factor for currently used Global Positioning System (GPS). So the metrology on time led to more advancement of technology of GPS. In an another example, the European Organization for Nuclear Research Laboratory (CERN) are accurately measuring, the effect of collision of particles that led to discovery of subatomic particle Higgs Bosons. So again metrology was part of the new invention. This leads to an advancement in technology and opens up the new dimensions for the invention and broadens the innovation horizon. All these technological advancements are ultimately for the improved quality of life, as shown in Fig. 1.

Metrology is basic to the economic and social development of any country. It is involved with providing accurate and precise measurements which impact our economy, education, health, safety and general well-being. Incorrect measurements lead to wrong decisions, which can have serious consequences. Metrology provides quality in measurement. Metrology helps us to take logical judgements on the basis of uncertainty with the measurements of results and process. It also enhances the confidence in the measurements and science behind it. Without the correct measurements, the ability to produce quality goods and fulfil consumer requirements would not be possible.

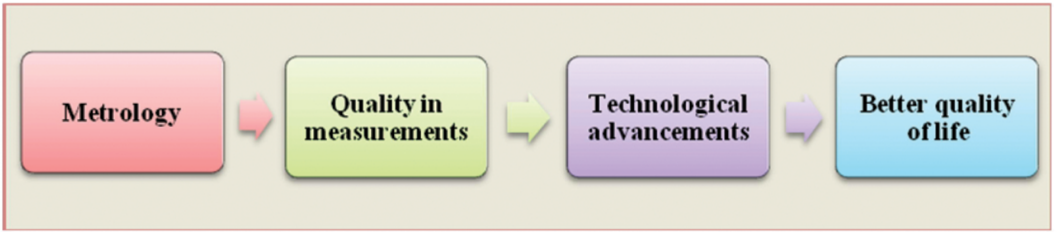

Fig. 1: Flow chart representing importance of metrology

1.2 Measurement Standards and Traceability

It is clear now that accurate and precise measurements are essentially required for the better quality and the confidence in products. For ascertaining the accuracy and precision of a measurement, a calibrated reference standard is must. For this, the measurement standards are developed which not just only provide the reference for the measurement value but also provide the quality of measurements by stating the uncertainty associated with the measurements. A better uncertainty is a proof, mark or evidence of better quality of a measurement. In order to judge the quality of the measurements with associated uncertainties, the users of any instruments should compare (calibrate) their measurement results with the respective measurement results obtained using standard. This results in to enhancement of performance of the instrument. Now such calibrated instruments can be used to calibrate another similar instruments or products in order to determine their quality. This is achieved only through unbroken chain of determining uncertainty and traceability to the national or international measurement standard. This unbroken chain of documented calibration with measurement uncertainty is known as traceability. So any instrument used for measurement or producing final product/services should be traceable to measurement standard in order to obtain the required quality. If for a parameter, a measurement standard is not present then certified reference material can be used as a reference for true measurement value. The national standards and certified reference materials are maintained by the National Metrology Institute (NMI) of the country.

1.3 Role of NMI in socio-economic development of country

In India, by the act of parliament CSIR-National Physical Laboratory (NPL) is the custodian of national measurement standards. It is mandated to establish, maintain, upgrade and disseminate the measurement standards throughout the nation. As NMI of India, NPL has the measurement standards for Physico-Mechanical, Time and Frequency, Electrical and Electronics parameters. It also provides traceability to many national industries for different mentioned parameters along with environment and biomedical instruments[1]. NPL also produces the certified reference materials known as Bhartiya Nirdeshak Dravya (BND). CSIR-NPL plays a pivotal role in enabling India to realize and conduct the quality measurements thus improving the quality in science and technology and henceforth improving its socio-economic status.

1.4 Need for revision in engineering course on metrology in country

In the engineering courses like Mechanical Engineering the most important aspect of the curriculum is the practical and experiments carried in order to inculcate technological know-how and realization of the technical principles amongst the students. The basic fundamental steps in these experiments include postulate a theory, identify main aim or objective, prepare mathematical model, perform predefined sets of measurements within control environment, observe the outputs, analysis the output data and conclude results. If the output of the measurements is incorrect then it will lead to wrong conclusion and whole experiment process will be rendered useless. Accurate and precise measurements are the backbone of reaching a conclusive idea after an experiment. In engineering courses theory behind a concept, mathematical model and instruments used, all are emphasized, only leaving behind the importance of correct measurements and how to obtained measurement with quality. These are the hindrances to the growth of innovative science and technology of the country. Even if some topics on metrology are covered, these are not sufficient and are also not directed towards the quality oriented measurements. Therefore, some revisions in the engineering courses regarding metrology are recommended to infuse the correct insights in the future torch bearer of technology of the country.

