EXPERIENCES IN FABRICATION AND TESTING THE PROTOTYPE OF THE 4.90 GHZ ACCELERATING SECTIONS FOR MAMI C#

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Abstract

The fourth stage of the Mainz Microtron (MAMI C) is under construction as a Harmonic Double Sided Microtron [1]: by 43 recirculations through two anti-parallel linacs, one working at the MAMI-frequency of 2.45GHz, the other at 4.90GHz, the beam energy is raised from 855 to 1500MeV. The biperiodic accelerating structures used are of the on axis coupled type [2], well proven in high power cw-operation at MAMI since 1978. For 4.90GHz a further optimisation of the cavity profile was done [3]. In addition, to ensure an efficient industrial production of the ten 35AC-sections needed, a prototype section was designed, built and power tested fully in house.

We report the final cavity profile and the configuration of this 4.90GHz-section with its cooling arrangement, tuning plungers and diagnostic probes. Details of machining, fine tuning and brazing the resonator discs are given. Finally the results of the high power test up to 22kW (1.29MV/m) are presented: the conditioning behaviour and the irreversible permanent as well as the reversible dynamic changes of passband gap and resonance frequency as a function of rf input power.

RESONATOR PROFILE

A detailed discussion of our modifications of the cavity profile compared with the just 2:1 scaled 2.45GHz dimensions was given in [3]. These changes were: a larger beam hole ($\varnothing_B$=7 → 10mm) for a relaxed loss free beam transmission along the 12m long linac; a further outward positioning of the coupling slots for higher coupling (k=-4.1% → -8.7%), i.e. less stringent tuning demands, and a less sharp nose cone for easier precision machining. The total sacrifice in shunt impedance by these measures was calculated to be 18%.

With MAFIA and URMEL the sensitivities of the AC- and CC-frequencies to small changes of cavity dimensions were calculated (Table 1). Because of the high sensitivity of ν_{CC} to the CC-length l_{CC} (+163MHz/mm), bearing in mind the layer of brazing alloy with not precisely known final thickness between the endfaces, as a final modification l_{CC} was enlarged from 1.94 → 2.94mm, sacrificing 0.5mm in web thickness. The sensitivity decreased to +99MHz/mm, the coupling increased by 0.5% and the final CC- and AC-diameter is 40.23 resp. 45.39mm. In addition in Table 1 the calculated sensitivities of ν_{AC} and ν_{CC} to special cuts applied by us for fine tuning (cf. 3) are given, as well as the range of empirical values (e) gained during this tuning. For the full end cells (EC) with only one pair of coupling slots a by 50MHz higher frequency was compensated by a 0.52mm larger diameter, and the magnetic coupling slot (22.1×5.5mm through a min. 3.1mm wall) in the input coupler (IC) demanded for compensation of -47MHz by a 0.49mm smaller diameter.

SETUP OF THE 35AC-SECTION

The design of the section is shown in Fig. 1. The number of 35AC (electr./mech. length = 1.071/1.121m) was chosen for two sections being fed by one 55kW cw-klystron (THALES / TH2166): dissipated power 2×15kW, max. beam load 2×4kW, and a margin for waveguide losses and controlling the rf-amplitude to $<10^{-3}$ via the klystron input power. The coupling slot pairs in the AC were chosen to be oriented parallel: for compensation of their rf-quadrupole effect [4], a larger splitting of the TM_{110}-BBU-mode [5] and a clear fulfilling of the mirror boundary conditions when tuning finite resonator stacks. The IC is located at the symmetry point AC18, so the next excitable modes are ±19MHz away from the π/2-mode. Detailed calculations with LOOP [6] were done for this section design, concerning its tuning tolerances and the optimum position of tuning plungers and probes. It e.g.

