A MICROCOMPUTER CONTROLLED HIGH-VOLTAGE CAPACITANCE AND DISSIPATION FACTOR MEASURING BRIDGE

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Abstract

A self-balancing bridge to measure the capacitance and the dissipation factor of high-voltage insulating materials has been developed.

The bridge uses a current comparator working in current transformer mode, thus the convergence trajectory is linear, which makes the balancing procedure simple and fast.

The accuracy of the bridge is better than 10^{-4} for capacitance and $2 \cdot 10^{-5}$ for tgδ measurements. The measuring speed of the instrument is about one measurement pro second.

Introduction

A high voltage, fully automatic capacitance and dissipation factor measuring bridge was developed at the Department. Instruments like this are frequently used in the test of insulating materials, cables, transformers, generators etc. The basic element of our bridge is a current comparator working in current transformer mode thus the convergence trajectory is linear, which makes the balancing procedure simple and fast. This structure was proposed by Petersons [1] in 1964. The Swiss firm *Tettex AG Instruments* also developed a measuring bridge in 1983, which has the same structure. [2]

The High-Voltage Self-Balancing Bridge

Figure 1 shows the block diagram of the bridge. It is easy to see that both the current comparator and the current transformer have an autonomous analogue feedback control loop to assure that the inductions in the cores will be equal to zero. So the equation for current and turns is as follows:

$$\mathbf{I}_x N_x = \mathbf{I}_N N_N + \mathbf{I}_K N_K + \mathbf{I}_i N_i. \tag{1}$$

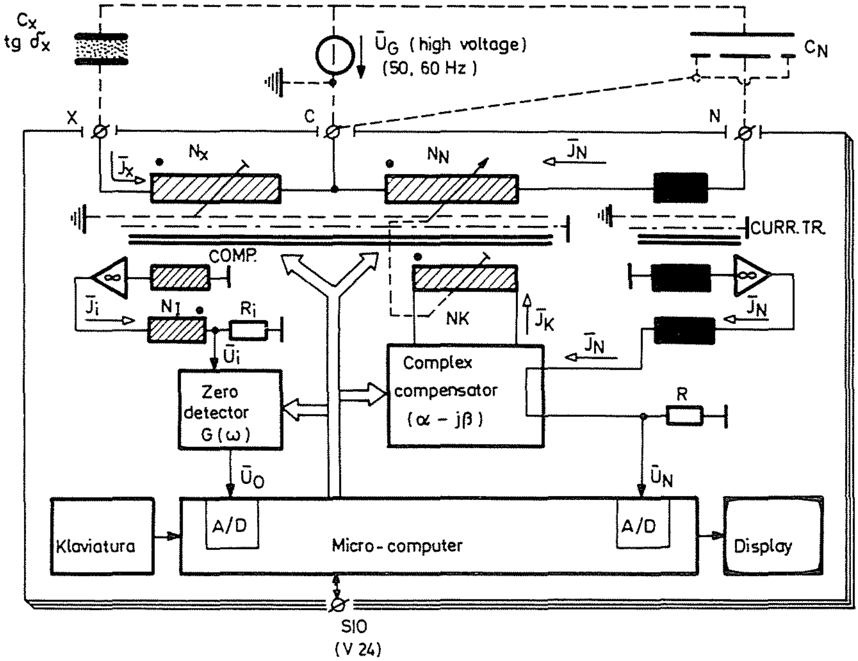

Fig. 1. Block diagram of the bridge

As the inductions of the cores are equal to zero and, neglecting the resistances of the windings, there are no voltages between the leads of the windings, the currents can be calculated as follows:

$$\mathbf{I}_x = \mathbf{U}_G(G_X + j\omega C_X) = \mathbf{U}_G \cdot \omega C_x(\operatorname{tg}\delta_x + j)\,,$$

$$\mathbf{I}_N = \mathbf{U}_G\; j\omega C_N\,,$$

$$\mathbf{I}_K = \mathbf{I}_N(\alpha - j\beta) = \mathbf{U}_G j\omega C_N(\alpha - j\beta)\,,$$

and

$$\mathbf{U}_0 = G_0 \mathbf{g}(\omega) R_i \mathbf{I}_i\,,$$

where G_0 is the variable gain of the zero detector and $\mathbf{g}(\omega)$ is the transfer function of its filter.

From (1) follows:

$$\frac{\mathbf{U}_o}{\mathbf{U}_N} = G_0 \cdot \mathbf{g}(\omega) \frac{R_i}{R} \frac{1}{N_i} \left[\frac{C_x}{C_N} (\operatorname{tg}\delta_x + j) N_x - N_k\beta - j(N_N + N_K\alpha) \right]. \tag{2}$$

When the bridge is in balanced state, the output voltage of the selective zero detector is equal to zero ($\mathbf{U}_0 = 0$), thus from (2) follows:

$$C_x = C_N \frac{1}{N_x} (N_N + \alpha N_K), \tag{3}$$

$$\operatorname{tg} \delta_x = \frac{N_K \cdot \beta}{N_N + \alpha \cdot N_K}. \tag{4}$$

In practice N_K is approximately equal to N_N, so we obtain:

$$C_x \cong C_N \frac{N_N}{N_X} (1 + \alpha),$$

$$\operatorname{tg} \delta_x \cong \frac{\beta}{1 + \alpha}.$$

N_x can be set to 1, 10, 100 or 1000 turns so it sets the range of C_x. N_N is composed of three turn decades with a resolution of one turn. The coarse balancing is realized by the varying numbers of the turns of these windings.

