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EVALUATION OF THE INFLUENCE OF THE UNEQUALIZED CURRENTS IN THE INDUCTANCE BRIDGE AT CEM

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Abstract: Inductance is realized at Spanish Centre of Metrology (CEM) by means of a modified coaxial Maxwell-Wien bridge. A study of the unequalized currents in the whole bridge network was carefully carried out in order to check their effect on the system's accuracy. Previously, stability and thermal coefficient of different kind of inductors have been evaluated to select those with the lowest temperature coefficient and best short-term stability to be employed in this evaluation.

Keywords: Inductance, capacitance, coaxial bridge, current equalizer.

1. INTRODUCTION

At CEM the unit of inductance is establish by means of a modified coaxial Maxwell-Wien bridge. Traceability chain for inductance realization is based on Quantum Hall Effect [1] and a Josephson potentiometer to obtain the dc resistance. In order to link the dc resistance to ac resistance a calculable resistor with a determined ac-dc difference is employed. The ac resistance is the starting point of the capacitance realization. That is obtained by means of four terminal-pair ac coaxial bridges (to compare like impedance standards) and a quadrature bridge to compare capacitors with resistances). As long as this system is not validated, traceability of the farad at CEM is assured through a transfer standard calibrated at BIPM. Thus, the realization of the henry is achieved from the capacitance and the ac resistance.

In an ideal ac coaxial bridge the current through the outer conductor of each coaxial cable is always equal and opposite to the current in the inner conductor. In such a bridge external electric and magnetic fields do not affect the network of cables [2] and the current in the network does not produce external electric and magnetic fields. In practice, cables are neither infinitely long nor completely straight or coaxial and are not isolated; they are part of a mesh in a network. Then, current equalization is not assured, the bridge balance condition is not achieved and systematic errors could appear.

A coaxial bridge could be regarded as two different networks: one low-impedance circuit for the outer conductors of cables and shields of components and a high impedance circuit for the inner conductors. Current equalization is obtained by threading a coaxial cable through a high permeability magnetic core. Both, core and cable, work as a current transformer. A current equalizer does not affect the current through the inner conductor.

The distribution of passive current equalizers varies for each coaxial bridge, depending on the elements of the circuit and the cables.

The Maxwell-Wien bridge built at CEM operates at 1 kHz and it allows to obtain a 10 mH inductance with an estimated relative expanded uncertainty of 30 μH/H, without the use of equalizers [3].

An evaluation of the influence of unequalized currents has been performed. This paper describes the methodology and results of this evaluation. Mainly the study of the appropriate number and position of the current equalizers in the Maxwell-Wien bridge. The goal is to maintain negligible net currents in the cables of the whole network. The results are compared with those obtained without the use of equalizers.

2. MAXWELL-WIEN BRIDGE AT CEM

In figure 1 the Maxwell-Wien bridge implemented at CEM is shown. The main elements of the bridge are the inductance to be calibrated, represented by the series equivalent inductance and resistance of the standard (L_x and R_x, respectively), a 10 nF standard capacitor C_s, a precise variable air capacitor C_v, two fixed resistors R_1 and R_2 and a variable resistor R_v

The standard capacitor C_s selected is a GR-1409-L highly stable, hermetically sealed with a ceramic dielectric and a fixed nominal value of 10 nF.

The fixed resistors R_1 and R_2 are 1 kΩ hermetically sealed resistances obtained from Vishay. They were chosen for their good stability, small temperature coefficient ($0.6 \cdot 10^{-6}$/ ºC), non inductive and low ac-dc difference.

Finally, R_v is a combination of two 50 kΩ Vishay resistors and three multiturn potentiometers, used to make fine adjustment between 100 kΩ and 120 kΩ. Furthermore, two switches in the box containing R_v allow the connection of two capacitors. This T-circuit generates a negative capacitance to balance the bridge if it is necessary.

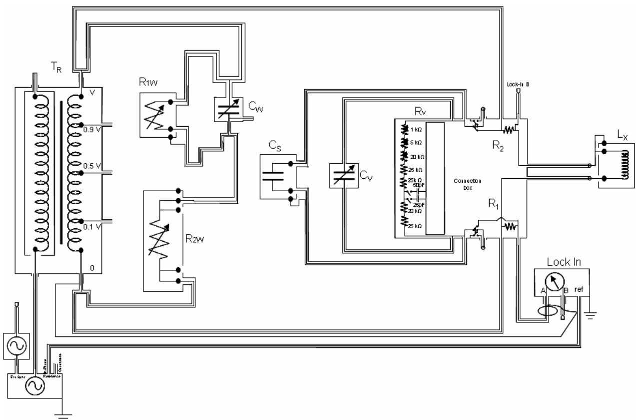

Fig. 1. Circuit of the Maxwell-Wien bridge with the Wagner arm.

