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HISTORY OF SYSTEMS OF MEASUREMENTS

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ABSTRACT

It is necessary to define physical quantities, both in type and magnitude, to ensure precise technical communication about the results of measurement and to perform calculations. The units of measurement may be defined as the standard measure of each kind of physical quantity. The number of measure is given as the number of times the unit occurs in any given amount of the same quantity. A large number of systems of measurement units have been used at various times during human history. Different measurement units have been found acceptable in different countries; however, there are some systems of measurement units which have been accepted throughout the world. With the development of science and growth of measurement technology, efforts were made to standardize terms so that instrumentation professionals could effectively communicate among themselves and with specialists in other disciplines. This research investigates in detail the history and evolution of various systems of measurement across the globe.

Index Terms: Fundamentals and derived units, CGS system of units, absolute system of units, MKS system of units, international system of units and English system of units

INTRODUCTION

According to Zimmerman and Lavine [1] from the very earliest times, human beings have found it necessary to weigh and measure the world around them, and the most ancient records include references to units of measurement. Most of these ancient units are now entirely obsolete. Our knowledge of them comes from texts and inscriptions which have survived, but the values of many have been quite reliably determined. This presentation of ancient systems of measurement is mainly for historical and general interest. Nevertheless, they illustrate the development of our modern systems, and the associated conversion tables could be of use to engineers and others reconstructing or evaluating ancient machinery, ships, or buildings.

Many early units, with an anthropocentrism which has persisted up to the present day, were based on the human body or its attributes. Units such as the finger, hand, palm, and foot are self-explanatory, while the span was the maximum width, thumb-tip to small fingertip, of the spread hand. The inch was the distance from the tip to the first joint of the thumb, and the surviving French word pouce in fact means ‘thumb’. As a matter of incidental interest, the English word ‘inch’ comes from the Old German for ‘one-twelfth’, and has the same derivation as the word ‘ounce’. The cubit was the distance from elbow to fingertips (from the Latin cubitum, elbow), and is also sometimes known as the ell from the Germanic word for ‘forearm’ (‘elbow’ being derived from Old German elnboga, arm-bend). Together with the fathom, derived from the span of the arms or the height of a man, these ancient units can still be seen in use today when builders, woodworkers, or other trades-people make rough estimates of quantities.

Anderton and Beg [2] has described that units of length greater than the human body itself were usually expressed in terms of walking distances. The yard was about the length of a pace, and one thousand paces was a mile (Latin millet passion). Other units which expressed distance in terms of human activity were rough periods of time such as an hour's walking, or a day's sailing.

Measures of area and volume using square or cubic units are relatively recent inventions. Areas were first thought of in terms of reasonable-sized fields, that could be ploughed in a given time, and indeed the word acre is ultimately derived from the Sanskrit for 'field' (ajra). Likewise, volumes were thought of in terms of containers such as churns or barrels, or of human-sized portable units such as bundles of wood, bales of hay, sacks of grain, or pails of milk. The parallel between liquids and granular or powered solids was also noted, with the same measures being used for both. Sometimes, however, to equalize the 'feel' of measured quantities, a smaller measure was used for heavier materials, resulting in different sized 'pints', for example, in dry and liquid measures.

Biggs [3] has described that weight units arose from these capacity measures, and there is a unit more or less equal to, and often called, a pound (Latin pandits, weight), in many ancient and obsolete systems. The relationship remains clear even in modern times. A pint of wine weighs about a pound, and a gallon of water weighs ten pounds. The word ton is from the same root as the name of the older unit, tun, a large wine cask of some 250 gallons, which would therefore weigh about 2000 pounds when full.

One of the oldest units of measurement is the degree of arc, which is usually supposed to have been invented by the Babylonians over 4000 years ago. It is curious that they should have chosen to divide the circle into 360 degrees: the simplest way would have been to divide it into halves, quarters, and so on, giving 256, or another multiple of 2. degrees in the circle. It has been suggested that the number 360 arose in an early attempt to guess the number of days in the year, but this is unlikely, since accurate astronomical data were known before recorded history began. However, the lunar month of approximately 30 days, the division of the solar year into 12 months, and the solar day into 12 hours, cannot fail to be related to the Babylonian number base of 60 and the division of the circle into 360 degrees.

I. FUNDAMENTALS AND DERIVED UNITS

Following two types of units are used in science and engineering:

(i) Fundamental units (or quantities)

(ii) Derived units (or quantities)

The measurement of a quantity means the comparison of the quantity with a standard of same kind of quantity. The magnitude of quantity being measured can be expressed in terms of the chosen unit and a numerical multiplier. But, it is not possible to have a series of standards for each of the quantities. Also, unit of a quantity cannot be freely chosen because physical quantities are not independent of each other, but they are related by some physical equation.

