LEAD ALLOYS FOR SUPERCONDUCTING CAVITIES

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Summary

For the superconducting separated orbit cyclotron Tritron six large, wedge shaped cavities for simultaneous acceleration of 19 parallel ions beams are needed. The indirectly cooled superconducting cavities with frequencies of ~170 MHz ± 3 % will be made of copper electroplated with lead alloy. With PbSn and PbBi as superconductor stable surfaces without chemical polishing can be obtained. The results of measurements on a 500 MHz test cavity (PbSn) are reported.

Lead Alloys for the Tritron Cavities

At the Munich Accelerator Laboratory a separated orbit cyclotron - the Tritron - is under construction with the magnets and the cavities both superconducting [1]. The demands to the RF-system are: a maximum voltage per turn of 1.45 MV at injection (r_1= 70 cm) and 3 MV at extraction (r_2= 149 cm), a RF-frequency of ~170 MHz ± 3 % and a gap of ≤8 cm. In order to keep the maximum voltage per cavity below 500 kV, this will be done by six wedge shaped cavities with a length of 1.2 m in radial direction, a maximum height and width of 70 cm and inserted accelerating lips with a length of 85 cm in radial direction for accelerating the 19 turns of the spiraling ion beam in parallel. The cavities consist of two parts - joined in the orbit plane - the lower half of which is shown in Fig. 1. The cavities of the reentrant type are driven in the TM010 mode. If they would be operated normal conducting, the dissipated heat corresponding to 300 kW would be produced in direct vicinity of the cold magnets. Therefore the cavities shall be superconducting. In the following the choice of the superconductor will be discussed.

The two characteristics of the cavities are the large dimensions and the missing rotational symmetry. In order to avoid complex bath cryostats, the cavities will be produced of OFHC-copper sheets (6 mm thick), which are covered with thin layers of superconductor. Due to the good thermal conductivity of copper, the cavities can be cooled indirectly by means of pipes. If the superconducting layers are sufficiently thin, their thermal conductivity does not hinder the diversion of heat produced in normal conducting defect areas. Thus the magnetic breakdown limit is shifted to rather high values of the RF magnetic field [2]. A well established method for this is electroplating of copper with lead.

If the upper limit for the power dissipated as heat in each cavity is set to be 6 W at a voltage of 500 kV, the surface resistance of the superconducting layer has to be less than $R_S < 3 \cdot 10^{-7}\,\Omega$. The RF-surface resistance can be represented additively by two terms. First, according to the BCS theory $R_{BCS}(\omega,T)$ decreases strongly with decreasing frequency and temperature. The R_{BCS} of lead [3] is shown in Fig. 2 for 4.5 K and 3 K (continuous lines). At the frequency of the Tritron cavities of ~170 MHz $R_{BCS} \approx 4 \cdot 10^{-8}\,\Omega$ for 4.5 K respectively ~$10^{-8}\,\Omega$ for 3 K. In any case, R_{BCS} is small compared to the demanded surface resistance. Therefore the temperature of the cavities need not be less than 4.5 K, which further simplifies the cooling system. The second contribution to R_S, the residual resistance $R_{RES}(\omega)$, is independent of temperature. R_{RES} is caused by many different effects, which are expected to have dependences upon the frequency as ω^α with different exponents α. The origin of R_{RES} may be for instance surface irregularities, a magnetic background field or dielectric layers from oxidation or adsorbed gases. The dielectric layers are of special importance for cavities in a complex accelerator like the Tritron, because they may be formed after installation (ageing process). Depending mainly on the cleanness of the surfaces, residual resistances as low as ~$10^{-9}\,\Omega$ are achievable. However, even to attain $R_S < 3 \cdot 10^{-7}\,\Omega$ considerable effort with respect to the surface preparation is needed. Usually the lead electroplating is followed by a chemical polishing procedure in order to reduce residual losses, to improve the longterm stability and to increase the field emission limit [4]. However, due to the large and complicated shape of the Tritron cavities, this procedure is rather uncomfortable. To avoid the chemical polishing process we looked for superconducting lead alloys, which would be more stable than pure lead.

By means of many probes, which were electroplated with PbSn (commercial electrolyte) or with PbBi (electrolyte based on perclorid acid) it could be shown, that the surfaces keep their state. Instead of chemical po-

