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An automatic system for measurement of impedance active component using a quasi-balanced method

Abstract

The paper presents the idea of the possibility of implementing automatic virtual instrument using the quasi - balanced method to measure the active component of impedance (resistance). The system is based on the structure of a non-bridge quasi-balanced circuit. The process of balancing is automatically performed. This meter has been built based on the data acquisition board NI USB-6251 from National Instruments and programming environment LabVIEW. Signal processing is made in an algorithmic way. The measurement of the phase angle is based on short-term Fourier transform. The results of preliminary experimental research are presented in the paper.

Keywords: virtual instruments, LabVIEW, capacitance measurement, impedance measurement, resistance measurement, phase shift measurement.

1. Introduction

Quasi - balanced methods with algorithmic phase detection are used to measure immitance components, electrical loss factors of capacitors and quality factors of coils. These methods are characterized by a special state in which the phase shift of selected signals assumes a predefined value (typically π/2). This is the so-called quasi-balance state of the circuit. In the measuring process the circuit is driven to this state by changing the setting of a single regulatory element [3, 4, 5].

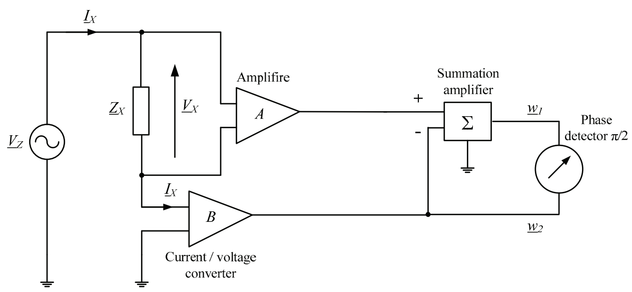

Fig. 1. Block diagram of the quasi-balanced circuit for measuring the active component of impedance $\underline{Z}_X$

An exemplary implementation of the quasi-balanced method for measurement of resistance or impedance active component is shown in Fig. 1 [4]. The blocks and symbols in Fig. 1 denote:

$\underline{V}_Z$ - voltage of the power source;
$\underline{Z}_X$ - tested impedance;
$\underline{V}_X$, $\underline{I}_X$ - voltage and current of the impedance $\underline{Z}_X$;
$\underline{w}_1$, $\underline{w}_2$ - signals being phase detected;
A - gain of the amplifier;
B - conversion factor of the current/voltage converter.

In this system, the variable gain A of the amplifier or the adjustable conversion factor B of the current/voltage converter can be an adjustable element. The phase shift between the signals $\underline{w}_1$ and $\underline{w}_2$ is measured by a phase detector.

The signals $\underline{w}_1$ and $\underline{w}_2$ from the system of Fig. 1 are given by:

$$\begin{cases} \underline{w}_1 = A\underline{V}_X - B\underline{I}_X \\ \underline{w}_2 = B\underline{I}_X \end{cases} \tag{1}$$

In the quasi-balance state, the phase shift between the signals $\underline{w}_1$ and $\underline{w}_2$ reaches the value of π/2. This angle is the difference of the arguments between the signals, hence the argument of the ratio of the signals $\underline{w}_1/\underline{w}_2$ may be written as follows:

$$\mathrm{Arg}(\underline{w}_1) - \mathrm{Arg}(\underline{w}_2) = \mathrm{Arg}\left(\frac{\underline{w}_1}{\underline{w}_2}\right) = \mathrm{arctg}\frac{\mathrm{Re}\left(\frac{\underline{w}_1}{\underline{w}_2}\right)}{\mathrm{Im}\left(\frac{\underline{w}_1}{\underline{w}_2}\right)} = 0 \tag{2}$$

From equation (2) it follows that the state quasi-equilibrium is determined by:

$$\mathrm{Re}\left(\frac{\underline{w}_1}{\underline{w}_2}\right) = 0\,. \tag{3}$$

Substituting (1) in equation (3) we obtain:

$$\mathrm{Re}\left(\frac{\underline{w}_1}{\underline{w}_2}\right) = \mathrm{Re}\left(\frac{A\underline{U}_X - B\underline{I}_X}{B\underline{I}_X}\right) = \mathrm{Re}\left(\frac{A}{B}\underline{Z}_X - 1\right) = 0\,, \tag{4}$$

from which the real component of the measured impedance $\underline{Z}_X$ can be determined:

$$\mathrm{Re}(\underline{Z}_X) = \frac{B_0}{A_0}\,, \tag{5}$$

where:
A_0 - voltage gain of the amplifier A in the quasi - balance state,
B_0 - conversion rate of the current/voltage converter B in the quasi-balance state.

