Q-MEASUREMENTS IN SUPERCONDUCTING LEAD CAVITIES AT 800 MHz

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Most measurements on the high frequency behaviour of the surface resistance in the superconducting state have been carried out at frequencies beyond 2 GHz because of the handy cavity dimensions for such wavelengths.

For the application in superconducting linear accelerators one is interested in frequencies below 1 GHz where almost no experimental results are available. Experiments have therefore been started at Karlsruhe to obtain results for the surface resistance of lead at about 800 MHz.

Two different types of cavities have been used:

I. A cylindrical cavity quoted in the TE_{011} - mode at 800 MHz

The resonator dimensions were 53 cm diameter and 37,4 cm heigth with a resulting geometry factor $(G = \frac{R}{Q_o})$ of 755 Ω.
The plating technique was as described in [3], except that moving the parts during the process was impossible because of their size.

The Q-values have been determined according to the decrement method, both for lock-in operation [7] and with a stable driving oscillator [12]. Separate coupling devices for input and output of the cavity have been used, each consisting of a lead plated cut off tube of 10 mm diameter with a 5 mm Ø coupling loop connected to a conventional coaxial line. About 600 ltr of liquid Nitrogen were necessary for cooling down to 80^oK and about 100 ltr of liquid Helium to reach 4.2^oK.

A measurement of the Q-value at the output loop as a function of the loop position yielded an extrapolated [8] $Q_o = 1 \cdot 10^9$ at 4.2^oK, which corresponds to $R = 7.5 \cdot 10^{-7}\Omega$. Measurements at 2^oK led to $Q_o = 3 \cdot 10^9$ ($\tau = 0.6$ sec, $R = 2.5 \cdot 10^{-7}\Omega$).

II. A shorted coaxial line quoted in the TEM_{001}-mode at 750 MHz

The outer diameter of the coaxial was 15 cm, the inner 5,5 cm, the heigth 40 cm yielding a geometry factor of 84 Ω[9]. The two halves of the split resonator were lead plated with a rotating anode, which was shaped such as to yield equal current densities on the inner and outer conductor of the resonator. With the same method as for the TE-resonator an extrapolated Q_o-value of $2 \cdot 10^8$ has been obtained which corresponds to a surface resistance $R = 4.2 \cdot 10^{-7}\ \Omega$ at 4.2^oK. The TEM cavity has not been cooled down to 2^oK since it has mostly been used for sparking experiments [9].

The reasons for the higher surface resistance of the cylindrical resonator (TE-mode) compared to the coaxial resonator (TEM-mode) are probably due to difficulties with the electroplating of the big TE-resonator. The numbers quoted above are preliminary figures which can probably be improved.

The results have been plotted vs frequency together with the results obtained at higher frequencies by different groups [5][11][2][6][12].

To allow a comparison with theoretical results, the residual RF-resistance R_{Res} which in principle can be obtained from the measured temperature dependence of the surface resistance should be subtracted from the experimental values. This correction, however, has not been applied since the foundation for the usually applied methods seem to be rather weak, e.g. the assumption of a temperature independent residual resistance.

The plot indicates an averaged dependence $R \sim \omega^{1.77}$ for the uncorrected R-values. With R_{Res} subtracted the exponent would increase since the experiments indicate an increasing ratio $\frac{R_{Res}}{R(4.2^oK)}$ with decreasing frequency.

Comparison between theory and experimental results

For a comparison of the measured data with the BCS-theory [1], we choose the following parameters for lead:

London's penetration depth:

$\delta_L(0) = 370$ Å [13]

Coherence length: $\xi_o = 830$ Å [13]

Mean free path l: $l \lesssim 1\ \mu$ has been measured [2) 6)]

for electroplated lead. A value for l in a surface layer has not yet been measured. Therefore we have chosen three different values ($\frac{\pi}{2}\ \frac{\xi_o}{l} = 0$; 0,25 and 1) for the computations.

Gapparameter: To take into account the strong coupling in lead, we have replaced the coefficient $(\frac{\Delta(0)}{kT_c})_{WEAK} = 1.75$ in the temperature dependence of the gap (Mühlschlegel [14]) by $(\frac{\Delta(0)}{kT_c})_{Pb} = 2.16$. This value is consistent with $T_c = 7.2^oK$ and the directly measured gap of $\Delta(0) = 1.34 \cdot 10^{-3}$ eV [15) 16)]. The following properties of the energy gap of lead are not taken into account.