2 SI units and their redefinition

2.1 Introduction to SI units

The globally accepted and uniform system of units of measurement is the International System of Units (Système International 'Unités, with the international abbreviation SI). This SI consists of a set of base units and derived units[2]. The SI base units are a choice of seven well-defined units which by convention are regarded as dimensionally independent: the metre, the kilogram, the second, the ampere, the kelvin, the mole, and the candela. Derived units are formed by combining the base units according to the algebraic relations linking the corresponding quantities. The names and symbols of some of the units thus formed can be replaced by special names and symbols which can themselves be used to form expressions and symbols of other derived units.

2.2 Redefined SI units

In a landmark decision, the BIPM's Member States voted on 16 November 2018 to revise the International System of Units (SI), changing the world's definition of the kilogram, the ampere, the kelvin and the mole. The decision, made at the 26th meeting of the General Conference on Weights and Measures (CGPM) in Versailles, France, means that all SI units will now be defined in terms of constants that describe the natural world. This will assure the future stability of the SI and open the opportunity for the use of new technologies, including quantum technologies, to implement the definitions.

In the revised SI four of the SI base units : namely the kilogram, the ampere, the kelvin and the mole are redefined in terms of constants; the new definitions are based on fixed numerical values of the Planck constant *(h)*, the elementary charge *(e)*, the Boltzmann constant *(k)*, and the Avogadro constant (N_A), respectively. Further, the new definitions of all the seven base units of the SI are also uniformly expressed using the explicit-constant formulation. The new definitions will come into force on 20th May, 2019.

2.3 Redefined SI units need and implications

Defining the kilogram in terms of fundamental physical constants will ensure its long-term stability, and hence its reliability, which is at present in doubt. The new definitions of the ampere and kelvin will significantly improve the accuracy with which electrical and radiometric temperature measurements can be made. The impact on electrical measurements will be immediate: the most precise electrical measurements are already made using the Josephson and quantum Hall effects, and fixing the numerical values of the Planck constant h and the elementary electrical charge e in the new definitions of the units will lead to exact numerical values for the Josephson and von Klitzing constants. This will eliminate the current need to use conventional electrical units rather than SI units to express the results of electrical measurements. The conversion factor between measured radiance and thermodynamic temperature (the Stefan-Boltzmann constant) will be exact using the new definitions of the kelvin and kilogram, leading to improved temperature metrology as technology improves. The revised definition of the mole is simpler than the current definition, and it will help users of the SI to better understand the nature of the quantity "amount of substance" and its unit, the mole. In a nutshell, the Revised SI will be a better fit to the technology of this century.

3 Recommendations on Revision of Engineering Courses

3.1 Existing Course Content

The existing course on metrology in engineering syllabus mainly emphasizes on the measurement of errors, dimensional metrology, transducers, limits, fits and tolerances *etc*. In some universities, the topic metrology is covered as one or two chapters in the courses like Manufacturing Technology, Instrumentation and Control, Measurement and Instrumentation *etc*. However, the comprehensive description about the SI units and the derived units, role of National Metrology Institute (NMI) of the country, realization of measurements standards for the SI units and derived units *etc*. is completely missing. As a general conclusion on the education of metrology and the theory on measurement science in the bachelor in engineering programmes of the Indian universities, the introduction to the modern metrology in the frame of measurement science and knowledge of the NMI and National Measurement Standards, will offer the students a sound basis for further continuing studies in a Master programme, Research (*e.g.* PhD), and shall equip them to face the challenges of engineering industries in Indian perspectives.

3.2 Recommended Revisions in the Course work

Based on exhaustive review of the engineering course in metrology, the following recommendations are proposed for the metrology course to educate the students with latest technological know-how and make them more competent to face the growing challenges in Indian industry:

- The metrology course should specifically cover the following aspects: SI units, Derived units, Realization of Measurement Standards, Measurement Traceability, Accuracy and Precision, Introduction to International and National measurement system including standards, accreditation, legal metrology, Introduction to metrology : Definition, types, need of inspection, terminologies, methods of measurement, selection of instruments, measurement errors, units, measurements standards, calibration, statistical concepts in metrology, Basics of evaluation of uncertainty in measurements, measurement system analysis[3].

