Proposed changes to the definition of the ampere and the kilogram and their influence in electrical and mass measurements

Héctor Laiz

Instituto Nacional de Tecnología Industrial (INTI), Buenos Aires, Argentina, laiz@inti.gob.ar

Abstract: The proposed redefinition of four base units of the International System of Units (Si) has produced an exiting scientific debate. The electrical metrology community will benefit from the reduction of the uncertainty of fundamental measurements related to the SI.

This presentation analyses the alternatives to the definitions and their impact on electrical and mass metrology.

Keywords: International System of Units. Fundamental Constants.

1. INTRODUCTION

The International System of Units is a coherent system built with base and derived units. The 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 those formed by combining base units according to the algebraic relations linking the corresponding quantities [1]. The definition of a base unit is drawn up so that it is unique and provides a theoretical basis upon which the most accurate and reproducible measurements can be made. The search for definitions of the units based on invariant of nature is as ancient as human technical activities. The unit of length based on the pharaoh elbow or based on one meridian of the earth are examples of that dream [2]. Nowadays we search for definitions of the units that relay on fixed values of fundamental constants of nature. In the definition of the metre, such a fundamental constant is the speed of light in vacuum, c_o. Another constant is the permeability of vacuum, μ_o, fixed in the definition of the ampere. Among the seven base units the definition of the kilogram is the one that is still based on an artifact, the international prototype kept at the BIPM in Sèvres, near Paris. Nevertheless, because of the way they are defined, three other base units relay on the definition of the kilogram, namely the ampere, the mole and the candela. Therefore, any uncertainty in the definition of the kilogram propagates into these units.

2. THE KILOGRAM

Although the international prototype has served science and technology during more than one century it has some inherent limitations. It can be damage, destroyed, it collects dirt from the ambient, and it may change its mass. Its seems that its mass may be changing with respect to the ensemble of Pt-Ir standards of about the same age 50 μg per century, or even more [3].

3. THE AMPERE

The current definition of the ampere is: *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 metre apart in vacuum, would produce between these conductors a force equal to 2 x* 10^{-7} *newton per metre of length* [1]. In the past, its direct realization with current balances led to uncertainties of about $1 \cdot 10^{-6}$. An alternative way with lower uncertainties for the realization of the SI-ampere is by means of the voltage balance [4] and the Thomsom-Lampard capacitor [5] or the watt balance [6]. The advent of two quantum macroscopic effects, the Josephson and the Quantum Hall Effects, allows for the generation of reference voltage an resistance with high reproducibility, although not in terms of the ampere definition, but in terms of the Josephson constant, $K_J=2e/h$ and the von Klitzing constant $R_K=h/e^2$. To take full practical advantage of this two experiments in 1990 the CGPM assigned by convention fixed values to K_J and R_K, based on all available data from voltage balances, watt balances, Thomsom-Lampard capacitors and other experiments [7].

4. DRAWBACKS OF THE CURRENT SITUATION

As a consequence of the current definitions of the base units we face the following problems:

a. The mass of the prototype of the kilogram may be changing, but its value is fixed by definition. Moreover, it is only accessible at the BIPM.

b. We have a practical electrical system of units “outside de SI”.

c. The uncertainty given to many fundamental constants of nature is rather high, due to de null uncertainty given to the mass of the international prototype [8].

The improvement in the accuracy on some fundamental experiments, mainly the watt balance, stimulated the CIPM to ask its Consultative Committees to study the possibility of having a fundamental constant based definition of the kilogram. This decision open and exiting scientific debate [2, 8, 9].

5. IMPACT ON ELECTRICAL MEASUREMENTS

Following the inquire of the CIPM, the Consultative Committee for Electricity and Magnetism proposed that the SI be changed by adopting fixed values of the elementary charge *e* and Planck constant *h*, and that this decision be taken in the near future, for example in 2011, provided that adequate agreement is achieved among independent experiments [10]. It also recommends that the ampere be defined, for example, as follows: "*The ampere is the electrical current equivalent to the flow of exactly* $1/(1.602\ 176\ 53 \times 10^{-19})$ *elementary charges per second*." It follows that this definition fixes the elementary charge as exactly $1.602\ 176\ 53 \times 10^{-19}$ A·s. This proposal would give values without uncertainty to K_J and R_K, binging electrical units back to the SI.

The forthcoming change in the SI will not only deal with the ampere and the kilogram but will also include the Kelvin, by fixing the value of the Boltzmann constant, and the mole, by fixing the value of the Avogadro constant [11].

6. IMPACT ON MASS MEASUREMETS

According to the proposed changes in the definition of the units the prototype of the kilogram should be calibrated with a watt balance in terms of the Plank constant. Nowadays, the best available watt balance has an uncertainty of $4 \cdot 10^{-8}$ [6]. This value is 2.5 times the uncertainty given today by the BIPM for the calibration kilogram standards made stainless steel. This increase in the uncertainty will increase the uncertainty in the dissemination of the national standards to multiples and submultiples but it will be negligible at the level of E1 standards [12].

7. CONCLUSIONS

The forthcoming change in the definition of the ampere, the kilogram, the mole and the kelvin, will reduce the uncertainty of measurements and fundamental constants, related to the new SI, in many fields of science and technology. It will increase the uncertainty of mass measurements at the highest level, but with no impact in legal and industrial mass measurements.

Attention should be paid in the new definitions to keep the SI as a widely understandable system, in which definitions of base units reflect the concept of the related base quantity.

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