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THE PREPARATION AND PERFORMANCE OF SUPERCONDUCTING CAVITIES

by

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The efficiency of the RF structures in a linear accelerator is given by the shunt impedance Z which is proportional to the Q-value. To minimize the power dissipation of the RF structures the Q-value must be improved which can be achieved by using superconducting cavities.

In order to investigate the improvement factors which can be obtained by superconductors it is expedient to excite a cylindrical resonator in the TE_{011} mode. In this case no currents flow across the edges and the problem of good joints is avoided. If the improvement factor (defined as the ratio of the Q-value of a superconducting cavity to that of a copper cavity at room temperature) has been determined the actual shunt impedance is obtained by multiplying the shunt impedance of a copper structure by this factor.

The measurement of the Q-value is performed by the decrement method which is suitable for the measurement of high Q. In this method the decay time τ is used to determine Q_L which is calculated by $Q_L = \omega\tau$, where ω is 2π. resonant frequency (2.45 GHz).

Three different processes are important for the production of superconducting cavities:

1. Electroplating,
2. electroless deposition,
3. evaporation.

With the electroplating of lead we achieved satisfying results and high Q-values are obtained. The 16 steps of the preparation process are shown in Fig. 1.

In the first test runs Q-values of 300 millions were typical at a temperature of 2°K and the dependence of the Q-value from temperature was small. By reducing the coupling hole to 3 mm diameter the residual losses became smaller and the Q-value went up to $2.6 \cdot 10^9$ at 2°K. Fig. 2 shows the dependence of Q from temperature.

Our experimental Q-values are at 4.2°K about a factor of 2 higher than the Stanford data (scaled to the same frequency). Our curve rises less steeply with decreasing temperature. The increase of the Q-value from 4.2°K to 2°K is only by a factor of 6 higher (Fig. 3). Our experiments indicate, that the coupling factor ß does not take into account all losses which occur in the coupling mechanism. Higher Q-values are expected by a reduction of the coupling losses. In order to investigate the influence of the magnetic field, two pairs of Helmholtz coils are used to compensate the earth magnetic field or to apply a higher field. Inside the cryostat the field can be compensated down to ± 7m Oe over the volume of the resonator. 3 Oersted is the maximum field which can be applied.

The compensation of the magnetic field improves the Q-value by the factor of 2 at high Q-values (Fig. 4). But at relatively low Q-values (below $300 \cdot 10^6$ at 2°K) nearly no influence was found. Later the measurements shall be extended down to below 1 m Oe. The best improvement factor we could measure at 2°K and at compensated earth magnetic field was 54 000 referred to copper at room temperature.

The second process, electroless deposition of lead is an ion interchange in which in a solution lead is interchanged by copper. The solution is composed of

lead nitrate
dimethyl sulfoxide
and thiourea.

To produce lead layers the copper surface only has to be cleaned and decreased and dipped for half an hour into the solution. The thickness of the lead layer depends on the time (Fig. 5). The first test was very good and the Q-values were 10% higher than those of electroplated surfaces. Later tests gave worse results probably because of a contamination of the solution. Q-values of $50 \cdot 10^6$ are typical. Most of these experiments were carried out with the removable bottom plate of a electroplated reference cavity. The investigation of the ageing showed that for electroplated resonators the Q-values drop according to an exponential function (Fig. 6). But for resonators with lead layers produced by electroless deposition the Q-values dropped only 20% during 3 months, i.e. from an initial value of $53 \cdot 10^6$ to $44 \cdot 10^6$ measured at 4.2°K. It might be mentioned that the lead solution is spoiled by the oxygen of the air after about one day. Further investigations of this process are going on.

The third method which was tried to produce superconducting resonators is evaporation. First attempts were made with very pure lead of 99.999%. The achieved surface was bright and shining but the Q-values attained are only 30 to 50 $\cdot 10^6$. The reason is that at our vacuum of about 10^{-5} Torr there is enough oxygen to attack the lead particles and this results in RF losses. We pursue the evaporation process for it is interesting in the investigation of hard superconductors and superconducting alloys which will be investigated later.

