COAXIAL CAVITY FOR MEASURING CONDUCTIVITY OF MATERIALS AT LOW TEMPERATURES

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For comparison of different samples of niobium a coaxial cavity is proposed with different materials used for the envelope and the inner conductor. The difference in the specific conductivity can be found by measuring the quality factor Q of the cavity with the same or with different materials for these parts of the cavity. The cavity will be more sensitive to the change of the specific conductivity σ of the inner conductor if the most part of losses is happening on the inner conductor. If the value of σ of the inner conductor is changed by 10 %, the maximal change of Q is about 5 % because of well known dependence of Q on σ. But this is the limiting case when all the losses are due to the inner conductor only. The actual value will be less, and we need to increase it as much as possible but staying in the reasonable physical limits: not losing the high Q that should be in the region inherent to superconductivity, and not losing the electric and mechanical strength of the design.

Let us introduce the parameter $p = \dfrac{\Delta Q/Q}{\Delta\sigma/\sigma}$ that corresponds to the described task. Let the value of $\Delta\sigma/\sigma = (\sigma_{in} - \sigma_{out})/\sigma_{out}$, the relative change of the specific conductivity between the inner and outer parts, be 10 %. We will optimize the shape of the cavity so that the value of $\Delta Q/Q$ (or of p) will be maximal. For the said value of $\Delta\sigma/\sigma$, the value of p will have an absolute maximum of 0.5.

For preliminary dimensions of the outer radius $R_{out} = 25$ mm, and the capacity gap of the coaxial cavity $g = 2$ mm or $g = 4$ mm, one can plot dependence p on R_{in}, the radius of the inner conductor, Fig. 1a. Roundings of the inner and outer conductor are taken, respectively, $r_{in} = R_{in}/10$ and $r_{out} = R_{out}/10$. It is seen that we can increase p taking a thinner inner conductor but lose in this case the value of Q, and the maximal electric field becomes too big at the end of the inner rod, Fig 1b. Here $k = E_{pk}/E_0$, ratio of the peak electric field, on the edge of the inner conductor, to the field on the axis of this conductor.

If we choose as a compromise $R_{in} = 6$ mm and analyze the dependence p on g, Fig. 2, we can see that there is not too much gain with g bigger than approximately 12 mm. So, let us take $g = 12$ mm.

For chosen R_{in} and g, the value of R_{out} can be checked. We see (Fig. 3) that the value $R_{out} = 20$ mm is

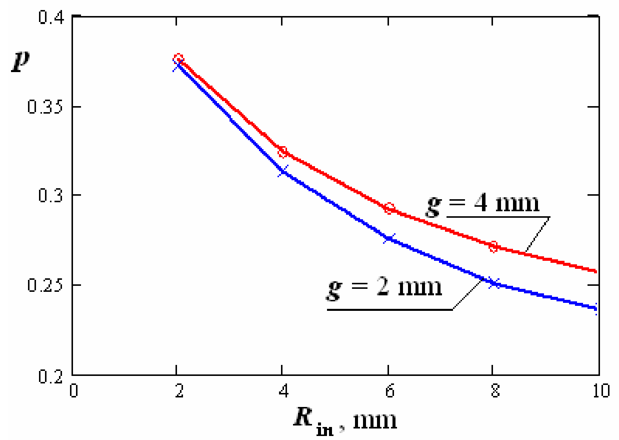

Fig. 1a. Dependence of p on the inner cavity radius.

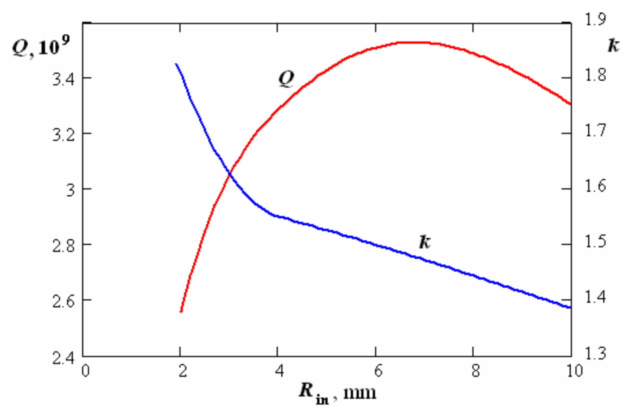

Fig. 1b. Quality factor and electric field enhancement vs inner radius.

