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EVOLUTION OF THE ITALIAN NATIONAL STANDARD OF INDUCTANCE

Luca Callegaro[1], *Gian Carlo Bosco*[1], *Franco Cabiati*[1] *and Vincenzo D'Elia*[1]

[1] Istituto Nazionale di Ricerca Metrologica I.N.RI.M., Torino, Italy, lcallega@inrim.it

Abstract: The realization of inductance unit and scale at the Istituto Elettrotecnico Nazionale Galileo Ferraris (IEN), the Italian national metrology institution, has evolved during the last 35 years. An historical survey of realization and dissemination methods, and a graphical analysis of the stability of the mantained national inductance standard, is here reported. Results confirm the high stability of artifact standards.

Keywords: Inductance; Measurement units; Impedance measurement; Bridge circuits.

1. INTRODUCTION

The Italian national metrology institute for electrical standards is since 1934 the Istituto Elettrotecnico Nazionale Galileo Ferraris, IEN (which in 2006 became Istituto Nazionale di Ricerca Metrologica, INRIM). Among its duties is the realization, maintenance and dissemination to calibration laboratories of SI unit of inductance, the henry. Since 1972 the inductance unit and scale is mantained with a set of artifact standards (high-quality air-core inductors), although traceability routes and corresponding stated uncertainties changed over time.

Since 1999 the Mutual Recognition Arrangement (MRA), imposes to national metrology labs to declare their Calibration and Measurement Capabilities (CMC), which contain claims about the uncertainty reached in calibration. These claims are sustained by strict control over measurement procedures, and international intercomparisons.

At present, calibration of customers' inductors are performed by substitution, reference standard being an inductor of the mantained set; the calibration uncertainty is significantly limited by very conservative assumptions on the stability of the mantained inductor reference value, which is periodically (in last years, yearly) reassigned when inductance unit and scale is realized.

Among efforts to propose better CMC uncertainty statements in the near future, and to relax the periodicity of unit realization, we are now conducting a retrospective study on the stability of some of the inductors composing the inductance scale over a period of more than 30 years. The study is still being refined, but main features are established and are here reported.

2. THE MANTAINED INDUCTANCE SCALE

The inductance scale is mantained with a set of air-core standard inductors. During the 1970s, the set was of 21 inductors:

- 15 Sullivan (various models) inductors, with a cylindrical copper winding on bakelite core, configured as two-terminal (2T) or four-terminal (4T) impedances;
- 6 General Radio GR-1482 inductors, having a copper winding on a toroidal steatite core, and immersed in a neutral elastic medium (ground cork and silica gel) and encased in an aluminum box. Binding posts permit a three-terminal (3T) or 2T measurement configuration (with a shorting link between L terminal and case). Specifications of the standards give a temperature coefficient of $30 \pm 5\times10^{-6}\ K^{-1}$ and a stability better than 100×10^{-6} per year.

During the 1980s, the Sullivan inductors have been progressively declassified as primary standards, because the improved uncertainty of the measurements was limited by the poor definition of the standards caused by stray magnetic flux, and are not taken into account in this survey.

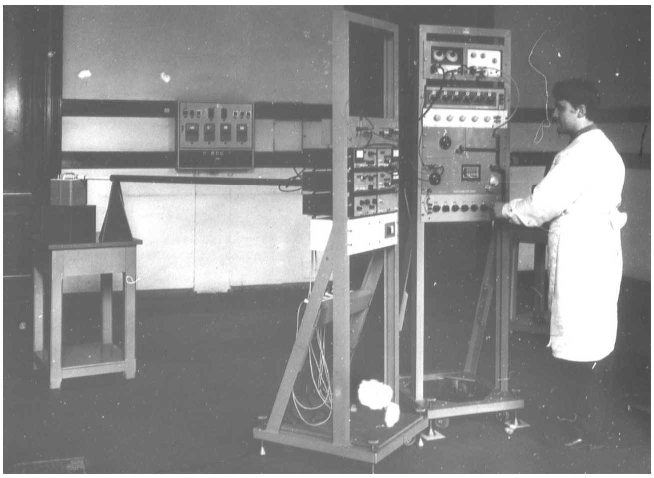

Fig. 1. 1970s: The inductance transformer ratio bridge.

3. REALIZATION OF UNIT AND SCALE

A. 1970s

Inductance unit is mantained with periodic comparisons and scaling with a transformer ratio bridge specifically designed for inductance comparisons [1-4].

A large set of ratio relations between the standard is measured, and an average reference value computed. Fig. 1 shows a photo of the bridge.

B. 1985

A new measurement system [5] is constructed: it performs L-C comparisons and is based on a two-phase digital sinewave generator [6]. Fig. 2 shows a photo of the bridge. Inductance is traced to the national standard of capacitance; each inductor of the mantained set is calibrated versus a capacitor, an scaling is no longer necessary. The system defines the inductor as a four terminal-pair (4TP) standard [7,8] and permit to avoid corrections for stray parameters, typical in other realizations [9]. An adapter from 4TP to 2T or 3T permit the calibration of mantained standards. The calibration technique is validated by participating in an international intercomparison [10, 11] on 100 μH, 10 mH, and 1 H at several frequencies.

