MEASUREMENT AND STANDARDS OF SPACE AND MASS

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Summary

An extremely prominent role that length, angle, and mass measurements and standards played in evolution and survival of the civilization of humankind is shown. The development of measurements and standards are reviewed historically. Metrological characteristics of a great many of the instruments used for measuring length, angle, and mass in different fields of science and technology are given. It is also shown that these measurements offer considerable prospects resulting from the development of technologies and associated with the widening of measurement ranges from extra-small to ultra-large values of the quantities to be measured.

1. Introduction

Measurements rank among the most important tools that humans have for cognizing nature. On the one hand, measurements characterize the surrounding world quantitatively by revealing the regularities acting in nature. Thanks to measurements, scientific and applied investigations are able to determine precise quantitative relationships that are representative of natural laws. On the other hand, no branch of technology—research studies, development, manufacture, and operation of apparatus included—could exist without an overall multi-parametric system of measurements governing the efficiency the technology processes and the properties and quality of products being manufactured. The global objective of measurements is ultimately to prevent emergencies and technogenic accidents and to assure human health and safety. That is why, in the majority of countries, undertakings aimed at assuring traceability and required precision of measurements have been implemented.

With the evolution of civilization, requirements for precision measurements have been growing, and measurement has undergone a rapid change according to the requirements of progress in engineering. The most important aspects of metrology include the vast array of measuring instruments intended for controlling dimensions and mass of different objects, the profitability of measurements, international certification of measurement methods and instruments, and international agreements on mutual confidence in measurement results, which should be confirmed in key comparisons.

Length, mass, and time instruments are among the most ancient ones and are the basis of the existing system of measurement units of physical quantities.
(See *Measurements and Measurement Standards, Physical Quantities and Units*.)

2. Space, Time, and Mass—Philosophical Categories and Objects of Measurements

Today's physics confirms the fundamental unity of space and time, manifested as mutual regular modification of space-time characteristics of systems, depending upon the motion of the latter. This also confirms interrelation between these characteristics and concentration of mass in the surroundings. Space and time concepts are the necessary components of the world's picture as a whole, and, hence, they are within the subject of philosophy. At the same time, humankind's concept of physical realities, something actually seen or experienced, is just a concept of size, distance, angle, duration, mass, force, and so on. We are also struck by processes of matter motion in space and in time. It is apparent that interaction of humankind with objects and processes in the surrounding world is impossible without exact evaluation, and accurate and reliable measurement, of such objects.

Therefore, metrology and measurement technology occupy a highly important place in all branches of science, in production, and in technical and ecological monitoring. On a global scale, billions of different measurements are routinely carried out. This sphere of activities represents the basis of a profession for millions of people. The share of expenses for measurement technology in mechanical engineering is no less than 15 %, while it attains more than 25 % in a number of other branches of industry.

3. The Need for Measurements and Metrology

Historically, the evolution of measurement science and standards has been connected with the growth of productive forces and a material culture on Earth. Even primitive humans needed measurements, primitive as those measurements were. Such measurements were completely subjective, and standards were accidental and did not have a universal binding force. The development of a material culture offers a possible explanation of the origin of the first standards with the aid of which these measurements were carried out. Length, area, volume, mass, and time were the first quantities to be measured. Measures of these quantities were borrowed from the dimensions of a human body or from surrounding objects and phenomena. This explains the kinship between different measures of all countries and peoples. For example, a foot and a step of a human were the first "natural" length standards, the weight of a grain or a fruit was used as a measure of mass, day and night's change was a measure of time, and so on. However, for lack of any predetermined prototype standards, measures, and instruments were different in different countries.

Primitive people "carried out" mass comparisons using a simple perception of gravity acting on a hand. With advances in barter relations between tribes and then between peoples, a continuing demand for more accurate mass measurements has appeared. The history of a material culture explains the appearance of the first standards and instruments for mass measurements. Archeological findings in Egypt made it possible to obtain an idea of how balances were designed in the ancient world. As regards the earliest findings, a balance's beam was suspended at its center with a rope fastened to a fixed support.

The greatest scientific findings, the strict interpretation of natural phenomena in the form of laws, have found their practical application in modern technology, including measurement technology. All measurements, no matter what the measurable quantity, method, or instrument may be, have in common something that forms the basis of any measurement—a comparison of the considered quantity performed by experiment against another similar quantity taken for the unit. In measurements of all kinds, we experimentally evaluate a physical quantity in terms of a certain number of units adopted for it, that is, we find its numerical value.

To assure the traceability of measurements, it is necessary to provide for the uniformity of the units in which all measuring instruments of some quantity are calibrated. This is achieved by accurate reproduction and maintenance of definite units of physical quantities, and by transferring the units to measuring instruments being used. Reproduction, maintenance, and transfer of units are carried out with the aid of standards and reference measuring instruments. Standards are at the top of a metrological hierarchical chain intended for dissemination of measurements units.

A standard is a high-precision measuring instrument, approved according to the law, which provides for reproduction and maintenance of a unit of a physical quantity, with the aim of disseminating its dimension to reference standards and, from them, to working standards.

Legal, theoretical, and applied metrology eliminate the possibility of using incorrect measurement methods, incorrect measures, not suited to the requirements for measuring instruments, and their incorrect verification. This makes it possible to prevent the growth of accidents at factories, violation of elementary requirements for human safety and health, inexact medical diagnosis and therapy of illnesses, an increase of defects in products, violation of methods for manufacture, vast unproductive losses, incorrect accounting for material valuables, extreme and inadequate consumption of energy, and, lastly, violation of interchangeability of parts and components. This being so, in the conditions of today's society, measurements become increasingly important. A demand arises, on the one hand, for the establishment of the units that assure traceability of measurements, and, on the other hand, for the development of standards and measuring

instruments intended for different fields of measurements. The most important problems facing metrology are thus the increase of precision of measurements and the realization of this precision level over the whole range of measurements.
(See *Applications of Measurements and Instrumentation*.)

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Biographical Sketches

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