The Superconducting RF-Cavities for the TRITRON

T. Grundey, G. Hinderer and U. Trinks
Technical University of Munich
D-8046 Garching, W-Germany

Introduction

The Tritron is a separated orbit cyclotron with both magnets and rf-cavities superconducting. It will be a booster for the existing MP tandem of the Munich Accelerator Laboratory (1,2).
The ion beam is guided by superconducting channel magnets along a spiral orbit of 20 turns with a constant turn separation of 40 mm. Six superconducting cavities operating at 170 MHz are used to accelerate the ions. The resonators are made out of copper which is electroplated with a layer of PbSn. Both resonators and magnets are cooled by pipes connected to a helium reservoir. Therefore only one vacuum system is necessary to provide the beam and isolation vacuum.

Cavity Design

The wedge shaped reentrant type cavities (Fig. 1) are used to accelerate a low beta ion beam ($0.05 < \beta < 0.14$ at injection and $0.10 < \beta < 0.30$ at extraction) along 20 parallel turns. The width of the accelerating gaps is growing from 60 mm at the injection radius to 130 mm at extraction, providing the highest accelerating voltages at the outmost orbits (Fig. 2), as required by the beam dynamics of the TRITRON. Avoiding parallel cavity walls also should help to suppress two-side multipacting.
Calculations with the 3-dimensional computer code MAFIA showed that the field enhancement factor is about 1.5, which is rather low compared to other cavity types used in low beta accelerators. The cavity dimensions are mainly given by the radius difference between injection and extraction and size limits set by other machine components, resulting in an operating frequency of 170 MHz.
In an ideal cavity no currents will cross the horizontal plane. Therefore the resonator can be made out of two halves which are connected by a flat joint.
Compared with superconducting resonators for most other accelerators the TRITRON cavities are quite large and complicated, so niobium cavities would be quite expensive. However, the low frequency allows the use of lead