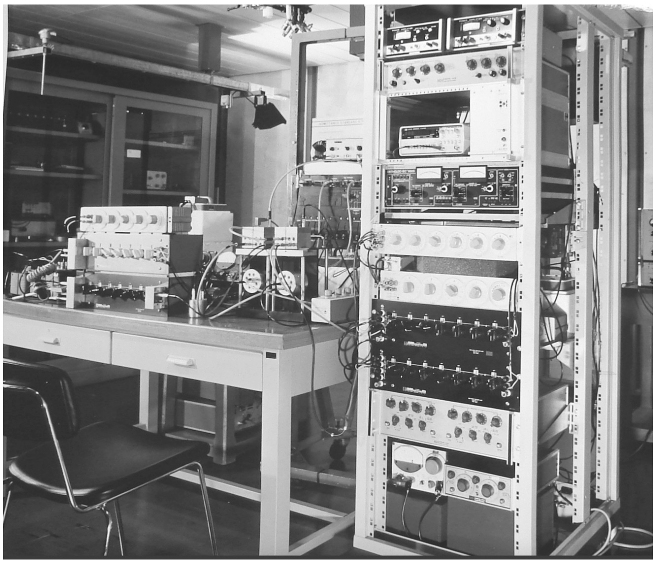

Fig. 2. 1985: L-C comparison system based on digital synthesis.

C. 1992-

A new measurement system, based on the three-voltage method, permit to compare unlike impedances [12]. Inductance is traced to the national standard of ac resistance, again without inductance scaling. An adapter from 4TP to 2T or 3T is used for inductors; resistors are defined as 4TP. The calibration technique is validated with an international intercomparison [13, 14] on 10 mH at 1 kHz.

D. 2001-

A new implementation of the three-voltage method is constructed. The new system [15] is based on new automatic compensators for 4TP definition of the standards [16] and is under complete computer control. The system trace both inductance and high-value (10 nF - 1 mF) capacitance to ac resistance. A photo of the bridge is shown in Fig. 3.

A new 100 mH 4TP thermostated inductance standard [17] is constructed and employed in an international intercomparison [18], IEN acting as pilot laboratory.

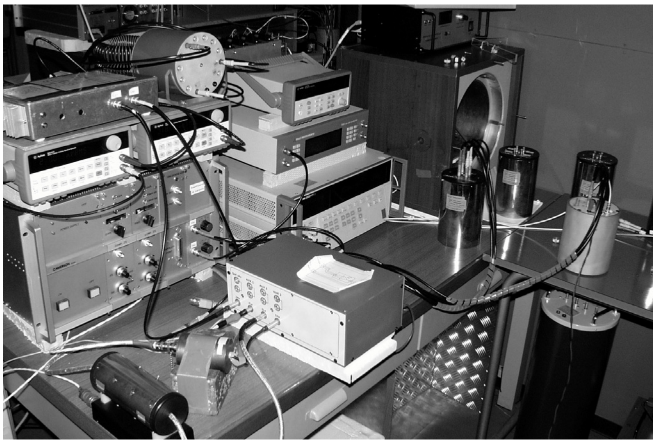

Fig. 3. 2001: The new implementation of the three-voltage method for R-L comparisons.

4. DISSEMINATION TECHNIQUES

The dissemination technique, at least after 1985, has always been performed with high-resolution inductance bridges (General Radio mod. 1693, Hewlett Packard mod. 4284A, Quadtech mod. 7600) with substitution measurements against the national inductance standard. More recently, the substitution method has been automated with a special coaxial switch [19], permitting an high number of measurement repetitions and giving the method a small transfer uncertainty [20].

5. RESULTS OF MEASUREMENTS

Results of measurements on the national inductance standard have been rendered in a graphical form to verify compatibility and drift of each inductor composing the standard. Examples of such analysis, on 10 mH and 100 mH nominal values, are reported in Fig. 4 and Fig. 5.

The result of such analysis is still under evaluation, but it is apparent from Fig. 4 and 5 that the measurement, performed with the different methods and implementations described, are consistent, and that the inductance standards employed have a small and predictable drift in the order of 1 ppm/year. This will permit to relax the periodicity of inductance standard realization and to verify the consistency of new measurement repetitions, and changes in the measurement setup.

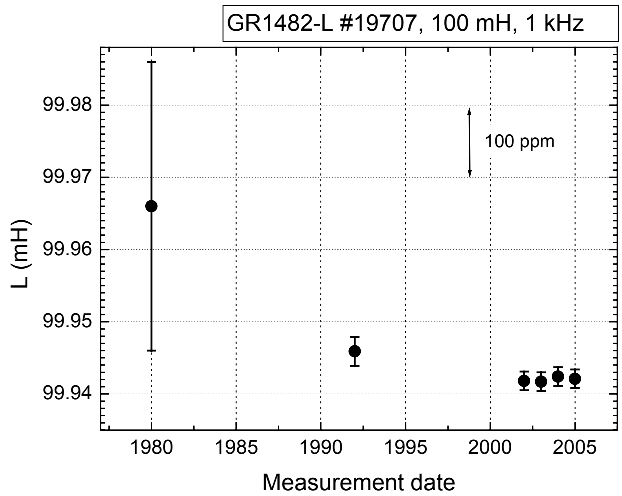

Fig. 4. Results of measurements in the 1980-2005 period, on the 100 mH inductor (General Radio 1482-L), with measurement expanded (2σ) uncertainty bars

