Improvement of the accuracy of the logometric impedance meters in wide frequency range
Amelioration de la precision de mesure des mesureurs logometriqies de l'impedance sur une large band de frequences

Michael Surdu[1], Alexander Lameko[1], Alexey Panich[1]
[1]Ukrmetrteststandard, Metrologichna str., 4 Kiev, 03680, Ukraine

Abstract   Logometric impedance meter with variational correction of the uncertainty, caused by finite loop amplification and admittance between protecting amplifier inputs has been developed. To correct named uncertainty, the variation of the protecting amplifier gain is provided and additional measurement of the voltage drop on the standard is implemented. Appropriate calculation eliminates influence of the described uncertainty source on the result of measurement. Proposed approach has been used in the logometric impedance meter MNS1200, delivered to Siberian Institute of Metrology to be used in secondary standard of inductance for frequency up to 1 MHz.

Les mesureurs logométriques de l'impédance avec la correction variationnelle de l'erreur de mesure, conditionnée par le gain de boucle terminal de l'amplificateur protecteur du mesureur et par la conductivité des câbles ont été élaborés. Le gain de l'amplificateur protecteur est varié un nombre de fois connu pour corriger cette erreur. Le mesurage de la chute de tension sur la mesure modèle avant et après la variation permet d'élaborer le système d'équations, dont la résolution exclut complètement l'impacte du gain de l'amplificateur protecteur sur le résultat de mesure de l'impédance. La solution proposée était utilisée dans le mesureur logométrique de l'impédance MNS1200, livré à l'Institut Sibérien de Métrologie pour l'étalon secondaire d'inductance jusqu'à 1 MHz.

1. Introduction

To measure impedance parameters first investigators used balanced bridge devises or movable-pointer indicators [1, 2]. Last type of measurement instruments was very simple but had rather big errors, because of the result of measurement depended on the applied voltage (current). This situation sharply changes from the beginning of seventies, when the first integral Operational Amplifiers (OpAmp) and Microprocessors were developed. At this time the movable-pointer indicators have been performed into the new class of measuring devises – auto-balancing or logometric meters [3, 4, 5, 6, 7.]. Today these meters have uncertainty better than 0.01%, and operate on frequency range from DC to tens MHz. Many companies manufacture now such devises (HP, Agilent, TeGam, IetLab, Wine Kerr, etc).

2. Main Idea

First automatic logometric meters [8] used an OpAmp, with feedback, created by measured and standard impedances Z_x and Z_o. Input and output voltages of this OpAmp were measured by simple vector voltmeter and their ratio was determined. The ratio of these voltages is approximately equal to the ratio of the impedances. But the voltage ratio in this case depends on the loop gain of the amplifier, so that appropriate uncertainty δ_Z of measurement is given by formula:

$$\delta_Z \approx (Z_0 + Z_x)/KZ_x. \qquad (1)$$

This uncertainty can achieve significant values on the high frequencies range, where the amplifier gain K sharply decrease. Other source of uncertainty here is caused by difficulties of the four terminal connections of both Z_x and Z_o on low impedance measurement range. To eliminate influence of these sources of uncertainty, H.P. Hall proposed the auto-balancing bridge [9], where voltage drops on the measured and standard impedances Z_x and Z_o are measured by the differential vector voltmeter. In this case amplifier gain K theoretically doesn't influence the result of measurement and OpAmp protects measuring circuit only.

Real measuring circuit contains not only the measured and standard impedances Z_x and Z_o, but some impedance Z_g, connected between negative and positive inputs of the protecting OpAmp. Usually admittance $1/Z_g$ consists of the cable admittance and the admittances of the low potential ports of the measured and standard

impedances Z_x and Z_o. Uncertainty caused by this impedance, can be estimated by the formula:

$$\delta_Z \approx Z_0 / K Z_g \qquad (2)$$

On high impedance ranges of measurement (when *Zo* increase, so that $Z_o > Z_g$) and on high frequency range (where K is low) this uncertainty can achieve considerable values. Today manufactures propose to enter into the devise the value of Z_g. Process of these data can eliminate or decrease this uncertainty [10, 11,12, 13]. Of course, amplifier gain and Z_g aren't stable and can change in rather wide range. In this way such correction can't eliminate fully described uncertainty.