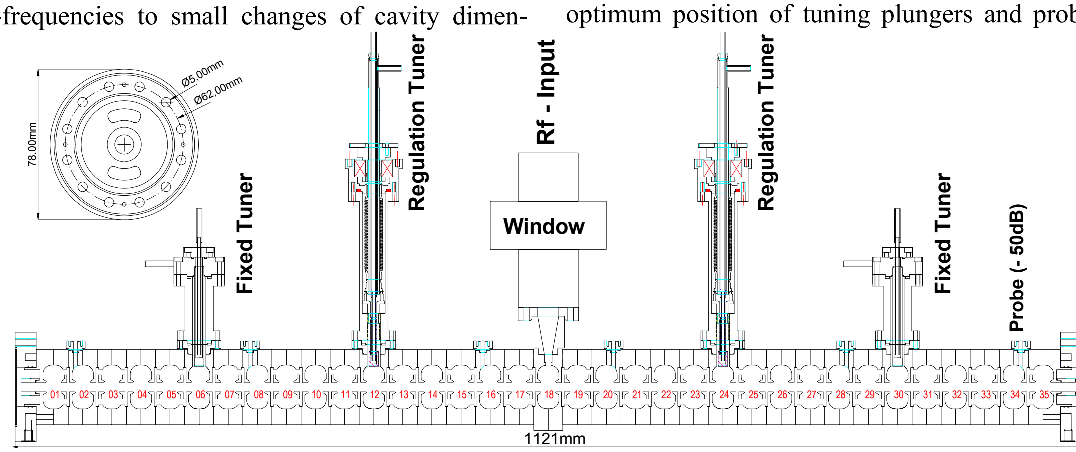


Figure 1: Scheme of the 4.90GHz section (already adapted for series production).

Work supported by HBFG and DFG (SFB443)

turned out that the difference in resonance frequency of left and right half section (which are fabricated separately and then brazed to the IC) must be less then 1MHz to avoid distinct losses in quality factor by growing CC-fields; alike the tolerance for the symmetry of the pass-band gap is ca. 2MHz for an E_{AC}-unflatness <5%. For the industrial production of ten series sections the possibilities of tuning after brazing were distinctly enhanced compared to the 2.45GHz-sections fabricated in house in the 1980´s [7]. The section has four symmetrically located tuning plungers, of which two are movable to regulate the resonance frequency under power via a phase detection loop. Their design is very similar to the ones described in [7], with a tuning head of 10mm moving from -3.5 to +6.5mm in a ∅=14mm hole, for a section tuning range of 2.1MHz. The other two plungers are simple fixed cylinders, machined to the right intrusion depth to compensate for frequency deviations and asymmetries having occurred during fabrication. Moreover, the EC were constructed to be tuneable by a 3mm thin wall extending from ∅=14 to 36mm. With a hammer-tool fixed to a thread on their cutoff-pipe the end nose cones can be moved by ca. ±0.25mm, resulting in a frequency range of ±20MHz for the EC, i.e. ±1.1MHz for the whole section. It turned out that, to get a good phase and amplitude signal, the vertically mounted -50dB coaxial antenna probes should only be placed in AC with the two coupling slot pairs oriented horizontally. For cooling two sections will be connected in parallel, their 2×44 l/min water flow then going to the klystron collector. The cooling manifold consists of twelve Ø=5mm channels drilled along the circumferential wall, resulting in a flow velocity of 3.1m/s (Re=18.700) with a pressure drop of < $1.5\cdot10^5$ Pa. The effective warm-up of the section under power, i.e. the necessary lab. frequency preset was calculated by the from [7] appropriately modified formula

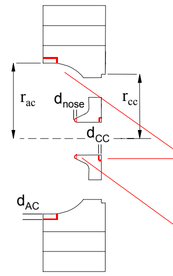
$$\Delta\nu = -0.0823\cdot P\cdot\left(7.17/D + 7.27/D^{0.82} + 0.447\right) \quad (1)$$

(Δν-MHz, P-kW, D-l/min). Here the first term accounts for the average warm up of the cooling water, the second for the temperature step at the copper-water boundary [8], and the third for the warm up of the rf-structure itself, including webdeformations [9]. For 15kW one gets Δν= -1.16MHz (eff. ΔT= +14.1°C).

MACHINING , TUNING , BRAZING

The materials used were OFHC-Cu (Zollern OF-Cu F20 certified) and SST304 (1.4301). This simple standard stainless steel was preferably used; because of its Ti-freeness it can be brazed to copper by Palcusil20 without Ni-plating. The machining was done in the following steps: The AC- and CC-resonator profile was machined on a CNC-lathe from copper discs with a 0.2mm skin staying all around, except on the outer diameter. As next on a CNC-milling machine the 12 cooling channels were drilled and especially very precisely (≤ 0.01mm) the holes for the two 2mm SST-centring pins between the segments. During the same step the coupling slots were milled to their final dimensions to avoid introducing any

Table 1: Sensitivity of tuning cuts at the cavity.



