The Key role of Giovanni Giorgi in Developing the MKSA System of Units

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***Abstract* – The International System of units used nowadays in most of the word experienced a turning point in the first half of the XX century with the introduction of the ampere (A) as a fourth unit in addition to the original length (M – meter), mass (K – kilogram) and time (S – second), hence turning from a MKS to a MKSA system. This addition was a non-trivial and lengthy process mainly carried on by the Italian engineer Giovanni Giorgi. This contribution retraces this revolution in the measurement system.**

Keywords—History, Measurement Units, Metrology

I. INTRODUCTION

This work deals with the turning point in metrology represented by the introduction of a fourth fundamental unit, electrical in nature, to the original three mechanical units (length, mass and time) and on the key role played by the Italian scientist and engineer Giovanni Giorgi in this development.

Giovanni Giorgi (Fig. 1, from [1]) was born in Lucca, Italy, on November 27, 1871, son of a famous layman, President of the Italian State Council and Senator. He took the degree in Civil Engineering in Rome in 1893 at the age of 22. From 1906 to 1923 he was Director of the Technology Office of the city of Rome and it was in this period that he produced the greatest part of his engineering works. From 1913 to 1927 he taught Mathematics and Physics at the University of Rome and at the School of Aeronautics and of Engineering.

He was also briefly at the University of Cagliari (1927-1929) and then at the University of Palermo (1929-1934) before returning to Rome, where he remained for the rest of his Academic career. Giovanni Giorgi died in Castiglioncello, near Leghorn, Italy, on August 19, 1950. An English biography can be found in [2].

From the scientific point of view, he was a pioneer in the application of the functional operator theory to electromagnetics and to electrotechnics. He also worked on the theory of Relativity and indeed him that foresaw light-ray deviation in the gravitational fields in a letter addressed to Einstein in 1912. An account of Giorgi's scientific achievements can be found in a book written by him [3].

II. THE SYSTEM OF UNITS CHAOS ERA: XIX CENTURY

The earliest attempt to build a rational universal system of units dates back to the French revolution, where only length and mass were indeed considered, time being added later on by Karl F. Gauss in 1821. These three represented the mechanical units, the only ones necessary for Newton's mechanics and believed at the time the only true fundamental ones. Developments in electricity, with forces between charges, magnets, and currents led to an initial hypothesis that electrical quantities could be defined in terms of these same three fundamental units.

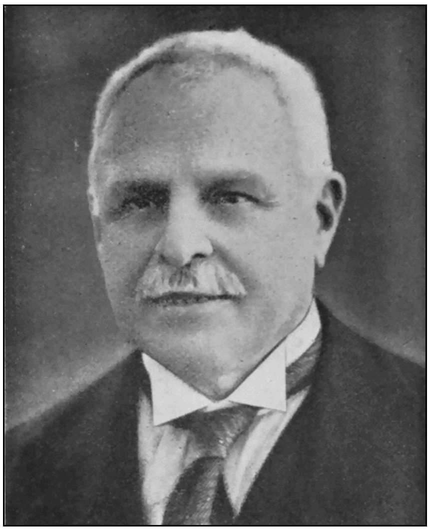

Fig. 1 A late photo of Giovanni Giorgi, from the obituary published in [1].

Yet this was possible only by having three multiplicative constants k_e, k_m and k_{em} in these formulas, two of which could be independently fixed. This of course led to many possible systems, which would be too lengthy to detail here, but are summarized in a recent paper [4].

The need of a standardization was very pressing and in 1861 the British Association for the Advancement of Science did a first attempt to define standard electrical units from mechanical ones, but obtaining units too small or to big to be of any practical use, so practical units derived as multiples or fractions (in base 10) of these were chosen.

The *I Congrès International des Electriciens* held in Paris in 1881. Ratified BAAS decisions and defined fundamental practical units ohm, volt, ampere, coulomb and farad, intended to replace the chaos generated by the 12 units of electromotive force, 10 units of current intensity, and 15 units of electrical resistance customarily used all over the world at the time [4]. Yet these units were still practical, hence defined on the basis of specimens of complex realization and handling.

The definitions of the various units were completed in the congress in St. Louis (1904) and in the conferences in Berlin (1905), London (1908) and Washington (1910) [4]. In St.