In this report we describe the new approach, which eliminate fully described above uncertainty. This approach is based on the variational method of uncertainty correction [14]. In compliance with this method to eliminate any uncertainty we need to vary the influence of the appropriate source on the result of measurement in well known ratio or on well known value. We determine twice the measured value: before and after variation. After that we solve the system of two equations, which describes these measurements, eliminate the uncertainty and get accurate results. In case if the influence of N uncertainty sources has to be eliminated, the N appropriate variations has to be done and the system of N+1 equations has to be solved to get accurate result of measurement.

The circuit diagram of the logometric impedance meter with variational correction of the described uncertainty is shown on Fig. 1. Logometric meter consists of the generator G and protecting amplifier A, which have the gain K. The measured and the standard impedances Z_x and Z_o create the feedback loop of the

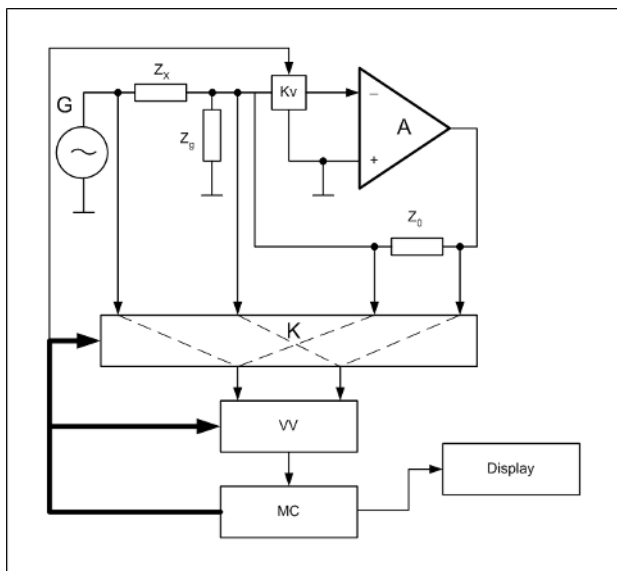Fig 1. Circuit diagram.

protecting amplifier A. Generator generates the current, which flow through the measured and standard impedances Z_x and Z_o

The switcher K connects the differential inputs of the vector voltmeter VV to the measured and the standard impedances Z_x and Z_o, so that appropriate voltage drops are measured. Microcontroller MC processes results of voltage measurements and display the impedance parameters on the Display.

In ideal case, if the amplifier A gain K is infinite, the input voltage of the protecting amplifier is equal to zero and no current flow trough impedance Z_g. If the amplifier A gain K is finite, its input voltage isn't equal to zero, so that the part of current which flow through Z_x , branches onto Z_g and creates appropriate uncertainty (effect of quazy increasing Z_x).

Let, in compliance with the variational method, we will vary the amplifier A gain K on the well known ratio K_v. To this end the switched divider K_v is connected serially with the amplifier A. This divider has transfer coefficient 1 or K_v, controlled by the microcontroller MC. To eliminate described uncertainty, the vector voltmeter, under the control of the MC, provide three measurements:

- measurement of the voltage drop U_x on the Z_x;
- measurement of the voltage drop U_0 on the Z_o when divider K_v has a transfer coefficient equal to 1;
- measurement of the voltage drop U_{0v} on the Z_o when divider K_v has a transfer coefficient equal to K_v.

These three measurements are described by the system of three equations:

$$U_x = I_x Z_x$$

$$U_o \left(1 - \frac{1}{K+1} \frac{Z_o}{Z_g} \right) = I_x Z_o \qquad (3)$$

$$U_{ov} \left(1 - \frac{1}{K_v K + 1} \frac{Z_o}{Z_g} \right) = I_x Z_o$$

MC solves digitally the system of equations (3) and finds the accurate ratio Z_x/Z_0. For further analysis there is better to get analytical solution. Taking into account that relative difference δU between U_0, and U_{0v} is very small and depends on the uncertainty itself, we get the next approximate formula for precised calculation of the measured value Z_x:

$$Z_x = Z_o \frac{U_x}{U_0} \left(1 / (1 + \delta U \frac{K_v}{1 - K_v}) \right). \qquad (4)$$

where: $\delta U = U_0 / U_{ov} - 1$

Uncertainty of the proposed meter doesn't depend at all on amplification of the protecting amplifier A on all the range of measurement and in frequency range. In this case its uncertainty budget includes, as usual logometric impedance meter, nonlinearity and sensitivity of the vector voltmeter, short term stability of the generator voltage magnitude, standard's uncertainty, etc., but adds uncertainty of the variation and greater influence of the

vector voltmeter sensitivity due to the increased quantity of voltage measurements.