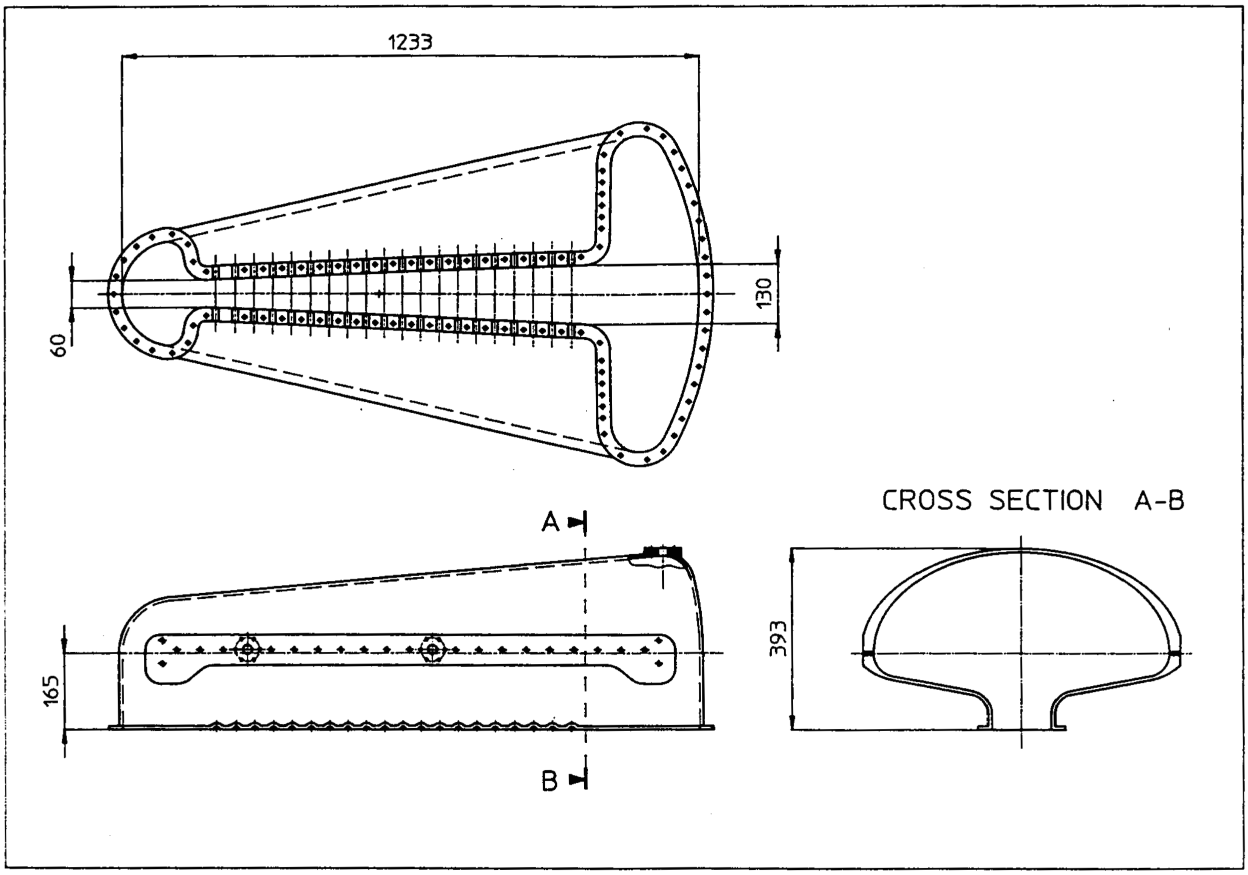

Fig. 1 The TRITRON cavity.

Superconductor	PbSn, 5 μm
Rf-frequency	170 MHz
Gap width at injection radius	60 mm
Gap width at extraction radius	130 mm
Maximum accelerating field E_{max}	4.7 MV/m
Field enhancement factor	≈ 1.5
Voltage at extraction U_{20}	530 kV
Quality factor Q_0	3.6 10^8
Dissipated power P	6 W
Beam power	≤ 200 W
Geometry factor G	94 Ω

Table 1 Cavity design data

electroplated on copper. Studies in our own laboratory (3) and at other laboratories (4,5) showed that PbSn might be superior to pure lead because of the enhanced stability against chemical reactions and the lower BCS-resistance. Therefore we use a thin layer (about 5 µm) of PbSn (3%Sn) as superconductor. A great advantage of using copper as substrate is its good thermal conductivity, which allows pipe cooling and is useful in preventing a thermal breakdown.

To avoid problems with ponderomotoric oscillations and to simplify the system for the frequency tuning the cavity has to be stable against mechanical vibrations. A minimum wall thickness of 8 mm was chosen to fulfil this requirement. The cavity design parameters are summarised in table 1.

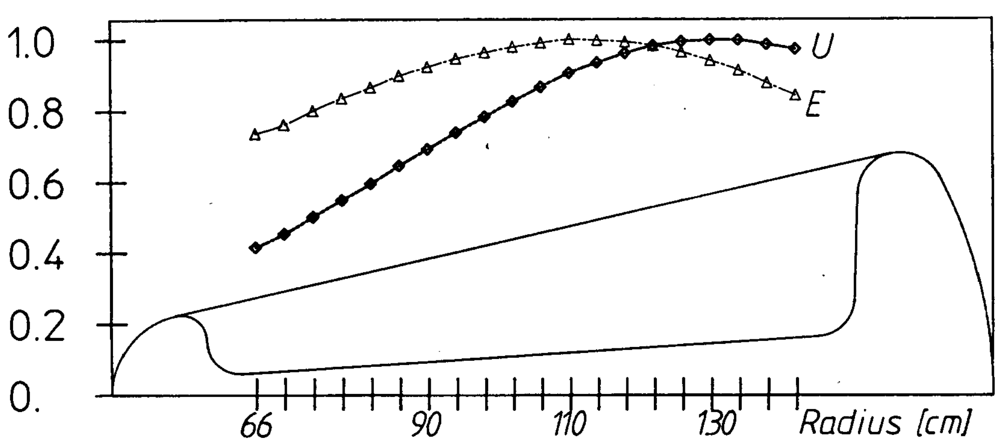

Fig. 2 Voltage and electrical field characteristics of the TRITRON cavity in relative units. The maximum voltage is at the 18th beam hole, the maximum accelerating field at the 12th hole. The design value for the voltage at extraction (20th hole) is 530 kV.