1) The anisotropy of the gap. Since it becomes negligible for small mean free path ($l \lesssim 3\xi_o$) only the gap $1.34 \cdot 10^{-3}$eV [16)] is effective.

2) Due to the strong coupling [17)] the temperature dependence of the surface resistance $R \propto e^{-\frac{\Delta(0)}{kT}}$ ($T < T_c/2$) may shifted $\frac{\Delta(0)}{kT_c}$ towards higher values.

The present knowledge does not, however, permit a available estimate of this effect. The theoretical results with these parameters are included in curves [1)-3)] of the figure.

There is obviously a qualitative agreement between theory and experiment, but it is obvious that the measured results are too low around 3 GHz.

A lowering of the curves by about 20 % can be obtained (curve 4 of the figure) if a value for the London penetration depth $\delta_L = 310$ Å [2)] is used instead of 370 Å [13)]. The value of 310 Å is not in contradiction to the penetration depth $\lambda = 390$ Å [13)]. Even this correction is insufficient. All $\simeq$ 50 % modifications of δ_L, ξ_o, l and $\frac{\Delta(0)}{kT_c}$ do practically only result in a parallel shift of the lines (cf. figure). The measurements seem, however, to indicate a stronger frequency dependence, $R \sim \omega^{1.9}$ as is expected for $\frac{\delta_L}{\xi_o} << 1$ (Pippard's limiting case).

Similar deviations, i.e. experimental values of R smaller than theoretical ones in the GHz-range, have also been found for Sn[2)] and In[4)]. This seems to be a general feature of the BCS-theory and is possibly due to surface effects since the main absorption is effected in a layer as thin as about 500 Å.

A better agreement between theory and experiment has to wait for a better understanding of the surface and certainly also for more precise experimental results. We attempt to obtain such results.

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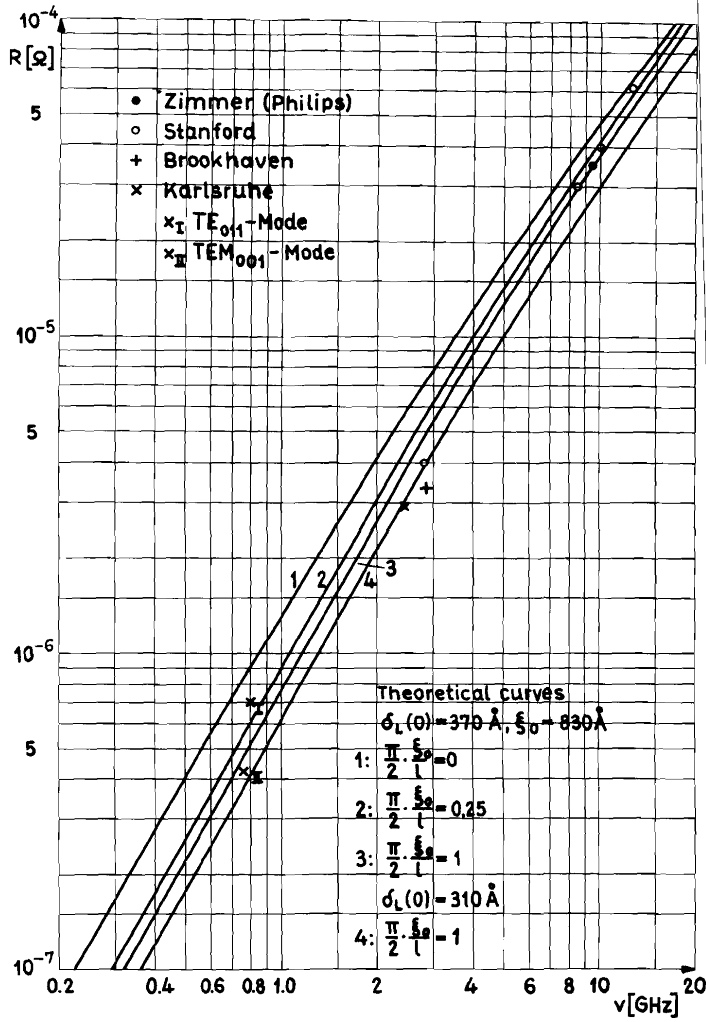

Figure 1 - Surface Resistance, Pb (4.2°K)