- The course work should provide atleast introductory knowledge about the realization of standards and the measurement process and related instrumentation for Physico-Mechanical parameters: Mass, Length, Temperature, Optical Radiation, Force and Hardness, Pressure, Vacuum, Acoustics and Vibration, Fluid Flow and Electrical and Electronic parameters: LF, HF Impedance and DC Metrology, LF, HF Voltage, Current & Microwave Metrology, AC High Voltage & Current Metrology and AC Power & Energy Metrology.
- The practical demonstration of the realization of measurement standards or some of the instruments like: Vernier Calliper, Micrometer, Weighing balances, Densitometer, Load cells, Torque transducers, Thermocouples, Hygrometers, Sound level and Vibration meters, Instrumentation for measurement of illuminance, luminous intensity, capacitance, inductance, current, voltage, magnetic field, microwave, AC power etc. shall be very helpful in nurturing the students with the technological knowhow and train them to become professional in precision measurements and quality control.
- The metrology course should also focus on the redefinition of four of the SI base units - namely the kilogram, the ampere, the kelvin and the mole that are redefined in terms of constants; the new definitions are based on fixed numerical values of the Planck constant (h), the elementary charge (e), the Boltzmann constant (k), and the Avogadro constant (N_A), respectively.
- Also, the course work should cover the attributes of Quality Management System as per ISO 17025[4] and ISO 9001 so as to impart education about the standardization of products and enhancement of quality of manufacturing in industrial units in Indian scenario.
- Furthermore, the students undergoing graduate and post-graduate in Engineering can explore the possibility of practical training at Regional Metrology Laboratories or at CSIR-National Physical Laboratory, New Delhi so as to impart training and hands-on experience on the various aspects of metrology and Quality Management System to engineering students. Also, the students can pursue their Masters' or doctoral work at CSIR-National Physical Laboratory, New Delhi for enhancing their expertise in this area.

3.3 Envisaged Benefits

Accurate and precise measurements are essential growth engines of any country and prompts innovations, which in turn, would save precious, resources and time. Today due to increasing pressure of demand of high quality products as well as their global acceptability at the same time, Industries and production units are standardizing their products with ISO/IEC conformity assessments following several International Standards of quality control, namely; ISO/IEC 17025: 2005 (General Requirements for the Competence of Testing and Calibration

Laboratories), ISO/IEC 17043: 2010 (Conformity assessment - General requirements for Proficiency testing), ISO 15189: 2012 (Medical laboratories - Requirements for quality and competence), ISO17034: 2016 (General requirements for the competence of reference material producers) *etc*. to overcome technical trade barriers, compete globally and also to cater international needs making their brand recognized internationally. During interactions with Industry, it is emerged that knowledge of precision measurements and quality control is generally, available with senior management and Technical persons. However, the people at shop floor level who are involved in day to day production and routine measurements do not have adequate knowledge of the subject. In today's competitive world, in order to maintain the quality of products and reduce the rejection ratio, it is essentially required that the staff actually working at shop floor level must have adequate training. The young minds trained in this discipline would have opportunities to become professional in precision measurements and quality controls to serve Industries, accredited testing and calibration laboratories, MSMEs, strategic sectors and other related areas. They will have unique advantage of getting exposure and hands on training on best measuring equipment through this course. The demand of skilled manpower in precision measurements in manufacturing sector and quality sectors identified above will be increasing day by day. This way the trained manpower in precision measurements through the revised curriculum course would have ample job opportunity in Indian industry.

3.4 Concluding Remarks

All the engineering institutes in India use different tools and techniques to teach students and test their skills. However, for years, many of them have neglected revising their curricula to keep up with the rapid strides in technological advancement. Engineering courses in India are yet to receive a syllabi revision that will make them contemporary enough to fulfil industry requirements. Thus, it is the need of hour to encourage the amendments in the metrology course with the suggested recommendations so that the skilled manpower is generated that can take the growing technological challenges in Indian industry.

ANNEXURE – 1

SI units and definitions till May 20, 2019

The SI base units are a choice of seven well-defined units which by convention are regarded as dimensionally independent:

1. **metre, m :** The metre is the length of the path travelled by light in vacuum during a time interval of 1/299 792 458 of a second.
2. **kilogram, kg :** The kilogram is the unit of mass; it is equal to the mass of the international prototype of the kilogram.
3. **second, s :** The second is 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 caesium 133 atom.
4. **ampere, A :** The ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed 1 m apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per metre of length.
5. **kelvin, K :** The kelvin, unit of thermodynamic temperature, is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water.
6. **mole, mol :** The mole is the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon 12.

   When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles.
7. **candela, cd :** The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} hertz and that has a radiant intensity in that direction of 1/683 watt per steradian.

   All other SI units can be derived from these, by multiplying together different powers of the base units.

ANNEXURE – 2

Redefinition of Mass, Temperature, Current and Mole

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In the revised SI four of the SI base units - namely the kilogram, the ampere, the kelvin and the mole - are redefined in terms of constants; the new definitions are based on fixed numerical values of the Planck constant *(h)*, the elementary charge *(e)*, the Boltzmann constant *(k)*, and the Avogadro constant (N_A), respectively. Further, the new definitions of all seven base units of the SI are also uniformly expressed using the explicit-constant formulation, and specific mises en pratique will be drawn up to explain the realization of the definitions of each of the base units in a practical way.

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