2. The measuring system

The measuring system of Fig. 1 was built as a virtual instrument. Its block diagram is shown in Fig. 2. The system consists of two basic parts: hardware and software.

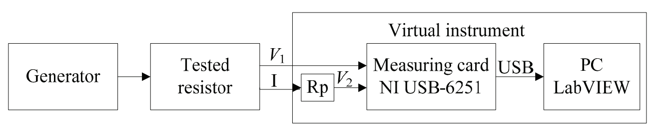

Fig. 2. Block diagram of the measuring system

The presented system is used for static measurements. It is assumed that in the circuit there is no change of the measured impedance and the relaxation effects have decayed. The parameters A and B of equation (1) are not dynamic, they are numerical coefficients. A measuring resistor, whose value is equal to the ratio B, has some parasitic parameters (capacitance and inductance). For the measurements performed at relatively low frequencies, it is assumed that these parameters are negligible. For measurements performed at high frequencies and accurate measurements, the impact of these parameters should be taken into account.

The hardware (Fig. 3) is a measurement card NI-USB6251 from National Instruments [11], a PC (they are connected to each other via a USB cable) and a current/voltage converter. The card has one 16-bit A/D converter with a maximum speed of 1.25 MS/s (1 MS/s with multichannel configuration). 8 differential inputs are connected to the converter via a built in multiplexer. Such a solution causes that individual measurement signals cannot be sampled at the same instant. The delay in sampling the signals is a source of additional errors. According to the manufacturer, the measuring card input resistance is 10 GΩ, while the value of the input resistance of the measuring system measured at the frequency of 100 Hz is approximately 1 MΩ. A function generator Rigol DG1011 is used as a power source for the tested object .

Fig. 3. The measuring system

Measurement of the voltage drop across the resistance to be tested is made directly by the measuring card. Measurement of the current is carried out by the use of an additional current/voltage converter, which is a precision resistor (of tolerance 0.1% or 0.01%). The device uses eight measuring resistors of different values, which are switched to change the measuring range. Adjusting the order of the measured voltages is to make the best use of the measuring range of the A/D converter. The coefficient B_0 in equation (5) is equal to the value of the resistor used in the measurement. Digital signal samples are sent to the computer for further processing.

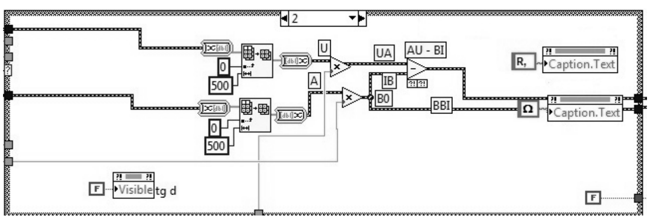

Fig. 4. Fragment of the program code

The measurement signal processing and the virtual instrument front panel were implemented in software based on the LabVIEW development environment. A fragment of the program, responsible for implementation of relationship (1) is shown in Fig. 4. The detection of quasi-balance state is realized on the basis of short-term Fourier transform (the "MATLAB script"). This algorithm is characterized by good metrological parameters (high resistance to interference, short time of calculations, high accuracy) [7], [9]. The phase meter using the measuring card NI USB-6251 and the software applying the mentioned method enable accurate measurements of the phase angle at the level of 0.01° [2].

The virtual measuring panel is divided into three tabs:
- measurement,
- settings,
- advanced.

The first tab (Fig. 5) presents the information on the progress of calculations, the current time and the measurement result. During a measurement, the progress bar is red (Fig. 5a), while at the end of calculations the color changes to green (Fig. 5b).

a) b)

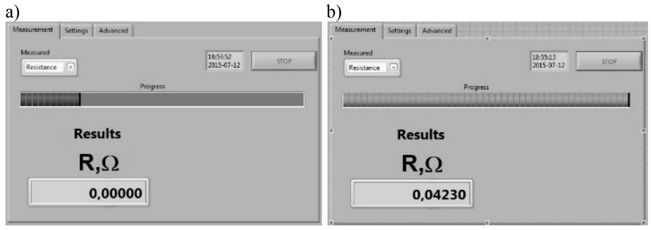

Fig. 5. Virtual instrument panel, tab "Measurement"

In the future, "Letter Box" will enable selection of a measured quantity. Then the virtual instrument will be a universal meter using quasi – zero methods to measure, among others, RLC parameters and a phase angle.