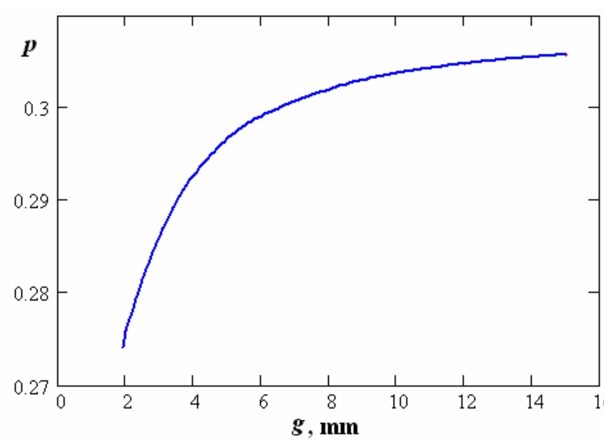

Fig. 2. Dependence of p on the gap width for $R_{in} = 6$ mm.

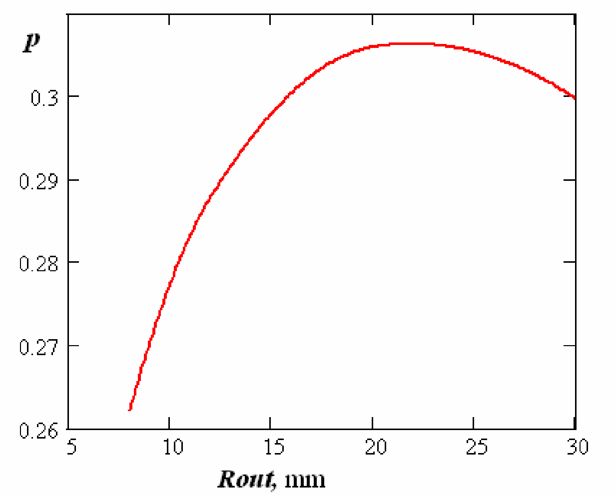

Fig. 3. Dependence of p on the outer radius of the cavity R_{out} for $R_{in} = 6$ mm, $g = 12$ mm.

good enough and the design is very compact with such a small R_{out}.

Finally, we notice that the electric field enhancement for these dimensions is about 2.1 at the edge of the inner conductor relative to the field at the axis of the cavity. We can decrease this factor to 1.76 changing the rounding radius to $r_{in} = R_{in}/4 = 1.5$ mm. The final look of the cavity with these dimensions is shown in Fig. 4. Electric and magnetic fields of the fundamental mode are shown.

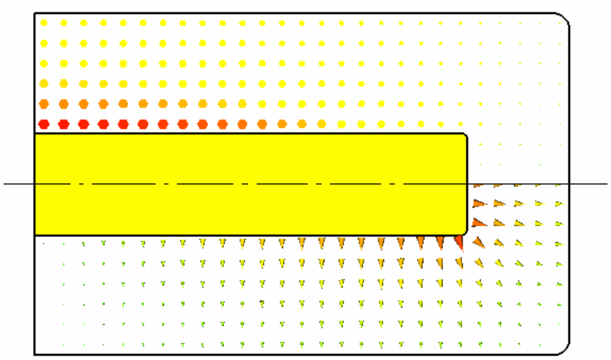

Fig. 4. Coaxial cavity. Magnetic field is shown above the symmetry line, electric field below.

Final chosen dimensions are presented in the Table 1. The frequencies of several first modes of the cavity are shown in the Table 2.

Table 1. Dimensions of the cavity, mm.

Outer radius	R_{out}	20
Inner radius	R_{in}	6
Length	L	62.96
Rounding of the outer radius	$R_{out}/10$	2
Rounding of the inner radius	$R_{in}/4$	1.5
Gap	g	12

Table 2. First resonant frequencies of the cavity.

Frequency, MHz	Comment
1300	¼ -wave-length capacity-loaded, fundamental TM
3820	¾-wave-length capacity-loaded, TM
4397	TE
5964	TM
5973	TE
7462	TM
7464	TE
7665	TM

The value of Q for the chosen dimensions is $Q = 3.0 \cdot 10^9$ with $\sigma = 2.0 \cdot 10^{19}$ Sm/m (surface resistance $R_s = 16$ nOhm) on all the surfaces. This Q-factor of the whole cavity can be presented as a Q-factor of the outer (Q_{out}) and a Q-factor of the inner part of the cavity (Q_{in}), so that $Q = Q_{out}Q_{in}/(Q_{out} + Q_{in})$. For the presented case, $Q_{out} = 8.3 \cdot 10^9$ and $Q_{in} = 4.7 \cdot 10^9$, so that losses on the inner conductor are approximately 2 times bigger than on the outer envelope.

Calculations were done with the program CST MICROWAVE STUDIO®.

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