To enable the connection of all the bridge components a metallic shielded box was designed and constructed, minimizing the residual parameters. All connections in the box are made by means of British Post Office (BPO) connectors. Resistors R_1 and R_2 are screened and placed in separate compartments of the box.

Other elements of the circuit are: an isolation transformer, a generator and a lock-in amplifier.

The bridge is balanced simultaneously by means of the main and the Wagner balances. The main bridge balance is achieved with components R_v and C_v. In order to avoid errors in the circuit resulting from leakage impedances an auxiliary Wagner arm is employed. The components used for the Wagner branch are two variable resistors (R_{1w} and R_{2w}) and a variable capacitor (C_{1w}).

To eliminate stray capacitance between bridge nodal points and ground and the stray inductance on the inductive coil, a zero-substitution method is used. Inductor L_x is replaced by a small home-made inductor, L_{xo}, which has an adjustable resistor R_{xo}. This resistor can be fixed at the same nominal resistance as the intrinsic resistance of the unknown inductor L_x. The capacitor C_s is removed from the bridge for the auxiliary measurement.

Thus, the unknown inductance L_x can be obtained from (1):

$$L_x = R_1 R_2 (C - C') + L_{x0} \qquad (1)$$

where C is the capacitance in the bridge when the unknown inductor L_x is connected, C' is the capacitance resulting when the small inductor L_{xo} is measured instead of L_x and L_{xo} is the value of the small inductor.

3. EVALUATION AND SELECTION OF APPROPRIATE STANDARD INDUCTORS

Stability and thermal coefficient of different kind of inductors have been evaluated to select those with the lowest temperature coefficient and best short-term stability to be employed in this evaluation. In order to determine the most appropriate inductor, two different types of 10 mH inductance standards have been considered: General Radio GR-1482 model and N. L. (Norman Lloyd) air core model.

Commercial inductance standards usually have a large temperature coefficient. In order to reduce the uncertainty due to temperature coefficient, they should be thermally stabilized or their internal temperature accurately measured. For the internal temperature evaluation, the dc resistance of the inductance is used as a thermistor. In order to apply the temperature corrections, the relation of the temperature, resistance and inductance is determined.

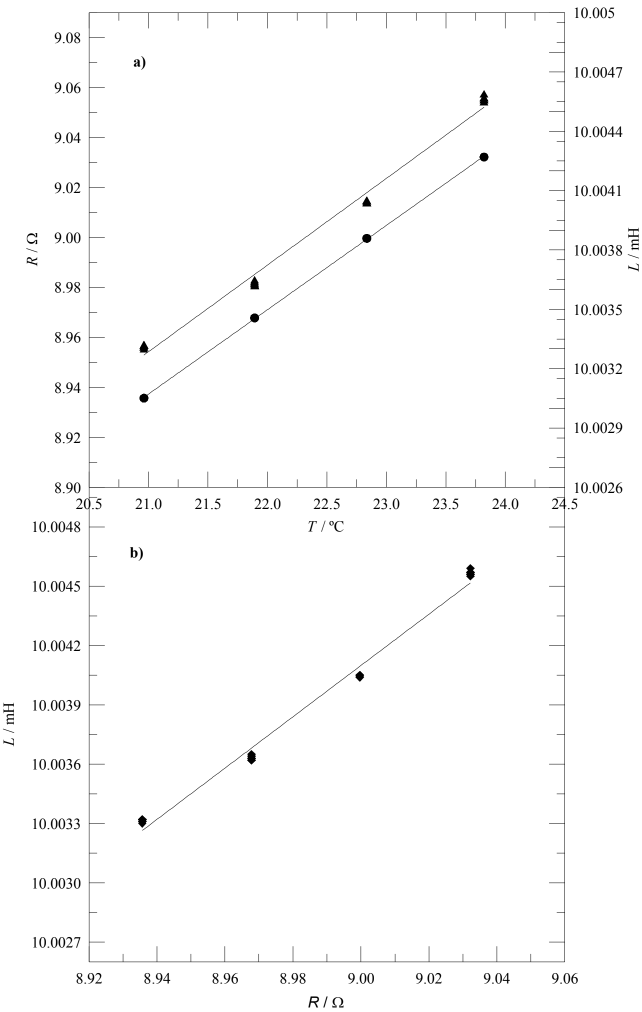

Fig. 2. a) Resistance (●) and inductance (▲) plotted as a function of temperature for the GR-1482 inductor. b) Inductance vs resistance for the GR-1482 inductor.