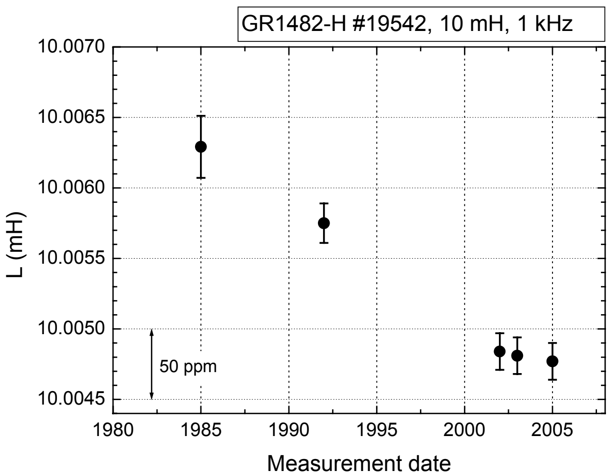

Fig. 5. Results of measurements in the 1985-2005 period, on the 10 mH inductor (General Radio 1482-H), with measurement expanded uncertainty bars.

6. THERMOSTATED STANDARD

The 100 mH inductance standard described in Sec.3D, based on a General Radio mod. 1482-L in a thermostatic enclosure, has been kept under observation since its construction. The inductor is defined directly as a 4TP standard, connectors are four British Post Office Multiple Unit Steerable Array (BPO-MUSA) connectors (the standard has been therefore measured with the three-voltmeter method [15] without any adapter), and the thermostat stabilizes the internal temperature within 0.01 °C for an ambient temperature in the 18-25 °C range.

Fig. 6 shows a comparison between 2T and 4TP measurements made during the EUROMET EM.S20 international intercomparison; between measurements the standard has been transported by plane and car for several thousands of km overall Europe.

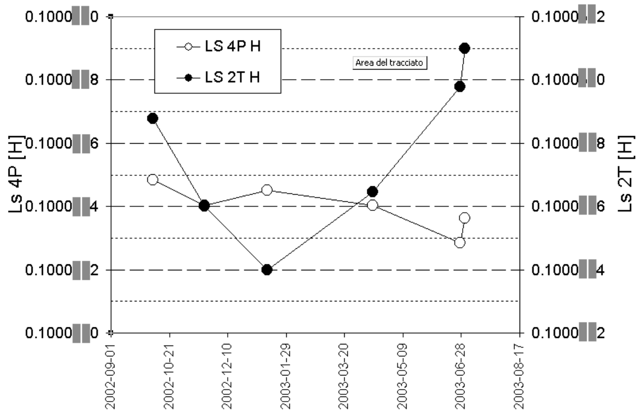

Fig. 6. Results of measurements on the 100 mH thermostatted inductance standard employed in the EUROMET.EM-S20 intercomparison. Some digits of the results have been obscured because the comparison is still under scrutiny.

Although the long-term stability should be similar to existing standard, the better 4TP definition permits a greater repeatability in mid-term (months).

7. DISCUSSION

We showed the history of inductance unit and scale realization at IEN in the last 35 years. Measurement methods changed over time, and so did the traceability paths for its realization.

Inductance unit has lost some of its status since the invention of calculable capacitor, which permits since then a more accurate realization of the ohm than the calculable inductor. However, inductance unit is actively mantained by the vast majority of national metrology laboratories with steadily increasing accuracy, and disseminated with calibration of artifact standards (standard inductors) to secondary calibration laboratories.

The survey confirms he high degree of stability of metrology-grade inductors composing Italian national standard of inductance, and give arguments to improve the accuracy in calibration for customers, and in the near future the declaration of new CMCs at the international level.

The new 100 mH standard show the interest of extending thermostatization and four terminal-pair definition of impedance standards to inductance. The realization of a whole set of 4TP thermostatted inductors to update the national inductance standard maintenance is now under consideration.

6. PROFILE: ERNESTO ARRI

Ernesto Arri was born in Turin, Italy, in 1927. He graduated in Electrical Engineering at the Politecnico di Torino, Torino, Italy in 1952. From 1952 to 1961 was Assistant Professor of Electrical Engineering at the Politecnico di Torino. In 1961 he joined IEN where, from 1965 to 1985, was the head of the Electrical Metrology department. In 1984 became Associate Professor of Measurement Theory at the Politecnico di Torino, and in 1986 Full Professor at the University of Cagliari and then at the Politecnico di Torino. Prof. Arri, among other researches, gave new impulse to inductance metrology at IEN by establishing an enlarged standard set for unit maintenance, a precision inductance bridge [1-4] and a regular measurement scheduling. He died in Pecetto (Torino, Italy) in November 2005.

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