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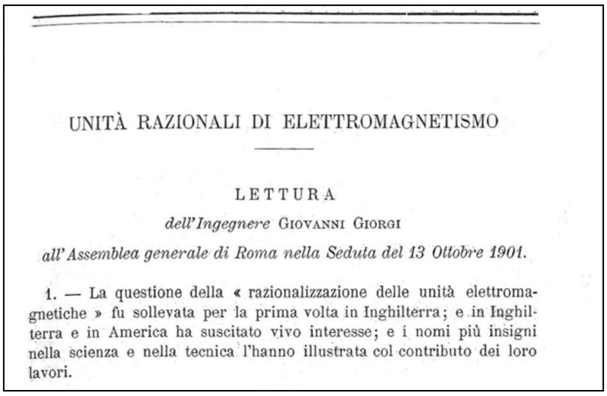
Louis, Giorgi proposal, originally conceived in 1901, was brought to world attention.

III. The System of Units Rationalization: XX century

The work of Giovanni Giorgi starts from this chaotic context. In a communication to the Congress of the Italian Electrotechnical Association in 1901 [5] (Fig. 2) and a subsequent publication in English [6], he proposed a solution to the problems which plagued the absolute systems and which could be summarized into the following points:


UNITÀ RAZIONALI DI ELETTROMAGNETISMO

LETTURA

dell'Ingegnere Giovanni Giorgi

all'Assemblea generale di Roma nella Seduta del 13 Ottobre 1901.

1. — La questione della « razionalizzazione delle unità elettromagnetiche » fu sollevata per la prima volta in Inghilterra; e in Inghilterra e in America ha suscitato vivo interesse; e i nomi più insigni nella scienza e nella tecnica l'hanno illustrata col contributo dei loro lavori.

Fig. 2 – Incipit of 1901 work by Giorgi [5] "Rational Units in Electromagnetism," the paragraph reads: *1- The problem of the "rationalization of electromagnetic units" was first risen in England; and in England and in America it raised great interest; and the most illustrious names of science and technology illustrated it in their works.*

1. The presence of a 4π in the "wrong" places, i.e. where spherical symmetry is absent, owing to the values, typically 1, assigned to two among k_e, k_m, and k_{em}
2. The existence of more than one absolute system, due to the freedom in the choice of the values and the dimensions of two among k_e, k_m, and k_{em}.
3. The fact that in every proposed system some of the units were too large or too small for practical purposes - this too due to the apparently "natural" choice for the electromagnetic constants
4. Even if the mechanistic vision of the physics was in full crisis, all the systems of units in use were still built on the three fundamental mechanical units of length, mass, and time.

Some of these points had already been addressed, for example the first by O. Heaviside, who had a long correspondence with Giorgi. Heaviside tried to overcome the problem by simply moving the 4π term inside the independent constants, Giorgi's brilliant intuition was that all the difficulties could be solved simultaneously, if one abandoned the absurd pretension to reduce the electromagnetic units to mechanical ones.

His fundamental observation was that the group of units more used in the practice - those of resistance, capacity, intensity of electric current, difference of potential and inductance - is fully determined by the units of work, time and one, independently of the choice, of the units of length and mass. The only condition is that the electrical and mechanical powers be both measured in watt.

In this way the units of the practical system can easily be inserted in an absolute system, arbitrarily chosen among those which have the second as unit of time, the joule of work and one unit, the fourth fundamental unit, coincident with the corresponding practical unit. It is now easy to see that the most natural choice for the other two units is the meter and the kilogram as it is in the current system. Of course, now k_e, k_m, and k_{em} cannot be chosen arbitrarily any longer. They can be written with an explicit 4π factor, as Heaviside proposed, but there still remain two dimensional factors (the so-called dielectric constant and magnetic permeability of vacuum), which now are fixed by the units choice and have to be determined experimentally. In other words, k_e, k_m, and k_{em} are no longer considered as pure numeric coefficients, but physical constants which express the capability of vacuum. The values of these constants are very small, which expresses the "rigidity" of vacuum and makes clear why, when they were arbitrarily chosen as unitary or close to unity, the derived units were impractical.

IV. Conclusions

It was only in 1935 that the International Electrotechnical Commission (CEI) decided its adoption, with the name of "Giorgi System." The CEI, however, did not choose the fourth fundamental unit – Giorgi proposed the ohm - leaving the decision to a subsequent meeting. In 1939 the ampere was selected as fundamental unit, and in 1940 vacuum permeability was fixed to $4\pi\times10^{-7}$ H/m, hence completing Giorgi's task: the new MKSA system was coherent and rational.

Giorgi's work had hence an immense impact on the very foundations of electrical and electronic engineer.

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