Cavity fabrication

At least six cavities have to be build with modest requirements in absolute dimensional tolerances but the differences between the cavities should be small. Each cavity half should consist of only one piece to avoid the problem of welding together large and complicated parts within small tolerances.

Machining out of solid copper was ruled out because it would require a lot of time and machining tools. It seems possible to fabricate complete half shells by casting copper but it would be quite difficult to get relative tolerances smaller than 1 mm. Deep drawing a complete shell is not possible because it is not possible to remove a mould from the inside without destroying it.

Therefore we chose the electroplating technique. The copper is electroplated onto a fibre glass mould which is destroyed and removed afterwards. The fabrication of the moulds is done in several steps: A solid plastic model of the cavity inside was machined by hand using a set of coordinates describing the inner cavity surface. In a second step a mould is shaped which exactly encloses the model. To remove the model it consists of two parts which can be fixed together. A rigid support structure guarantees that deformations of this mould will be small. Using the mould thin fibre glass shells which are copies of the solid model can be fabricated in nearly unlimited quantities. They have the same surface quality as the solid model. A thin conducting layer is sprayed on the shell surfaces to make them ready for the electroplating.

After the electroplating some machining is necessary to remove excess material at the horizontal symmetry plane where the joint between two cavity halves is located. To fix a strip of copper with attached cooling pipes and the cavity suspension a flat plane has to be machined at the outmost region (see Fig. 1). To allow the use of screws in this area the wall thickness is locally increased to 40 mm. Most parts of the cavity have a wall thickness of about 10 mm. The flat plane is also used to fix adjustable coupling probes. All fabrication steps described so far are carried out by a small company specialised in the manufacturing of models for the automobile industry.

Electroplating PbSn on each cavity half is done by our own group at the galvanic laboratory of the Gesellschaft für Schwerionenforschung (GSI) at Darmstadt. We use a commercially available plating bath (Slotolet KB, Schlötter GmbH,7220 Geislingen). The fraction of Sn relative to Pb is adjusted to 3%. Because of the large cavity dimensions we need electrodes which are mechanically very stable. Also we wanted electrodes which can be removed quickly from the cavity inside after the electroplating. These requirements can be fulfilled by a setup of titanium rods (ø 12 mm) covered with a thin layer of platinum which can be moved into the resonator through the narrow acceleration gap. We use a current density of about 10 mA/cm^2. Another set of electrodes is located outside the cavity half which is supplied with a somewhat smaller current than the main setup. Its purpose is to cover the resonator outside with a thin PbSn layer to prevent the dilution of copper into the bath.

The following procedures were developed after the first cavity test. The preparation for the first test was somewhat simpler. The preplating treatment now consists of soaking the half shell with the electrodes attached in an alkaline solution for several minutes, rinsing in sulphuric acid and rinsing with deionized water. The half is stored in the same acid which is the main component of the electroplating bath (Schlötter FF). From there it can be moved directly into the plating bath.

After the electroplating the half is moved into another container with FF-acid and rinsed afterwards in two containers with deionized water. The wet resonator half is dried quickly with nitrogen to minimise surface oxidadation. The last step is the removal of the electrodes.

It is very important to get a good surface during this procedure because the chemical polishing methods often used for Pb cavities do not work for our PbSn surface.

So far one resonator was fabricated and plated with PbSn as described above. The manufacturing of a second resonator is under way. A total of 8 cavities are ordered.

Cavity tests

The first TRITRON cavity was tested several times. Typical values for the vacuum pressure in the cryostat are $3 \cdot 10^{-5}$ before cooling down and $5 \cdot 10^{-8}$ at 4.5 K. Every time the resonator was exposed to air strong multipacting at very low field levels showed up, resulting in a Q-drop of several magnitudes. It can be removed by adjusting the input coupler in such a way that all of the available rf-power (200 Watt) is fed into the resonator under this conditions. After some minutes of rf-processing the multipacting disappears permanently. We never observed ponderomotoric oscillations. Oscillations of the resonance frequency caused by acoustic noise are smaller than 50 Hz.

To obtain values for the accelerating voltage the outmost beam hole is equipped with a detector to measure the energy gain of electrons from a BI^{207} source on the opposite side of the accelerating gap.