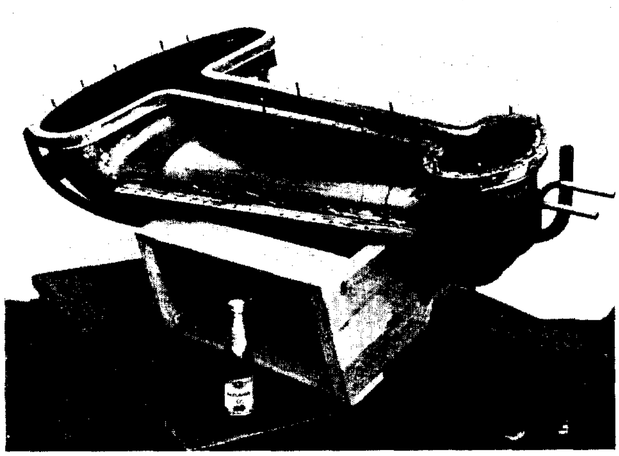

Fig. 1: The lower half of a Tritron cavity

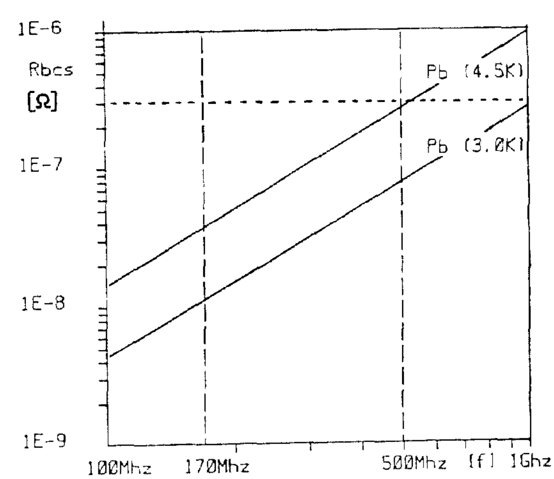

Fig. 2: Surface resistance R_{BCS} of lead for 4.5 K and 3K and the design limit $R_S = 3 \cdot 10^{-7}\,\Omega$ (broken line)

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lishing a simple aceton rinsing was performed which gave a mirror like finish being stable even after long-term exposure to air. Before the results of measurements on a PbSn test cavity are reported, a remark on possible applications for other purposes than the Tritron is made. Measurements made on PbBi alloys by Flécher [5] show a reduction of R_{BCS} compared to the pure lead data given in Fig. 2. As an example, for a $Pb_{0.99}Bi_{0.01}$ layer produced by UHV vaporization, without any additional preparation a reduction of 36 % at 4.2 K and 3 GHz was measured, resulting in $R_{BCS} = 2.8 \cdot 10^{-6}\Omega$. In the same experiment $R_{RES} = 10^{-7}\Omega$ was determined. It is assumed that this reduction is caused by a shortening of the electron mean free path length [3,5]. This improvement of R_{BCS} is especially important at high frequencies and may be advantageous also for lower frequencies, if sumultaneously the residual losses can be kept small enough. Of course, for use in particle accelerators besides the surface resistance the maximum attainable electrical field strength is important as well.

Measurements with the Test Cavity

For testing the lead alloys with a real cavity a shape was chosen which is of the reentrant type as the Tritron cavities but with rotational symmetry. This enables calculations with the SUPERFISH code [6]. The dimensions of the cavity (diameter = 44 cm, gap = 10 cm) are somewhat smaller for easier handling leading to a frequency of 490 MHz. The curved shape was chosen to suppress multipactoring and to keep the peak electric field low. A view of the cross section is shown in Fig. 3 together with electrical field lines. Some calculated data of the test cavity for the TM 010 mode:

frequency	490 MHz
Q(Cu,300K)	34000
R_{Shunt}(Cu,300K)	9.5 MΩ

Normalized to U = 500 kV:

E_{peak}	6.6 MV/m
B_{peak}	71 Gauß

The cavity is built up from two shells connected at the equator by a 5° wedge-shaped joint. After mechanical and electropolishing a normal conducting Q-value of 34000 was measured, corresponding to the SUPERFISH value.

The first alloy tested with this cavity was a 1 µ thick (mean-value) electroplated $Pb_{0.95}Sn_{0.05}$ layer which was then rinsed with acetone. Mounted in the µ-metal shielded cryostat the following data were obtained at T = 4.5 K:

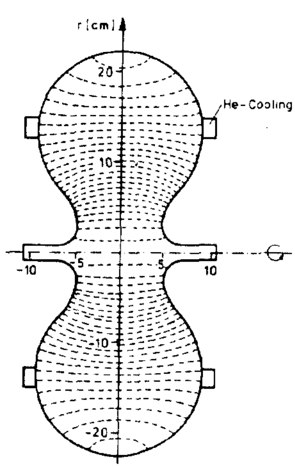

Fig. 3: Cross section of the test cavity with electrical field lines

Dissipated power	3.7 W
Unloaded Q	$3.5 \cdot 10^8$
Surface resistance	$5.3 \cdot 10^{-7}\Omega$
Gap voltage	600 kV
E_{peak}	7.9 MV/m
B_{peak}	85 Gauß

Above this field strength field emission started. There were no multipactoring problems. Assuming for R_{BCS} the value for pure lead of $2.6 \cdot 10^{-7}\Omega$ the residual resistance becomes $R_{RES} \approx 2.7 \cdot 10^{-7}\Omega$.

The first data obtained with the test cavity already show agreement with the demands for the Tritron cavities. However, they are moderate compared with results from pure lead surfaces at other laboratories. We assume that some reasons for the residual losses in this test have been:

- the mean thickness of the superconducting layer was only 1 µ. Locally this value could have been much smaller, causing losses in the copper. We have even observed some small copper spots (Ø ≤ 0.5 mm).
- dielectric losses
- losses caused by currents across the joint, connecting the two shells at the equator.

We have just startet testing lead alloys. Systematic tests will follow with the aim to reduce residual losses and to increase the attainable electrical field strength.

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