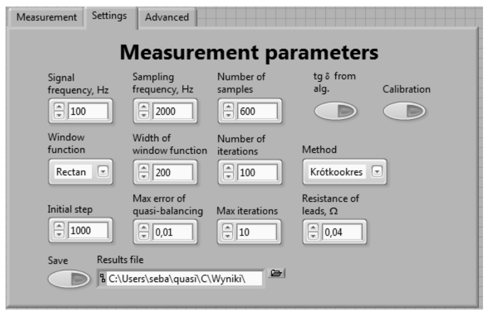

Fig. 6. Tab "Settings"

In the "Settings" tab (Fig. 6) there are options for specifying a frequency of the test signal, setting the parameters of the phase shift angle measurement algorithm and automatic quasi - balancing as well as configuration of the measurement card (sampling frequency, number of samples). Archiving the results to allow further analysis is an additional option. It is also possible to perform calibration to determine the lead resistance (the value obtained is subtracted from the measurement results).

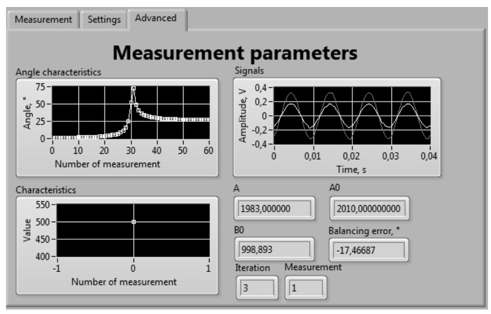

Fig. 7. Tab "Advanced"

The "advanced" tab (Fig. 7) presents, in a graphical form, signals of the measured impedance (voltage from current/voltage converter and voltage signals $\underline{V}_X$ of the object), the characteristics of quasi - balancing, numerical values of the coefficients in equation (1) and the error of the quasi-balancing process (the difference between the result obtained and the angle π / 2).

The measurement process (Fig. 8) consists in an iterative change of the coefficient A in equation (1) within a range set by the user. The results from the quasi - balancing process are searched to find the value closest to π / 2. In the next stage, the measuring step is reduced and subsequent determination of the quasi - balancing characteristics near the found earlier maximum is performed. There is the possibility to set a width of the searched interval.

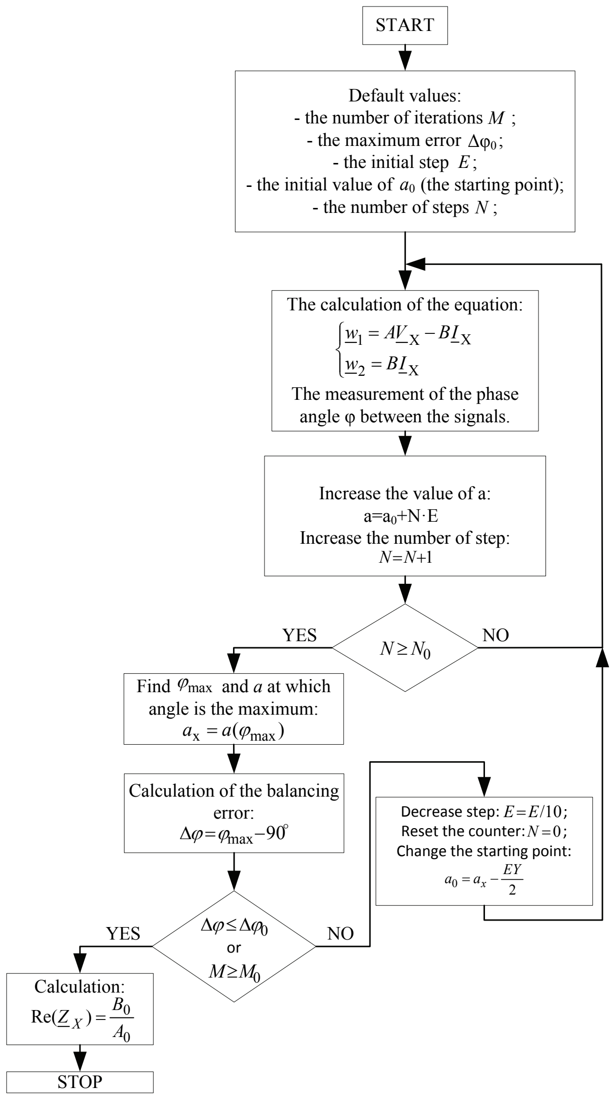

Fig. 8. Diagram of the algorithm of automatic quasi-balancing

The algorithm is repeated until the error of the quasi - balancing process has a value less than the predetermined settings or the user-specified number of cycles.