Let we will estimate the increasing in uncertainty caused by last factors.

Vector voltmeter measures two quadrature components a and b of the input signals U_x and U_o in the known logometric meter and components of three input signals U_x, U_0 and U_{ov} in proposed meter. Its transfer function, which takes into account additive error Δ (the limited sensitivity, caused by the noise) can be described by two functions:

$$a = kU_s + \Delta; \quad b = kU_c + \Delta \qquad (5)$$

here k is vector voltmeter gain and U_s and U_c are quadrature components of the measured signals.

Let the vector voltmeter dinamic range is A_m, and it is used in such way that :

$$A_m = a_0^2 + b_0^2, \text{ and } \quad A_m \geq a_x^2 + b_x^2 \qquad (6)$$

Known formulas for impedance component calculation [3], formulas (5) and (6) we get the expressions of the dependence between the uncertainty of the measured impedance components and the vector voltmeter additive conventional uncertainty δ in the known logometric meter, described in [9] :

$$\delta_{r(b)} \approx -\delta; \quad \Delta_{r(b)} / R_0 \approx \delta; \quad \Delta_{b(r)} / R_0 \approx \delta. \qquad (7)$$

where $\delta_{r(b)}$ is the multiplicative uncertainty of the active (reactive) impedance component measurement and $\Delta_{r(b)}, \Delta_{b(r)}$ are the additive components of the uncertainty of measurement when main active(reactive) component of impedance is measured.

Using formulas (4), (5) and (6) we get the expressions for the dependence between the uncertainty of the the measured impedance components $\Delta(\delta_{r(b)})$ and the vector voltmeter additive conventional uncertainty δ in proposed impedance meter :

$$\Delta(\delta_{r(b)}) = \sqrt{2}\delta \frac{K_v}{1-K_v} \qquad (8)$$

Formulas (8) show that the proposed algorithm of measurement only slightly imcrease the influence of the vector voltmeter noise on the uncertainty of the result of measurement.

The proposed algorithm needs three measurements instead on two measurement in the known meters, i.e. decreases the speed of measurement on one third. Because of it, this algorithm is preferable to be used on high frequency and high impedance parts of the range of measurement only. In such way we will decrease speed of measurement only in part of measurement range, where correction is necessary.

Formulas (8) show that uncertainty of measurement increase at the end of the measurement range. In this place we measure two (or three) voltages, which have nearest values. In other parts of the measurement range $U_0 > U_x$. Because of it the multiplicative uncertainty component is lower than additive one and sum uncertainty decreases.

To increase the speed of measurement and align the uncertainty of measurement on whole range of measurement it we proposed the algorithm, where the time of the voltage U_0 measurement is directly proportional to the ratio of the voltages U_x/U_0. This algorithm significantly increases the speed of measurement in main part of the measurement range.

3. Experimental results

Described above approach was used in logometric impedance meter MNS1200. MNS1200 was delivered to Siberian Institute of Metrology, to be used in wide frequency working inductance standard. Its appearance is shown on fig. 2.

Fig.2 MNS1200 appearance

MNS1200 operates on range from DC to 1MHz.

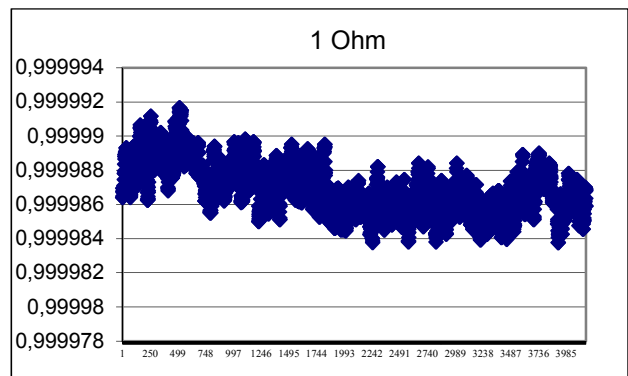|	
Frequency set discreteness	$2 \cdot 10^{-5}$
Capacitance range of measurement (F)	10^{-17}-10^5
Resistance range of measurement (R)	10^{-6}-10^{14}
Inductance range of measurement (H)	10^{-12}-10^{10}
Dissipation factor tgδ (tgφ)	10^{-6} – 1.0
Main uncertainty (ppm)	10
Sensitivity (ppm)	0.5
Inner standard instability (24 hours, ppm)	± 2

Fig3. Results of 1 Ohm resistive standard measurements during 24 hours

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