The fine balancing is effected by N_K winding and the current of it is proportional to the current of a standard capacitor and controlled by the complex compensator. $\alpha_{max} = 1$ and its resolution is better than 10^{-3}. The $\beta_{max} = 2$, its highest resolution is about $5 \cdot 10^{-6}$ and it is controlled in three ranges.

Since C_N and R are known, $|\mathbf{U}_N|$ and ω are measured by the microcomputer, so $|\mathbf{U}_G|$ is also calculable:

$$|\mathbf{U}_G| = \frac{|\mathbf{U}_N|}{\omega} \frac{1}{R\, C_N}. \tag{5}$$

The Balancing Process

The (2) balancing equation can be written in the following form (here we supposed that N_N is approximately equal to N_K)

$$\mathbf{Z} = G_0[\mathbf{A} N_x - \mathbf{B}(\beta + jN_N(1 + \alpha))], \tag{6}$$

Where **Z**, **A** and **B** are complex quantities.

$\mathbf{Z} = x + jy$ is measured by the microcomputer, the complex parameters **A** and **B** are unknown. To determine the complex values of parameters **A** and **B**, the balancing process starts with two measurements.

a) First the microcomputer sets $N_X = 1$ (i.e., the maximal capacitance measuring range) sets $G_0 = 1$, $N_N = 0$, $\alpha = 0$, $\beta = 0$ and by means of an A/D converter it determines the real and imaginary parts of the complex quantity **Z**

(x_1, y_1). From these values it computes the value of **A:**

$$\mathbf{A} = a_r + ja_i = x_1 + jy_1 \tag{7}$$

b) In the second step the microcomputer sets $N_x = 1$, $G_0 = 1$, $N_N = 1000$, $\alpha = 0$, $\beta = 0$ and measures the real and imaginary parts (x_2, y_2) of **Z.** From (6) and (7) follows that the value of **B** is:

$$\mathbf{B} = b_r + jb_i = 10^{-3}(x_1 - x_2) + j\,10^{-3}\,(y_1 - y_2) \tag{8}$$

c) As a results of the above process the parameters **A** and **B** are known, thus the program can determine the point (β_0, N_{N0}) of the coarse balancing where the **Z** becomes equal to zero (and α is still equal to zero).

From (6) follows:

$$N_{N0} = N_X \frac{a_i b_r - a_r b_i}{b_r^2 + b_i^2}, \tag{9}$$

$$\beta_0 = N_x \frac{a_r}{b_r} + N_{N0} \frac{b_i}{b_r}. \tag{10}$$

If $N_X = 1$ and N_{N0} is too small, the program sets the range winding N_X to the higher value where N_{N0} is $100 < N_{N0} < 1000$. This is the autoranging process.

After N_X, N_{N0} and β_0 are determined and set by the microcomputer, the autoranging and the coarse balancing are completed.

d) For fine balancing the microcomputer increases the zero detector sensitivity and measures the real and imaginary parts (x_3, y_3) of the remaining Δ**Z.** From (6) the convergence equation follows for small deviations:

$$\begin{bmatrix} \dfrac{\Delta X}{G_0} \\ \\ \dfrac{\Delta y}{G_0} \end{bmatrix} = \begin{bmatrix} -b_r & b_i \\ -b_i & -b_r \end{bmatrix} \cdot \begin{bmatrix} \Delta\beta \\ \Delta N \end{bmatrix} \tag{11}$$

and from (11) follows:

$$\begin{bmatrix} \Delta\beta \\ \Delta N \end{bmatrix} = \begin{bmatrix} -\dfrac{b_r}{D} & -\dfrac{b_i}{D} \\ \\ \dfrac{b_i}{D} & -\dfrac{b_r}{D} \end{bmatrix} \cdot \begin{bmatrix} \dfrac{\Delta x}{G_0} \\ \\ \dfrac{\Delta y}{G_0} \end{bmatrix} \tag{12}$$

where

$$D = b_r^2 + b_i^2 .$$

From $\Delta x = x_3$, $\Delta y = y_3$ and the equation (12) follow the required corrections of the bridge variables:

$$N_N(1+\alpha) = N_{No} - \Delta N\,,$$
$$\beta = \beta_0 - \Delta\beta$$

Hereafter, the microcomputer sets these new balancing variables.

e) If the ΔN, $\Delta\beta$ corrections are larger than the resolution value of the bridge, the program goes back to point *d)* and computes the sets of the next approximation. Otherwise it terminates the balancing process and evaluates (3), (4), displays the values of the capacitance and the dissipation factor of the tested object.

Conclusions

From *Fig. 1.* it can be seen that the electronic circuits are galvanically separated from the high-voltage circuits of the bridge and the effect of the coupling capacitances between the windings is supressed by a double shielding technic, thus reducing the possibility of damage caused by a breakdown in the test object [2].

The resolution of the displayed values are 10^{-5}, but the resolution of the bridge is better, since it is determined by the resolution of the complex compensator. The accuracy of the bridge is limited by the accuracy of the current comparator, and by the resistances of the windings (N_X, N_N) and that of the measuring cable.

The resistance of the cable can be given from the keyboard, the resistances of windings are automatically assigned according to the value of windings, thus the microcomputer automatically corrects the displayed values. Consequently the accuracy is higher than 10^{-4} for capacitance and $2 \cdot 10^{-5}$ for tg δ measurements.

The microcomputer controlled balancing process uses a I-type control loop, which results in full balance. The time of full balancing takes about 5 seconds, but in balanced state it follows any changes by the speed of one measurement pro second.

The microcomputer of the bridge can communicate with an external computer, via an RS-232 serial interface and it also contains a self-test program to assure the testing of the whole instrument.

References

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