LOW-INDUCTION THREE-PHASE WATTMETER
FOR COMMERCIAL AND HIGHER FREQUENCIES

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In the Electrochemical Institute of the USSR Academy of Sciences the authors developed a multirange low-induction wattmeter for the range of 50-2000 cps for measuring power by the equal temperature method [1].

In the above method of measurement the thermal effect which is proportional to the measured power is compared with a similar thermal effect produced by a direct current. The equality of powers is gauged by the equality of temperatures.

The balance is indicated by two metallic heated resistors ($R_1$ and $R_2$) placed in air, each having three electrically insulated heaters. The characteristics of the heater resistors are similar but can be of an arbitrary type. The measuring process is carried out by means of three heaters of the second heated resistor ($R_2$) and two heaters of the first resistor ($R_1$); the third heater is only required for constructional symmetry and serves as a spare.

Let us now determine the conditions under which the heated resistor with several electrically insulated heaters will be equally sensitive to the power dissipated in any of them, including the power dissipated in the corresponding control resistors of the heaters.

Let us assume that in a heated resistor with several heaters the ohm-ampere characteristics $R = F(I)$ have a difference $\eta$ expressed in terms of the resistance increment above its value at a nominal heating current. The above value can be reduced to $m$ if the heaters are shunted by resistors and it is assumed that current $I$ is the total current before it divides. The resistances of the two branches, as a rule, are not equal, and therefore the heated resistance possesses a different sensitivity with respect to the voltage at the branching.

If the building-out resistance is connected in series with the two branches and the heater circuit resistances are equalized, the relative deviation of the volt-ohm characteristics of heated resistors $R = F(U)$ will also be equal to $m$. Voltage $U$ represents the total voltage across the building-out resistor and the branching. It is obvious that the relative deviation of the heater resistance characteristic $R = F(P)$, where $P = UI$, will in this case also be equal to $m$. In fact, if the maximum absolute deviation of the ohm-ampere characteristics of the heater resistances is equal to $I$ ohm and occurs at a current $I = I_1$ and a voltage $U = U_1$, the maximum absolute deviation of the ohm-watt characteristics will occur at the power of $P_1 = U_1 I_1$ and will also be equal to $I$ ohm. Considering that it is possible to provide an equality of the heater circuit resistances with high precision, the relative deviation in the ohm-watt characteristics of the heater resistances will in practice be equal to the relative deviation of their ohm-ampere characteristics.

The conditions for which two different heater resistors have equal ohm-watt characteristics are wholly identical.

The heater resistances differ considerably from each other in their value; therefore the difference in their ohm-watt characteristics is relatively large. However, the temperature of the heater resistances has the same relation to the power dissipated in their heater circuits. The deviation of these characteristics is equivalent to that of ohm-watt or ohm-ampere characteristics of one heated resistor with several heaters.

In heated resistors of the IEM type deviations in ohm-ampere characteristics with a shunt do not exceed $m = 0.02 - 0.03\%$, and without a shunt $n = 0.30 - 0.35\%$. For relatively rough measurements heaters need not be shunted, but heater building-out resistances remain necessary.

The wattmeter we have developed consists of two single-phase converters and a measuring bridge with automatic balancing. The converters are connected in a two-wattmeter circuit (Fig. 1). Each converter consists of a voltage transformer, a shunt and two heaters.

By means of adjustable building-out resistors in the heaters (not shown in Fig. 1) the following condition can be met:

$$R_{LT} = R_{ST} = R_{HE} = R_{EF} = R.$$
Through heater 1 of the first converter a current will flow equal to

\[ i_1 = \frac{1}{R} \left( \frac{u_{ab}}{2k} + i_a \frac{R_s R}{2R_s + R} \right), \]

and through heater 3 a current equal to

\[ i_3 = \frac{1}{R} \left( \frac{u_{ab}}{2k} - i_a \frac{R_s R}{2R_s + R} \right), \]

In the second converter the current flowing through heater 2 will similarly be equal to

\[ i_1' = \frac{1}{R} \left( \frac{u_{cb}}{2k} + i_c \frac{R_s R}{2R_s + R} \right), \]

and through heater 4 it will be equal to

\[ i_2' = \frac{1}{R} \left( \frac{u_{cb}}{2k} - i_c \frac{R_s R}{2R_s + R} \right), \]

where \( u_{ab}, u_{cb}, i_a \) and \( i_c \) are the linear voltages and currents; \( k \) is the transformer ratio; \( R_s \) is the resistance of the shunt.

The mean powers dissipated in resistances \( R_{LT}, R_{HE}, R_{ST} \) and \( R_{FE} \) amount respectively to

\[ P_1 = \frac{1}{TR} \int_0^T \left( \frac{u_{ab}}{2k} + i_a \frac{R_s R}{2R_s + R} \right)^2 dt; \]

\[ P_3 = \frac{1}{TR} \int_0^T \left( \frac{u_{ab}}{2k} + i_a \frac{R_s R}{2R_s + R} \right)^2 dt; \]

\[ P_2 = \frac{1}{TR} \int_0^T \left( \frac{u_{ab}}{2k} - i_a \frac{R_s R}{2R_s + R} \right)^2 dt; \]

\[ P_4 = \frac{1}{TR} \int_0^T \left( \frac{u_{ab}}{2k} - i_a \frac{R_s R}{2R_s + R} \right)^2 dt, \]

where \( T \) is the period of the alternating current.

The difference of powers \( (P_1 + P_2) - (P_3 + P_4) \) is directly proportional to the mean value of the measured power \( P_x \):

\[ (P_1 + P_2) - (P_3 + P_4) = \frac{2R_s}{kT(2R_s + R)} \int_0^T (u_{ab}i_a + u_{cb}i_c) \, dt = \]

\[ = \frac{2R_s P_x}{k (2R_s + R)} = k_i P_x, \]

where

\[ k_i = \frac{2R_s}{k (2R_s + R)}. \]

The above expression does not depend on the nature of the heater resistances, hence not on their construction, their properties or the composition of the surrounding medium, etc.

The difference of powers \( (P_1 + P_2) - (P_3 + P_4) \) can be measured by a balancing method. For this purpose heater resistor \( R_5 \), whose temperature during measurements is lower than that of resistor \( R_4 \), is provided with an additional heater 5. For a certain value of the current flowing through the additional heater the temperature of both heater resistors will be equal; at the same time their total powers dissipated in the heater and additional resistors of the first and second heated resistances will be equal. Hence, \( P_{ad} = k_i P_x \), where \( P_{ad} \) is the power dissipated in heater 5 and in its building-out adjustable resistor.