DISCUSSION

R. HIETSCHOLD, Karlsruhe

MONTAGUE, CERN: You mentioned in your last few words the possibility of using hard superconducting alloys. I have heard that there is some reason why these are not very promising. Are these reasons objective or are they based on superstition?

HIETSCHOLD: The investigation of the performance of hard superconduction for rf cavities has just started. This is a study of superconducting alloys and metals, which, possibly, could be used for linear accelerator structures.

FAIRBANK, Stanford: It was once suggested that type II superconductors would have a much higher Q than type I superconductors. But what apparently happens is that in type II superconductors there are small regions containing magnetic flux which are essentially in the normal state. Direct currents flow around these regions and thus suffer no losses, but high frequency currents cannot bypass these regions, and power is dissipated. We have tried niobium and certain other materials and, except for one experiment, all the tests I know of have been poorer with type II superconductors. There are some Russians at Karkov who recently published a paper on type B lead, which is apparently some kind of a low-grade lead in Russia. It had a very low room temperature Q and a helium temperature Q which was much higher than the theory says you can get. We don't know any more than that although some people talked to them during the low temperature conference. There are some doubting Thomases about those experiments because of the theory.

HAIMSON, MIT: With regard to the oxidation problem, would you care to comment on what could be considered a safe practical value for vacuum?

HIETSCHOLD: The vacuum inside the resonator?

HAIMSON: You mentioned that there is sufficient oxygen in the normal vacuum system to cause trouble with the lead.

HIETSCHOLD: Maybe I said it in the wrong way. I meant that during the preparation process there was too much oxygen in the vacuum-tank, and then you deposit, not lead alone, but lead oxide too, and at rf measurements you have very high rf losses. Until now people made a lot of tests on evaporated lead with dc, but if you have dc, this lead oxide doesn't destroy the superconductivity.

SMITH, Stanford: I would just like to make a comment which has some bearing on this point as well as on one of the slides where there was some data shown on the degradation of the Q as a function of time plating. As I recall, you keep your cavities under helium at one atmosphere.

HIETSCHOLD: The slides referred to cavities kept on open air. We have only made one test with a cavity kept under helium at one atmosphere.

SMITH: The point I want to make is that we have occasionally stored cavities under fore-pump vacuum, and the Q does not seem to change over a month.

FEATHERSTONE, Minnesota: Do the cavities deteriorate in normal air?

SMITH: I don't know.

FAIRBANK: Water, or water vapor, seems to be harmful.

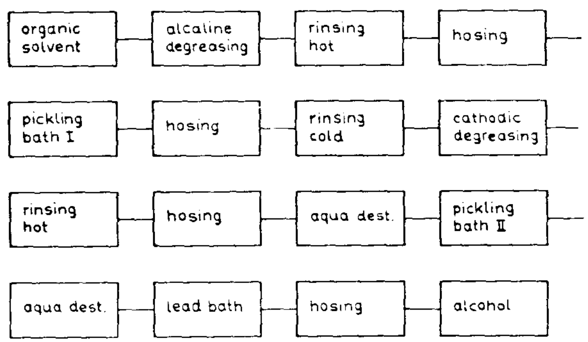

Fig. 1. Preparation process for lead deposition.

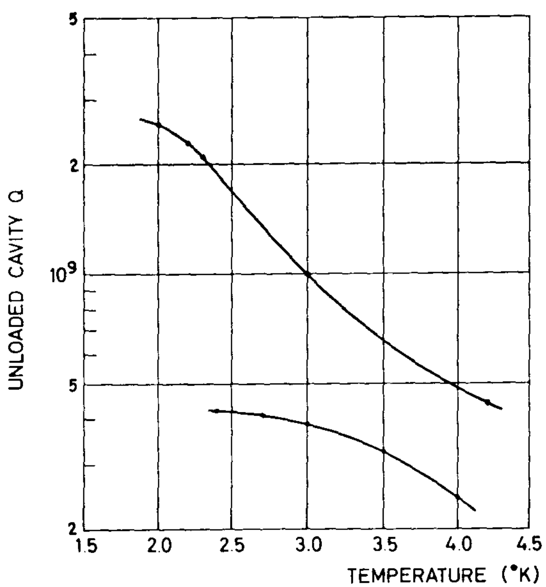

Fig. 2. Measured temperature dependence of the cavity Q.