During the first cavity test a rapid drop of the quality factor was observed even at low field levels (Fig.3, lower curve). Probably this drop was caused by surface oxidation which could be seen as dark spots on the surface. Field emission caused the even more rapid drop at voltages above 300 kV.

The cavity was electroplated a second time using the more sophisticated procedures described above. To reduce the presence of dust particles the inside of the two cavity halves was blown out with dust free air immediately before they were assembled. The assembling took place one week after the electroplating.

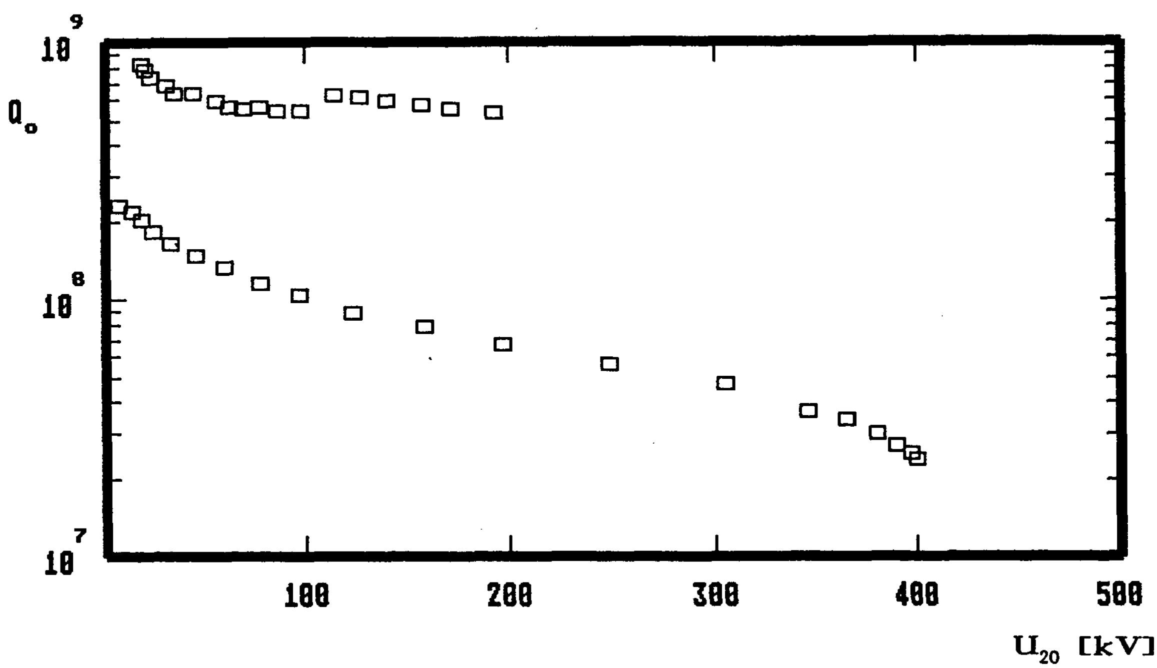

Fig. 3 Unloaded quality factor Q_0 of the first TRITRON cavity versus the voltage U_{20} at extraction. The voltage was calibrated by observing the energy gain of electrons from a ^{207}Bi source. The lower curve was measured after the first electroplating with PbSn. The upper curve was measured one week after the cavity was electroplated a second time with improved surface preparation.

This time the quality factor was almost independent from the accelerating field but the maximum voltage was limited to 190 kV (Fig. 3, upper curve). The limitation may have been caused by a small piece of steel sticking in the cavity wall at a high magnetic field region.

After reopening the cavity and the removal of the steel piece the resonator was mounted in the cryostat with no further surface preparation besides a second cleaning with dust free air. After the disappearance of the multipacting an acceleration voltage slightly exceeding 400 kV was measured, limited by field emission. After several hours of rf- and He-processing this limit could be increased to 690 kV (Fig. 4). The maximum value of 690 kV corresponds to a maximum accelerating field of 6.1 MV/m. During the processing γ-radiation with levels up to 400 mRem/h was measured outside the cryostat.