Inductors are immersed in an air bath. The temperature of the bath is varied from 21 ºC to 24 ºC in steps of about 1ºC. Due to the high thermal inertia of the inductor the measurements are carried out 24 hours after each temperature change. DC resistance and inductance are measured as a function of temperature (figure 2a for the GR-1482). The dc resistance value of the inductance corresponding to a temperature of 23 ºC is taken as a reference. In figure 2b variation of inductance with resistance is plotted for each type of inductor. Then, each inductance measurement is corrected by means of the dc measured resistance, taking into account the variation plotted in figures 2b.

4. NUMBER AND DISTRIBUTION OF CURRENTS EQUALIZERS IN THE MAXWELL-WIEN BRIDGE

First step is the evaluation of the number of required current equalizers. With this aim, as can be seen in figure 3, the mesh of outer conductors and networks nodes are drawn, being a node the component where more than two cables are connected. According to [4] each independent mesh should have one and just one equaliser, but the location of this equaliser in the mesh is irrelevant. It is stated that if n is the total number of nodes, c the total number of cables and m the number of independent meshes, m=c-n+1.

From figure 3 the number of cables in this bridge is 18, the number of nodes is 11, and then the number of independent meshes is 8. This is the number of current equalizers required.

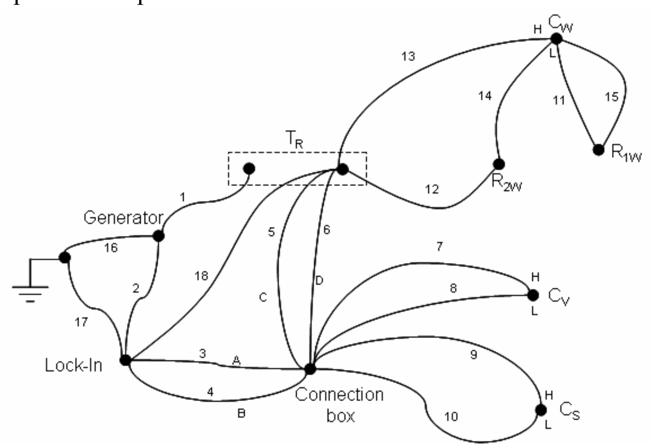

Fig. 3. Outer conductors and network nodes of the Maxwell-Wien bridge with the Wagner arm.

Once the number of passive current equalizers is quantified, it is necessary to determine their location. With this aim each cable of the network (with and without an equalizer) is wounded through a net current detection transformer. The voltage indicated by a lock-in amplifier connected to the transformer estimates the net current in the cable. If the bridge is balanced net currents are not greater than $1 \cdot 10^{-3}$ of the main current through the impedance standards [5]. Finally, equalizers having the largest effect in current balance are installed, taking into account that each independent mesh should have only one equalizer and the network of conductors without current equalizer should not include loops or isolated branches.

Passive current equalizers employed in the Maxwell-Wien bridge are constructed by winding a coaxial cable through a high-permeability magnetic core with a quality factor Q of 2.5. In order to improve the current equalization between inner and outer conductors, cables are threaded 20 turns around cores.

Once the bridge is equalized, the Standard Inductor is measured and the results compared with those obtained without the use of equalizers. The previous repeatability of 6 μH/H was improved to 2 μH/H and the relative expanded uncertainty to 22 μH/H ($k = 2$).

Finally, validation of the measurement system previously described has been carried out by means of a 10 mH standard inductor calibrated at PTB with an uncertainty of 20 μH/H ($k = 2$). The degree of equivalence D given with respect to the PTB certified value and its expanded uncertainty are obtained as:

$$D = L_{CEM} - L_{PTB} = 2 \quad \mu H/H \tag{2}$$

$$U_D = \sqrt{U_{CEM}^2 + U_{PTB}^2} = 30 \ \mu H/H \tag{3}$$

where L is the mean of ten different measurements.

5. CONCLUSIONS

The evaluation of the influence of unequalized currents in the CEM inductance bridge has been performed in order to improve the uncertainty of the bridge. The number and position of current equalizers in the Maxwell-Wien bridge have been determined to achieve negligible net currents in the cables of the whole network. The main effect of the equalizers in the bridge was the improvement of the repeatability and therefore the reduction of the relative expanded uncertainty.

6. REFERENCES

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