3. Results

The study aimed at examining the possibility of virtualization of the quasi-balanced system for measurement of the active component of impedance (resistance) and the accuracy of results. The objects of experimental studies were resistors with values ranging from 10 Ω to 360 kΩ. Due to a relatively low input resistance of the system, the resistors of greater values were not measured. A sinusoidal signal with the amplitude of 1 V and the frequency of 100 Hz obtained from a generator Rigol DG1011 was a test signal. 600 samples of the current and voltage signals at the sampling rate of 2 kHz were collected by means of the measuring card NI USB 6251. To determine the phase angle, there was used the algorithm based on short-term Fourier transform of a rectangular time window half-width of 200 samples. The result of the process taken to determine the state of quasi - balance was the average of 100 measurements.

To eliminate the resistance of leads, that resistance was measured: R_L= 0.0480 Ω, $u_A(R_L)$= 0.0017 Ω ($u_A(R_L)$ is a standard uncertainty of a measurement result) and then subtracted from the results. To verify the received results, there was used a precise Agilent E4980A RLC bridge. According to the manufacturer, it is characterized by the 0.05% basic accuracy and high repeatability of measurements [1].

The results obtained from the virtual instrument can be evaluated by comparing them to those obtained from the meter Agilent E4980A (Tab. 1). The measurement errors were compared to the results obtained using a commercially available instrument, which was assumed to be a model.

Tab. 1. Results of resistance measurements

Nominal value	Agilent E4980A		Virtual instrument		Errors
R, Ω	R, Ω	$u_A(R)$, Ω	R, Ω	$u_A(R)$, Ω	δ_R, %
10	9.9190138	0.0000075	9.9879	0.0075	0.69
20	19.91861333	0.000028	20.003	0.015	0.42
150	149.9214083	0.00017	149.819	0.082	-0.068
500	499.6373833	0.00012	499.42	0.24	0.044
1000	998.804625	0.0024	998.83	0.59	0.0025
1000	1000.0665	0.00014	999.62	0.58	-0.045
5900	5900.167	0.0011	5897.7	9.1	-0.042
20000	20002.917	0.0052	19962	41	-0.2
360000	359858.1	0.3	277900	500	-23

The measurement result of the 360 kΩ resistor (order of values comparable with the value of input resistance) was loaded with the error of 23%, that is why it was rejected in further considerations. The average relative error of resistance measurements by the virtual instrument was equal to 0.19%. The smallest errors were obtained in the range of 150 Ω to 5.9 kΩ.

The measurement uncertainties obtained from the quasi - zero method were, on average, about three orders worse than those obtained with the LCR meter Agilent.

4. Conclusions

The paper presents the possibility to realize a quasi - balanced system in the form of a virtual instrument for measuring the active component of impedance. The resistance measurement is made in an algorithmic way on digital signal samples, making it possible to simplify the hardware part. The software processing gives you the ability to easily adapt the operation of the meter.

The resultant resistance measurement accuracy at the level of 0.19%, can be considered good, regardless of the class of the used hardware. Due to the relatively low value of the input resistance of the system (at the level of 1 MΩ), it is not recommended to measure a resistance of a comparable value. Such a low input resistance can be caused by poor insulation of the connecting cables, the resistance of the circuit leakage of PCBs, housing or influence of the input resistance of the measuring card. A further detailed study is necessary to determine it.

The application of a specific measuring card, a current/voltage converter and a measuring circuit affects the accuracy of the resistance measurement results directly. In order to improve the metrological characteristics, it is necessary to use a buffer system of the test object from the meter having a high input resistance, and components that do not cause distortion of the signals. When measuring low values of resistance, one should include the resistance of leads in the measurement result.

The influence of the algorithm parameters measuring the phase angle for the phase shift measurement results are presented in publications [2, 7, 9]. The analysis of the properties of the measurement channel with analog-to-digital converters is known and described in detail in the literature [8]. For advanced measurements, the key aspect is to take into account the parameters of the algorithm and the measurement channel. This paper presents the idea of an automatic quasi-balanced system to measure the active component of impedance and such errors are not so important, so the authors have not considered these issues so far. Further research will be aimed at improving the metrological characteristics of the system. The influence of the parameters of the phase angle measuring algorithm and the data acquisition system on the measurement results of impedance components will be analyzed.

A measuring instrument using the quasi - zero method can be a part of the system for checking the insulation of cable lines. The proposed solution seems to be competitive in financial terms because its hardware part is limited to the minimum (measuring signal processing is performed in software). Easy archiving of the obtained results helps tracking the changes of parameters in time caused by e.g. dampness or aging processes. The quasi - balanced system gives you the ability to measure many quantities without the need to change the hardware configuration, e.g. the phase angle, the active and reactive component of the impedance, the dielectric loss factor tan δ. The advantages of these methods hold promise for their further development.

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