MEASUREMENT OF SMALL CAPACITANCE AND INDUCTANCE INCREMENTS BY THE PERIODIC COMPARISONS METHOD

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In practice it is often necessary to test with high precision small increments of L and C at high frequencies. This occurs particularly in evaluating the temperature coefficients of inductors and capacitors and in electrical measurements of nonelectrical quantities by means of high-frequency capacitive and inductive transducers. The application of balanced bridge circuits which are suitable for testing with high precision at low frequencies is impeded by the requirement for protecting the bridges from stray couplings at high frequencies. Therefore, for precise testing of L and C at high frequencies, double oscillatory circuits, or oscillatory circuits operating with a substitution method are used.

Double oscillatory circuits (with a reference and measuring oscillator) have a limited precision due to the instability of their components, unless they are appropriately recalibrated during their operation. The recalibration is often undesirable, especially in continuous testing. Circuits operating with the substitution method are highly precise, but their manual operation makes them unsuitable for continuous testing of L and C increments.

Oscillatory circuits operating with the periodic comparison method (automatic substitution) have, as compared with the manual circuits, several advantages which can be reduced to the following.

1. Automatic switching reduces considerably the time required for a single cycle of this operation, thus raising the precision of testing by reducing the effect of the circuit parameter instabilities.

2. Oscillatory circuits which operate with the automatic substitution method do not contain any adjustments, and therefore, they are suitable for testing varying values of L and C.

3. It is possible with automatic substitution to check the amplitude and frequency of the measuring oscillator's voltage simultaneously with testing two parameters consisting of inductance and capacitance, or reactance and Q-factor.

The principle of operation of oscillatory circuits which operate with the automatic substitution method, is shown in Fig. 1. The tested and reference inductors, whose small difference it is required to measure, are denoted by \( L_x \) and \( L_r \). The compared inductors are connected sequentially by switch S to measuring oscillator \( G_1 \) as elements of its oscillator circuit. Packets of high-frequency oscillations then appear at the oscillator's output whose frequency is proportional to the values of \( L_x \) and \( L_r \) and are equal respectively to \( f_{1x} \) and \( f_{1r} \) (Fig. 2a).

The packets' repetition frequency is equal to switching frequency \( f_s \).

The packets are fed from oscillator \( G_1 \) output to mixer \( M_x \) which is fed simultaneously with frequency \( f_z \) from reference oscillator \( G_2 \). The voltage packets of difference frequencies (see Fig. 2b)

\[
\begin{align*}
I_{dx} &= f_{1x} - f_z, \\
I_{dr} &= f_{1r} - f_z
\end{align*}
\]

are fed from the mixer to frequency discriminator FD whose turnover frequency is set in its adjustment to \( f_{do} \). The detector's output voltage is determined during the operation by the deviation of frequencies \( I_{dx} \) and \( I_{dr} \) from \( f_{do} \), and in the best case they have the shape shown in Fig. 2c. In this case the useful signal is equal to

\[
U_m = S_t \cdot (f_{dx} - f_{dr}) = S_t \cdot \Delta f,
\]

and, since for small variations of \( L_x \) it is possible to consider that \( \Delta f = \Delta L_x f_{1x} / 2 L_x \cdot f_{1x} \), we find that

where $S_t$ is the frequency detector's transfer factor; $\Delta L_x / L_x$ is the relative variation of the tested inductance.

The detector's useful signal is registered on indicator $I$ (see Fig. 1). The inductor instrument can be calibrated directly in deviation units of the tested from the reference quantity.

In order to raise the circuit sensitivity, it is necessary to select the detector's turnover frequency $f_{do}$ considerably lower than $f_{ix}$. However, this increases the effect of the circuit components' instability which, in the course of operation, makes the dc component $U_0$ of the detector voltage attain values exceeding its linear characteristic, thus shifting the operating point into the nonlinear range. Moreover, even if $U_0$ does not exceed linearity, it affects the operation of the indicator, reducing the precision of testing. These circumstances point to the necessity of reducing the dc component of the detector voltage, which is attained by automatic frequency tuning, as shown in Fig. 1. The voltage is fed from the output of frequency discriminator $FD$ through filter $F$—which attenuates the alternating component—to the controlled reactance element $RE$ for changing the frequency of oscillator $G_2$ in a manner to reduce $U_0$.

The effect of the voltage amplitude instability of oscillators $G_1$ and $G_2$ on the precision of testing can be reduced by limiting the voltage fed to the input of the frequency discriminator.

The maximum error in testing increments by the above method can be evaluated from

$$
\delta = \frac{\Delta L_x L_x}{L_x} = \frac{1}{2} \left[ \frac{\Delta L_x}{L_x} + \frac{\Delta C_g}{C_g} + \frac{\Delta L_x}{L_x} \cdot \frac{\Delta U}{U} + 2 \frac{\partial K_1}{\partial r} \Delta r + 2 \frac{\partial K_2}{\partial r} \Delta r + \frac{2}{S_t f_{ix}} \frac{\delta_i}{i} + \delta_u \right],
$$

where $\Delta L_x$ is the absolute error; $\Delta L_x / L_x$ is the test inductance's relative variation which is subject to measurement; $\Delta C_g / C_g$ is the relative variation of the capacitance in the measuring oscillator's oscillatory circuit; $\Delta U / U$ is the relative variation of the amplitude in the voltage packets fed to the frequency detector's input; $K_1$ and $K_2$ are respectively the linear and nonlinear measuring oscillator's frequency corrections; $r$ is the direct resistance of the switch key; $\Delta r$ is the variation in the difference between the direct resistances of switch keys; $\delta_i$ is the absolute error of the frequency detector's indicator; $\delta_u$ are the unaccounted errors due to transient processes in the measuring oscillator produced by the reactances of switches, etc.

If $\Delta L_x / L_x = 0$, then expression (3) will indicate the maximum precision with which it is possible to judge the equality of the tested and reference reactances. This precision will be determined in the main by the constancy of the switch key's direct resistance and by the voltage indicator error. The error due to the voltage indicator will be small if product $S_t f_{ix}$ is made sufficiently large.

The switch keys may consist of polarized relay contacts, magnetically controlled contacts, or semiconductor point-contact diodes.