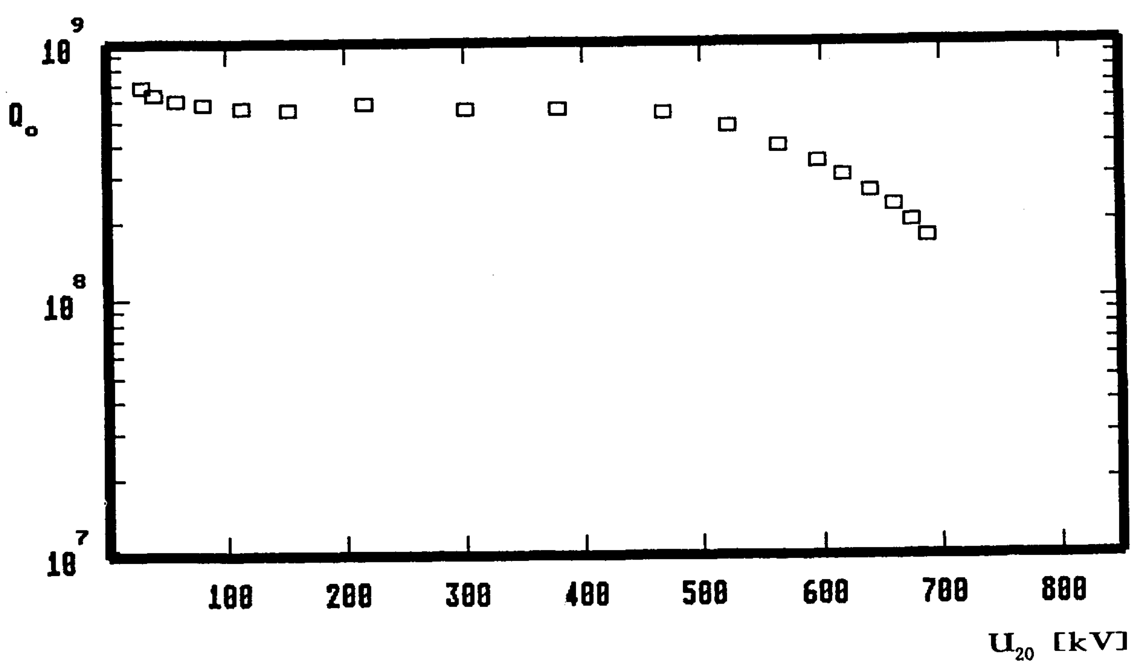

Fig. 4 Unloaded quality factor Q_o versus the voltage U_{20} at extraction. After the measurements shown in Fig. 3 the resonator was opened, a small magnetic particle was removed and the cavity was reassembled. Before the test it was exposed to laboratory air for several weeks. The maximum voltage corresponds to an accelerating field of 6.1 MV/m.

Conclusion

Tests with the first TRITRON cavity have shown that the design values (U_{20}= 530 kV at Q_o= 3.6 10^8) can be exceeded after a refined surface preparation. It was not necessary to assemble the resonator in a clean room. Before the final test it was exposed to laboratory air for several weeks and opened twice for surface inspection.

The value for Q_o was 4.7 10^8 at U_{20}= 530 kV corresponding to a dissipated power of 4.6 W. At the maximum voltage reached so far the losses were 21 W and could be handled by the pipe cooling.

The next steps will be the production and testing of more resonators and the implementation of a tuning system. For the tuning a combined system with a slow mechanical tuner and a fast electronic feedback device is foreseen. The electronic tuning system is an adapted version of the type which was developed for the Darmstadt superconducting accelerator (6).

References

1 U.Trinks, W. Assmann and G.Hinderer, Nucl. Instr. Meth. A244, 273 (1986).
2 U. Trinks, Proc. of the Third Workshop on RF-Superconductivity ANL-PHY-88-1, 389 (1988).
3 L. Dietl, Thesis, Techn. Univ. Munich, 1988, to be published in Nucl. Instr. Meth.
4 J.M.Brennan et. al., IEEE Trans. Nucl. Sci. NS-32, 3122 (1985).
5 M. Steck, Thesis, Max-Planck-Institut für Kernphysik Heidelberg (1985).
6 H. Gräf, Proc. of this conference.