	AC	CC
Radius	$\frac{\partial\nu_{AC}}{\partial r_{AC}} = -193.1\frac{MHz}{mm}$ (e): –185 ... –197	$\frac{\partial\nu_{CC}}{\partial r_{CC}} = -148.8\frac{MHz}{mm}$ (e): –138 ... –186
Tuning	$\frac{\partial\nu_{AC}}{\partial d_{AC}} = -40.4\frac{MHz}{mm}$ (e): –32 ... –38	$\frac{\partial\nu_{CC}}{\partial d_{CC}} = +150.7\frac{MHz}{mm}$ (e): +149 ... +157
AC-Nose		

flat cut d_{nose} [mm]	0.05	0.10	0.15	0.20
$\Delta\nu_{AC}$ [MHz]	2.1	7.7	11.5	16.4

(e)

stronger stress into the webs later. These “raw” segments were thermal stress relieved at 450°C under vacuum and then finally machined. An excellent surface quality (the skin depth in Cu is 0.93μm at 4.90GHz) was obtained with the following CNC-lathe operation: cutting velocity 3.3m/s at a feed rate of 0.05mm/turn; infeed 0.1mm; cutting tool a sintered diamond circular plate with ∅=2.9mm; lubricant alcohol; special chuck with contact on the whole circumference.

At test samples without coupling slots a Q_0=11800 was measured, 99% of the reliable URMEL-value. The dimensions of the segments were for a machining preset $\Delta\nu_{AC}$= +1.5MHz and gap g= -5.2MHz; max. deviations of ±0.6MHz and ±2.1MHz respectively occurred, roughly consistent with a lathe accuracy of ±0.003mm. These presets in ν_{AC} and g were intended for easy fine tuning cuts (Table 1): an “inductive” 2mm broad ring at the outer diameter of the AC and a “capacitive” 1mm broad ring around the beam hole at the CC.

The fine tuning was done by measuring stacks of segments with a NWA in S_{11}-mode. Two ½-AC served as boundary “etalon-cells”, with movable tuning stubs for e.g. compensating the detuning by the small rf-antenna. Only the accelerating mode (AM) was measured and the frequency of the coupling mode (CM) then determined by DISP-4 Par. fits [6]. It turned out, probably because of a quite strong second coupling ($k_{AC/CC}$= -8.7%, $k_{CC/CC}$= -0.7%, $k_{AC/AC}$ ~ 0), that the fitted gap g=ν_{CM}-ν_{AM} was significantly dependent on the length of a stack up to ≤ 8 segments (9 frequencies on the dispersion curve). Therefore with two segments at a time between the etalon-cells (5 frequencies) only the constancy of ν_{CM} was controlled, and then with long stacks its value for the global correction of the CC. The stacks were measured in a hydraulic press with a force of 1400kp; beyond this value the Q_0-value did not grow any more, indicating a sufficient rf-contact. However, as a bad surprise the gap changed by -5MHz for a pressing force between 300 and 1400kp. The reason for this effect was most probably the shape of the abutting faces of the segments: they had been machined with linear recess of 0.005mm from inner to outer edge of the circumferential wall, for ensuring a safe contact at the inner edge. So by the pressing the webs were slightly elastically bended, thus changing the effective length of the CC. To overcome this difficulty several test brazings on short tuned stacks were done, which with good constancy suggested a tuning preset before brazing of

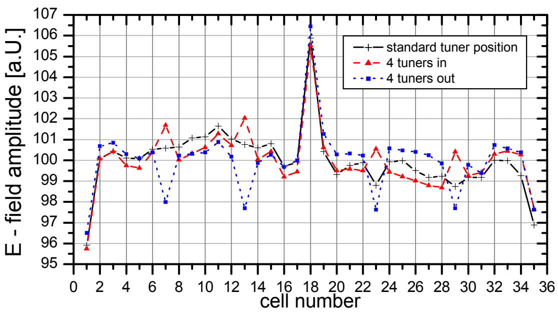


Figure 2: AC- field amplitudes for different tuner positions.