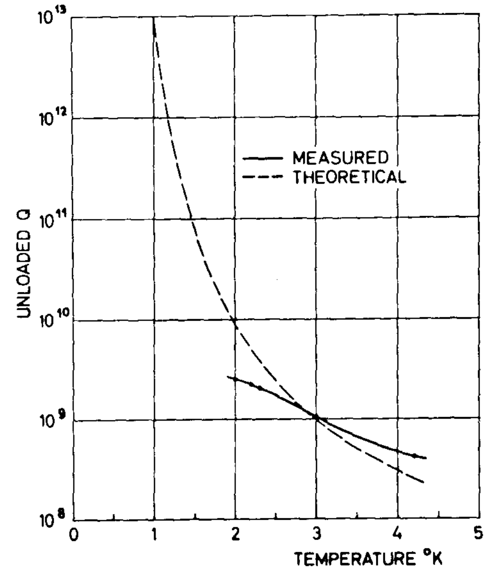

Fig. 3. Measured Q-values and theoretical curves.

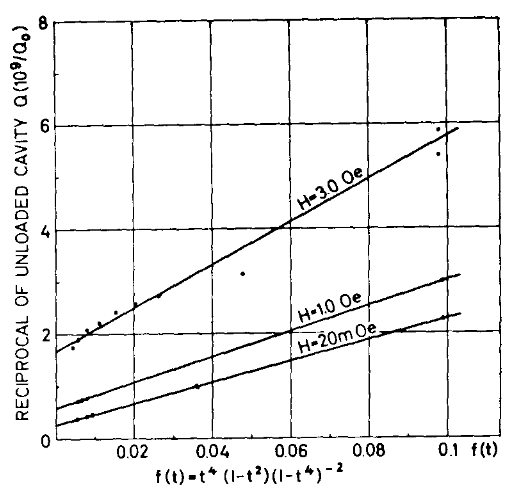

Fig. 4. Dependence of cavity Q on magnetic field.

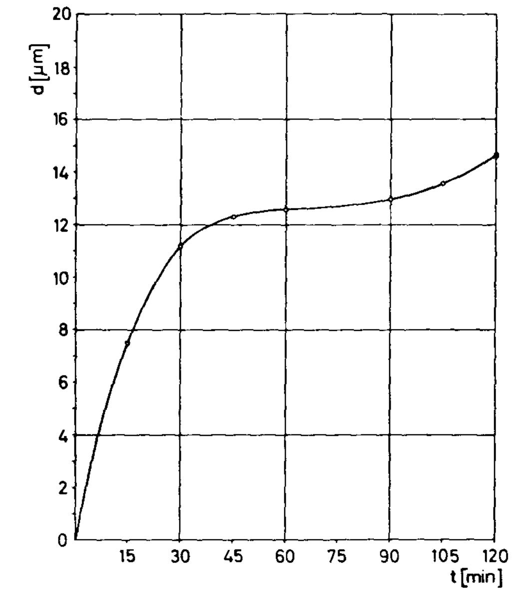

Fig. 5. Dependence of lead deposition on time.

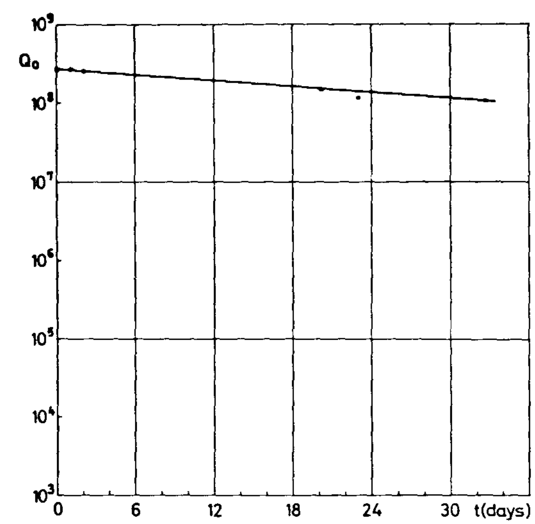

Fig. 6. Dependence of cavity Q-value on time.