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# Calibration of current measuring network for wet contact of leakage current tester

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***Abstract* –In this paper, the transfer characteristics of current measuring network for wet contact are determined, the current measuring network is calibrated with the method of high frequency voltage source. It has been verified that the measurement results consist with the requirements of IEC 61010-1.**

***Keywords* –Leakage current tester, current measuring network for wet contact, transfer characteristics, leakage current expectations**

## I. INTRODUCTION

Leakage current testers are widely used in electrical inspection as a kind of security measurement instrument. By simulating the human body impedance network and its contact with the actual electrical equipment, the current measurement circuit can provide security information in detail according to the value of the real time leakage current.

Most electrical equipment works on power supply under the line frequency, and leakage current tester is typically calibrated under the same work situation. Besides, with the widespread use of electronic switch technology in the power supply system and corresponding equipment, high frequency harmonic voltage and current in the circuit are also harmful to human body and need draw public concern. So the leakage current measurement is not only limited to the line frequency, but also the high frequency signal should also be taken into consideration [1-4].

Three current measuring networks have been defined by IEC 60990, measuring networks for perception or reaction, let-go, and electrical burns [5]. Current measuring network for wet contact has been defined by IEC 61010-1, and used to check the leak performance of the instrument in wet conditions [6].

According to measuring networks specified in IEC 60990, the measuring networks of the leakage current testers have been calibrated with the high frequency voltage source method and high frequency current source method, since the transfer characteristics have been given in Appendix L of IEC 60990. The current measuring network for wet contact of the instruments specified in IEC 61010-1 cannot be calibrated because of unknown transfer characteristics.

## II. CURRENT MEASURING NETWORK FOR WET CONTACT

Current measuring network for wet contact specified in IEC 61010-1 is shown in Fig. 1, and $R_1$ and $C_1$ model the total skin impedance of two points of contact, and $R_2$ models the internal impedance of the human body.

This network is similar to the current measuring network for electrical burns specified in IEC 60990, and the difference is that the resistor $R_1$ is replaced by 1500 Ω with 375 Ω, because of the total skin impedance is reduced in wet conditions.

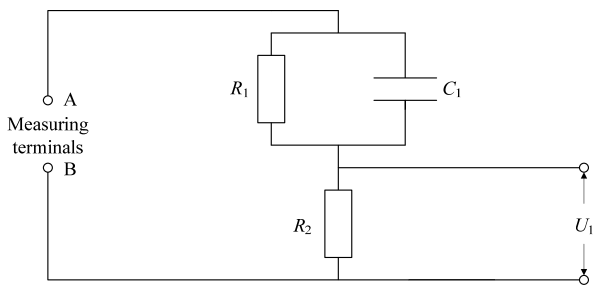


*Fig. 1. Current measuring network for wet contact*

($R_1$ : 375 Ω, $R_2$ : 500 Ω, $C_1$ : 0.22 μF)

The transfer characteristics of the network are prerequisites for calibration, we get the transfer characteristics of current measuring network for wet contact by simulation with MATLAB. The transfer characteristics are shown in Table 1.

In order to verify the correctness of the simulation results, the transfer characteristics of the current measuring networks for electrical burns have also been simulated since the two networks are similar, and compared with the transfer characteristics specified in IEC 60990. The transfer characteristics are shown in Table 1.

*Table 1. The transfer characteristics of current measuring network for wet contact and for electrical burns*

| Frequen-cy Hz | Input voltage per milliampere indication | | |
|---|---|---|---|
| | Current measuring network for wet contact | Current measuring network for electrical burns | |
| | Simulation results K | Simulation results | IEC 60990 |
| 20 | 0.875 | 1.998 | 2.00 |
| 50 | 0.875 | 1.990 | 1.99 |
| 60 | 0.875 | 1.986 | 1.99 |
| 100 | 0.874 | 1.961 | 1.96 |
| 200 | 0.872 | 1.857 | 1.86 |
| 500 | 0.856 | 1.434 | 1.43 |
| 1 k | 0.810 | 0.979 | 0.979 |
| 2 k | 0.706 | 0.675 | 0.675 |
| 5 k | 0.563 | 0.533 | 0.533 |
| 10 k | 0.518 | 0.509 | 0.509 |
| 20 k | 0.505 | 0.502 | 0.502 |
| 50 k | 0.501 | 0.500 | 0.500 |
| 100 k | 0.500 | 0.500 | 0.500 |
| 200 k | 0.500 | 0.500 | 0.500 |
| 500 k | 0.500 | 0.500 | 0.500 |
| 1000 k | 0.500 | 0.500 | 0.500 |

As seen from Table 1, the simulation results of the current measuring network for electrical burns are agreed with the values from IEC 60990 at frequenceis from 20 Hz to 1 MHz (ignoring the factor of data revision). This agreement will also prove the correction of the simulation results of the measuring network for wet contact.

## III. CALIBRATION METHOD

Leakage current measuring network is usually included in the measurement circuit, and the output of the network is connected directly to sampling and display circuit. Based on the method of high frequency voltage source, this measuring network can be calibrated by applying the ac voltage output to measuring terminals at working frequencies.

According to the transfer characteristics of current measuring network for wet contact, when the high frequency voltage source applies AC 1V voltage, the measurement results of the leakage current expectations under different frequency have been obtained from Table 1 and shown in Table 2.