If there are M kinds of quantities to be evaluated and N independent physical equations expressing relationships between them, the sizes of units of only (M-N) of the quantities can be chosen. The sizes of units of remaining N quantities can be derived with the help of N physical equations so that the numerical multipliers are usually unity. The (M-N) quantities, which are independently chosen, are called fundamental quantities. The remaining N units are called derived quantities. The units of fundamental quantities are called fundamental units and that of derived quantities are called derived units [4].

In mechanics, the fundamental units are measures of length, mass and time. The sizes of the fundamental units, whether foot or meter, pound or kilogram, second or hour, are arbitrary and can be selected to fit a certain set of circumstances. Since length, mass and time are fundamental to most other physical quantities besides those in mechanics, they are called primary fundamental units. Measures of certain physical quantities in the thermal, electrical and illumination disciplines are also represented by fundamental units. These units are used only when these particular classes are involved, and they are therefore defined as auxiliary fundamental units. 0020 All other units, which can be expressed in terms of fundamental units, are called derived units. Every derived unit originates from some physical law defining that unit. For example, the volume of a substance is proportional to its length (l), breadth (b) and height (h), or V=I x b x h. If the meter has been chosen as the unit of length, then the volume of the substance of 4 m by 5m by 6 m is 120 m^3. Note that the number of measures are multiplied (4 x 5 x 6) as well as the units (in x in x in = m^3). The derived unit of volume (V) is then cube of meter (m^3) [5].

II. ABSOLUTE UNITS

A system in which the various units of measurement are all expressed in terms of fundamental units is called absolute unit. An absolute measurement does not compare the measured quantity with arbitrary units of the same kind, but are made in terms of some of the fundamental units. The committee of the British Association of Electrical Units and Standards formulated the absolute system of units in 1863 and decided on centimeter and gram as the fundamental units of length and mass. They expressed that the units should not be defined by a series of master standards, each defining one quantity in the way in which the units of length, mass and time are defined. Instead, some natural law that expresses the relation between the quantity concerned and the fundamental quantities of length, mass and time, for which internationally accepted standards have already been established, should define each electrical unit [6].

III. C.G.S. SYSTEM OF UNITS

According to Semioli [7] Centimeter-Gram-Second (C.G.S) system of units was the most commonly used system of units in electrical works before the Meter-Kilogram-Second (M.K.S.) system of units came in existence. This system was developed from absolute system of units formulated by the committee of the British Association of Electrical Units and Standards. Complication arose when the C.C.S. system was extended to electric and magnetic measurements because of the need to introduce at least one more unit in the system. Following two parallel systems of unit were established:

(i) **C.G.S. Electrostatic Systems** In the C.G.S Electrostatic system, the unit of electric charge was derived from the centimeter, gram and second by assigning the value 1 to.the permittivity of free space in Coulomb's law for the force between electric charges. It is given as

$F= Q1Q2 / Er^2$

Where F = force between the charge, expressed in g cm/s = dyne

Q1, Q2 = equal point charges expressed in statecoulomb

E= Permittivity of the medium

r = distance (separation) between the charges expressed in cm

(II) C**.G.S. Electromagnetic Systems In the C.G.S.** Electromagnetic system, the basic units are the same and the unit of magnetic pole strength is derived from the centimeter, gram and second by assigning the value I to the permeability of free space in the inverse square formula for the force between magnetic poles. It is given as

where F = force between two current carrying conductors expressed in dyne

p= permeability of the medium

l = current flowing in the conductor expressed in ampere

b = length of current carrying conductor expressed in cm

a = distance of separation of conductors in cm

Disadvantages of C.G.S. System of Units

(i) There are two systems of units: C.G.S. electrostatic and C.G.S. electromagnetic for fundamental theoretical work, and a third system of unit (practical units) for practical engineering work.

(ii) There are two sets of dimensional equations for the same quantity (Milone and Giacomo, 1980).

IV. M.K.S. SYSTEM OF UNITS

Mcgreevy [9] has mentioned that Meter-kilogram-second (M.K.S.) system of units was first suggested by the Italian Physicist, Prof. Giorgi in 1901. He pointed out that the practical units of current, voltage, energy and power, used by electrical engineers, were compatible with the meter-kilogram-second system. He suggested that the metric system be expanded into a coherent system of units by including the practical electrical units. The Giorgi system, adopted by many countries in 1935, came to be known as the M.K.S.A. system of units in which the ampere was selected as the fourth basic unit. This system was adopted by the International Electrical Commission (IEC) at its meeting in 1938. In order to connect the electrical and mechanical quantities, a fourth fundamental quantity, permeability, was introduced.

Advantages of M.K.S. System of Units

(i) Its units arc identical with the practical units.

(ii) Its units are the same whether built up from the electrostatic or electro-magnetic theory.

(iii) The cumbersome conversions necessary to relate the units of the elec-trostatic and electromagnetic C.G.S. systems to those of the practical system arc avoided.

