tion made it necessary to retain the length of the connections at high frequencies, which was done by the successive replacement of the four series-connected type D2-26 (for 2 dB) with type D2-32 (for 20 dB) attenuators. The discrepancy of the phase-amplitude characteristics for the phase meter tested as obtained by means of the types D2-26 and D2-32 attenuators and by the resistive and capacitive dividers did not exceed 0.1° in the range from 20 Hz to 10 MHz.

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TUBULAR BROADBAND SHUNT FOR MEASURING HIGH-CURRENT PULSES

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The use of existing shunt constructions [1-3] to investigate electrical discharges over the surface of a semiconductor in low-inductance discharge circuits of capacitive quenching systems meets with certain difficulties. A tubular shunt of manganin [3] has a time constant $\tau \approx 10^{-7}$ sec. However, the fundamental measurement error using this shunt refers not to its inductance but to the nonuniformity of the current distribution over the metal of the tube due to the surface effect. The shunts described in [1, 2] have a broad frequency range but have a large resistance which may be comparable with the resistance of the discharge channel. Circuits with differential amplifiers to eliminate the error due to the surface effect [4] are fairly complex and require the use of additional devices. Below we describe a shunt in which the error due to the surface effect is eliminated by reducing the thickness of the current-carrying part down to 15 μ.

The main part of the shunt, as shown in Fig. 1, consists of a ceramic tube 2 on the surface of which, previously metallized, a copper coating 1 is deposited. The resistance of the metallized surface is 1-4 Ω, while that of the copper coating is less than 0.01 Ω. A conductor 4 of cable (3 is the cable insulation), matched to the input of an oscilloscope, runs inside the tube and is soldered to one of its ends, while the screen 6 is soldered at the other end. Hence, the shunt is an extended matched coaxial line which reduces to a minimum the distortions in the signal shape and reduces pickup [3]. Leads 5 of copper foil are soldered to both ends of the tube.

The shunt was made with great care. The metallized tube must first be degreased before depositing the coating. The copper coating must be deposited in a regular layer since this ensures uniformity of the distribution of the current lines. The error in measuring a discharge current using a shunt of this construction is minimal.

The equivalent electrical circuit of the shunt is a series connection of an inductance and a resistance. The instantaneous value of the voltage drop across the shunt u_{sh} when a discharge current i flows through it is

$$u_{sh} = iR_{sh} + L_{sh}\frac{di}{dt} + F(i,f), \tag{1}$$

where R_{sh} is the shunt resistance, L_{sh} is the shunt inductance, F(i, f) is the voltage drop across the shunt due to the increase in the shunt resistance at high frequencies as a result of the surface effect, and f is the frequency.

It follows from Eq. (1) that the current strength can be found knowing u_{sh}, when

$$iR_{sh} \gg L_{sh}\frac{di}{dt} + F(i,f). \tag{2}$$

To satisfy condition (2) it is necessary to reduce L_{sh} and F(i, f). The inductance of a shunt of this construction can be estimated from the equation [5]

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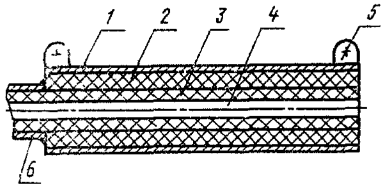

Fig. 1

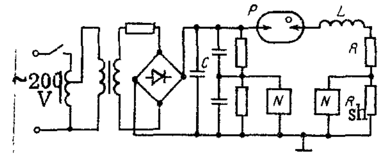

Fig. 2

$$L_{sh} = \mu_0 \, \delta l / 2\pi r,$$

where δ is the thickness of the copper coating, l is the length of the shunt, and r is the internal radius of the copper coating.

The shunt shown in Fig. 1 has the following dimensions: $l = 0.15$ m, $r = 3.3 \cdot 10^{-3}$ m, and $\delta = 15.4$ μ. The resistance of the shunt measured with an MOD-54 dc bridge is $R_{sh} = 0.00762$ Ω, and the inductance $L_{sh} = 10^{-10}$ H, whence the time constant of the shunt $\tau = L_{sh}/R_{sh} \approx 10$ nsec.

For this ratio between the thickness of the current-carrying part and the tube diameter the surface-effect coefficient is practically unity at frequencies up to 10^7 Hz. Hence, the voltage drop F(i, f) in (2) can be neglected; the value of L_{sh} di/dt is also small over this frequency range, i.e., condition (2) holes up to frequencies of $\sim 10^7$ Hz.

A sketch of the arrangement for determining the resistance of the shunt for different currents and frequencies is shown in Fig. 2. The circuit operates as follows. The storage capacitor C is charged from a high-voltage source. Breakdown of the switching discharger P occurs when the voltage on the capacitor becomes equal to the breakdown voltage of the discharger. When the discharger breaks down, the capacitor discharges through the inductance L and the resistors R and R_{sh}. The required frequency of the discharge process is governed by the values of C, L, and R.

The voltage drop across the measuring shunt $u_{sh}(t)$ and the voltage on the storage capacitor $u_C(t)$ were recorded using oscilloscopes with synchronized sweeps.

For the discharge of the capacitor through the resistance and the inductance the following relation holds:

$$u_C(t) = U_0 - \frac{1}{C}\int_0^t i(t)\,dt,$$

where U_0 is the initial voltage on the capacitor.

Taking into account the fact that $i(t) = u_{sh}(t)/R_{sh}$, we obtain

$$R_{sh} = \frac{\int_0^t u_{sh}(t)\,dt}{C\,[U_0 - U_C(t)]}, \tag{3}$$

The resistance of the shunt was calculated for any arbitrarily chosen instant of time t by graphical integration of the curve $u_{sh}(t)$; the voltage on the capacitor at this instant was found from the oscillogram of $u_C(t)$. For the working frequencies of the discharge current ($f = 1\text{–}10^3$ kHz) according to (3) $R_{sh} = 0.00793$ Ω.

Hence, the values of R_{sh} measured with the MOD-54 dc bridge and those calculated using (3) differ by not more than 5%.

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