+1.3MHz and -3.6MHz for ν_{AM} and ν_{CM} respectively. For a future design, however, abutting faces with a ca. 3mm flat part and then a recess should be preferred. The full EC of the section were tuned to ν_{AM}. To do so without compensation for the symmetry breaking was decided experimentally by a bead pull measurement on a 4½-resonator stack with the EC hammer tuned in the range $\nu_{AM} \pm$ 20MHz: the fields in the CC had a clear minimum for $\nu_{EC} = \nu_{AM}$, whereas the AC-fields nearly did not change, the EC being down by -3%. The tuning and match of the IC were performed by alternately measuring its frequency in the ½-cells etalon with the input waveguide pressed on it and terminated by a matched load, and by measuring the coupling factor β though the IC being pressed between the two section side parts. The adjustment of β to 1.127 (for match at 43×50μA beam loading) was done by machining in steps the length l and width w of the input slot, with roughly $\beta \sim l^5 \times w$.

The vacuum brazing was done mainly with Cusil (780°C, Cu/Cu), two 0.7mm wires in notches of the segments abutting faces at 26 and 36.5mm radius. The other alloys used were Palcusil 20 (905°C, Cu/SST304), Palcusil 10 (860°C, Cu/SST304-Ni-plated) and for the final connection of the two ready brazed and rf-measured section side parts to the input coupler Incusil 13 (720°C, Cu/Cu). The brazing presets for ν_{AM} and gap proved to be quite good, the deviations for the two 17-AC side parts were +0.57/+0.57MHz and +0.10/+0.52MHz respectively.

TESTS OF THE SECTION

The parameters measured on the ready brazed section were: shunt impedance r=81.5MΩ/m, i.e. only 14% less than the 2.45GHz scaled value; frequency ν_{AM} by 0.48MHz high; gap g= +0.31MHz and Q_0=10600. When detuning the section by ± 2.3MHz with the four tuning plungers Q_0 lowered by only 3.6%, indicating a very good field stability (CC-fields staying low) by the high coupling of k= -8.7%. This is also shown by the small changes of the AC-field amplitudes in Fig. 2. The 3-4% lower fields in the full EC were already mentioned. The 6% higher field at the IC clearly results from a design mistake: in this cell the two coupling slot pairs were oriented vertically and thus the coupling k is lowered by the big rf-input slot between them. For the series sections the orientation of the slot pairs will be changed by 90° in each cell and the tuner positions moved by one AC to stay with horizontal slot pairs also here.

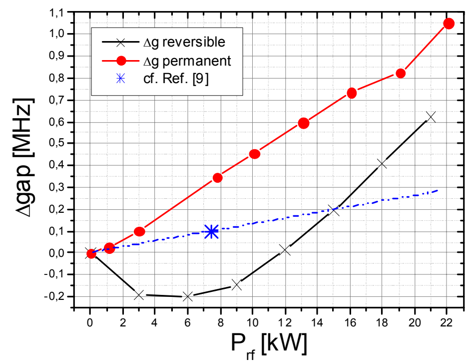


Figure 3: Permanent and reversible change of gap g.

The high power test began by heating the section without coolant flow by 1-2kW of rf-power up to 100°C and pumping it one day. Then, with the 4 tuners staying in nominal position, the power, with tightly set vacuum and reflected power interlocks, was raised up to 22kW, 47% more than the nominal dissipated power. After every advance by 2-4kW the conditioning was interrupted and the spectrum of the section measured with a NWA, to determine the permanent irreversible changes of ν_{AM} and gap. With good linearity the following values were measured: -4.7kHz/kW for the frequency and +49kHz/kW for the gap (cf. Fig. 3), indicating a permanent bending of the webs to their AC side by ca. 0.1μm/kW. An important measure was the visual observation of the sections interior under power by two glass windows at its ends: the bright glow of many microparticles gradually diminished with conditioning time, but not any blue plasma cloud, indicating a multipacting discharge, was observed. The dynamic reversible change Δg of the passband gap with input power (Fig. 3) was determined by a NWA-S_{21}-measurement of the sections spectrum through two of the diagnostic probes, with a +35dB-TWT in the 1-arm and a -70dB notch-filter in the 2-arm of the NWA. The strong nonlinearity of Δg differs significantly from the behaviour of our 2.45GHz-profile [7], and also the prediction of the thermoelastic calculation [9] done at 7.5kW input is locally not too good. Fortunately, during the design of the section this one point was used by us for a linear extrapolation to 15kW. Equation (1) was tested for coolant flows of 23, 45 and 67 l/min, the deviations to the measurement being +6%, +2.5% and 0% respectively.

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