V. INTERNATIONAL SYSTEM (SI) OF UNITS

At the Eleventh General Conference on Weights and Measures, a more comprehensive system was adopted in 1954 and designated in 1960 by international agreement as the System International d'Unites (SI) for worldwide standardization. In the SI system, six basic units are used, namely, the meter (m), kilogram (k), second (s), and ampere (A) of the MKSA system and, in addition, the kelvin (K) and the candela (cd) as the units of temperature and luminous intensity, respectively. In addition, there are three supplementary units, namely, the radian (rad) for plan angle, steradian (sr) for solid angle and mole (mol) for quantity of substance. Everything else falls into the category of derived or defined units; defined in terms of the six base and three supplementary units (National Bureau of Standard, [10]).

VI. ENGLISH SYSTEM OF UNITS

The English system of units uses the foot-pound-second (F.P.S.) as the three fundamental units of length, mass and time. This system of units has been historically employed in the United Kingdom and the United States. Starting with these fundamental units, the mechanical units can be derived. The con-version between SI. CGS and FPS units.

Although the measures of length and weight are legacies of the Roman occupation of Britain, the inch (defined as one-tenth of the foot) has been determined at exactly 25.4 mm. Similarly, the measure for the pound (lb) has been determined as exactly 0.45359237 kg. These two figures allow all units in the English system to be converted into SI units.

VII. STANDARDS OF MEASUREMENT

A standard of measurement is a physical representation of a unit of measurement. The term standard is applied to a piece of equipment having a known measure of physical quantity. It is used for obtaining the values of the physical properties of other equipment by comparison methods. A unit is realized by reference to an arbitrary material standard or to natural phenomena including physical and atomic constants. For example, the fundamental unit of mass in the SI system is the kilogram, defined as the mass of a cubic decimeter of water at its temperature of maximum density of 4 °C. This unit of mass is represented by a material standard: the mass of the International Prototype kilogram, consisting of a platinum-iridium alloy cylinder. This cylinder is preserved at the International Bureau of Weights and Measures at Sevres, near Paris, and is the material representation of the kilogram. Similar standards have been developed for other units of measurement, including standards for the fundamental units as well as for some of the derived mechanical and electrical units.

Therefore, standards are always arbitrary, whether they be the length of the foot of a long-deaf king, or the duration of a second. Each standard is an invention of human beings to facilitate or make possible the measurement process. One of the most important responsibilities of government is to set and maintain standards, thereby providing a commonly accepted basis for comparison [11].

1.7.1 Hierarchy of Standards

Just as there are fundamental and derived units of measurements, there is a hierarchy of standards of measurements classified by their function and application in the following categories:

International Standards The International standards represent certain units of measurement which are closest to the possible accuracy attainable with present day technological and scientific methods. They are defined on the basis of international agreements. International standards are regularly evalu-ated and checked against absolute measurements in terms of the fundamental units. International standards are maintained at the International Bureau of Weights and Measures and are not available to the ordinary user of measuring instruments for purposes of comparison or calibration [12].

Primary (or Basic) Standards Horvath [13] has mentioned that the primary standards represent the fundamental units and some of the derived mechanical and electrical units. One of the main functions of primary standards is the verification and calibration of secondary standards. They are maintained by national standard laboratories or stored in a government vault in different parts of the world. They are independently calibrated by absolute measurements at each of the national laboratories. The results of these measurements are compared against each other, leading to a world average figure for the primary standard. The National Bureau of Standards (NBS) in Washington is responsible for maintenance of the primary standards in North America. Other national laboratories include the National Physical Laboratory (NPL) in Great Britain and, the oldest in the world, the Physikalisch-Technische Reichsanstalt in Germany. Primary standards are the ultimate authority against which secondary standards are compared. They are not available for use outside the national laboratories.

Secondary Standards Linderburg [14] has mentioned that the secondary standards are the basic reference standards used in industrial measurement laboratories. These standards are maintained by the particular involved industry and are checked locally against other reference standards in the area. The industrial laboratories are entirely responsible for maintenance and calibration of the secondary standards. Secondary standards are normally sent to the national standard laboratories on regular basis for its calibration and comparison against primary standards, after which they are sent back to the industrial user with a certification of their measured value in terms of the primary standard.

Working Standards The working standards are the principal tools of a measurement laboratory. They are used to check and calibrate general laboratory instruments for accuracy and performance or to perform comparison measurements in industrial applications. The working standards may be less accurate and less expensive [15].

VIII. Conclusion

Finally, of course, it should be remembered that these early units were connected with measuring time and constructing a calendar. In this respect it is interesting to consider that the second, determined by the Babylonians, is still the fundamental unit of time in all current systems of measurement, even the SI itself. It is therefore the unit in longest continuous official use, and, with the degree of arc, one of only two to have been in use throughout recorded history.

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