*Table 2. Measurement results of the leakage current expectations*

| Frequency Hz | Input voltage V | Leakage current expectations $I_0$ mA |
|---|---|---|
| 20 | 1.000 | 1.143 |
| 50 | 1.000 | 1.143 |
| 60 | 1.000 | 1.143 |
| 100 | 1.000 | 1.144 |
| 200 | 1.000 | 1.147 |
| 500 | 1.000 | 1.168 |
| 1 k | 1.000 | 1.235 |
| 2 k | 1.000 | 1.416 |
| 5 k | 1.000 | 1.776 |
| 10 k | 1.000 | 1.931 |
| 20 k | 1.000 | 1.980 |
| 50 k | 1.000 | 1.996 |
| 100 k | 1.000 | 2.000 |
| 200 k | 1.000 | 2.000 |
| 500 k | 1.000 | 2.000 |
| 1000 k | 1.000 | 2.000 |

The specific measurement circuit is shown in Fig. 2, connect the voltage output of high frequency voltage source to the measuring terminals of the network, the coaxial cable is used to reduce interference.


*Fig. 2. The specific measurement circuit*

The displayed value of leakage current tester is obtained by applying AC voltages of different frequencies to the network.

The relative error of leakage current is calculated by (1).

$$\gamma = \frac{I_x - I_0}{I_0} \times 100\ \% = \frac{I_x - V/\mathrm{K}}{V/\mathrm{K}} \times 100\ \%\ , (1)$$

where $I_x$ is the displayed value of leakage current tester in mA, $I_0$ is leakage current expectations(shown in Table 2) in mA, $V$ is input voltage for measuring network in V, K is input voltage per milliampere indication (shown in Table 1), V/mA.

## IV. CALIBRATION RESULTS AND UNCERTAINTY

The ST5541 leakage current tester manufactured by HIOKI is an instrument for household appliances safety measurement with multiple current measuring networks, and the current measuring network for wet contact is one of them.

Using FLUKE 5720A as a high frequency voltage source, the current measuring network for wet contact of ST5541 is calibrated by applying AC voltages of different frequencies to the network. Calibration results are shown in Table 4.

As seen from Table 4, the maximum relative error of current leakage is -2.3%, and much smaller than the required value of 10%.

The uncertainty budgets of measurement results include the following quantities:

$u_1$ display current resolution of the leakage current tester

$u_2$ voltage output of high frequency voltage source

According to (1) , $c_1$ and $c_2$ (sensitivity coefficient of $u_1$ and $u_2$) are as follows:

$$c_1=1, (2)$$

$$c_2=-\frac{1}{\mathrm{K}}\ , (3)$$

The combined standard uncertainty is calculated by (4) since $u_1$ and $u_2$ are uncorrelated.

$$u_c = \sqrt{(c_1 u_1)^2 + (c_2 u_2)^2}\ , (4)$$

The extended uncertainty is calculated by (5).

$$U = k \bullet u_c\ , (5)$$

where $k$ is coverage factor, and $k$=2.

For example, the evaluation of measurement uncertainty at the 1000 kHz is shown in Table 3.

*Table 3. The evaluation of measurement uncertainty at the 1000 kHz*

| | | Sensitivity coefficient |
|---|---|---|
| $u_1$ | 0.00029mA | $c_1$=1 |
| $u_2$ | 0.0012V | $c_2$=-2mA/V |
| $u_c$ | 0.0025mA | / |
| $U$ | 0.005mA | / |
| $U_{rel}$ | 0.3% | / |

And so on , by calculating the combined standard uncertainty and extended uncertainty, the relative extended uncertainty of each measurement points are shown in Table 4.

*Table 4. Calibration results of current measuring network for wet contact of the leakage current tester*

| Frequency<br>Hz | $I_x$<br>mA | $I_0$<br>mA | Relative Error<br>% | Extended Uncertainty<br>% |
|---|---|---|---|---|
| 20 | 1.120 | 1.143 | -2.0 | 0.1 |
| 50 | 1.122 | 1.143 | -1.8 | 0.1 |
| 60 | 1.123 | 1.143 | -1.7 | 0.1 |
| 100 | 1.125 | 1.144 | -1.7 | 0.1 |
| 200 | 1.128 | 1.147 | -1.7 | 0.1 |
| 500 | 1.149 | 1.168 | -1.6 | 0.1 |
| 1 k | 1.214 | 1.235 | -1.7 | 0.1 |
| 2 k | 1.392 | 1.416 | -1.7 | 0.1 |
| 5 k | 1.736 | 1.776 | -2.3 | 0.1 |
| 10 k | 1.890 | 1.931 | -2.1 | 0.1 |
| 20 k | 1.946 | 1.980 | -1.7 | 0.1 |
| 50 k | 1.964 | 1.996 | -1.6 | 0.1 |
| 100 k | 1.965 | 2.000 | -1.8 | 0.1 |
| 200 k | 1.963 | 2.000 | -1.9 | 0.1 |
| 500 k | 1.957 | 2.000 | -2.2 | 0.2 |
| 1000 k | 1.955 | 2.000 | -2.3 | 0.3 |

## V. CONCLUSIONS

In this paper, we simulated the transfer characteristics of current measuring network for wet contact and verified the correctness of the results by comparison with the transfer characteristics given in Appendix L of IEC 60990. The current measuring network is calibrated with the method of high frequency voltage source. It has been verified that the measurement results are in well agreement with the requirements of IEC 61010-1. Based on this measurement setup, the current measuring network for wet contact can be calibrated.

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