MANUFACTURING AND TESTING OF 2.45GHZ AND 4.90GHZ BIPERIODIC ACCELERATING STRUCTURES FOR MAMI C

H. Euteneuer, O. Chubarov, A. Jankowiak, Institut für Kernphysik, Universität Mainz, Germany
K. Dunkel, C. Piel, P. vom Stein, H. Vogel, ACCEL Instruments, Bergisch Gladbach, Germany

Abstract

At the Institut für Kernphysik (IKPH) of Mainz University the fourth stage of MAMI, a 855MeV to 1500MeV Harmonic Double Sided Microtron (HDSM, [1]), is now on the verge of first operation. For this project ACCEL Instruments GmbH manufactured bi-periodic on axis coupled standing wave accelerating structures at the frequencies of 2.45GHz and 4.90GHz. Four resp. eleven multicell sections were manufactured, low power characterized and after delivery high power tested at IKPH. Here we describe the manufacturing and characterization of these structures, present results of their power tests and compare these data with results gained at IKPH for an in house built 4.90 GHz prototype and the 2.45 GHz structures built there in the 1980´s.

SPECIFICATION OF THE TASK

For the HDSM of MAMI C two 9 MeV n.c. linacs are needed: one operating with 5 sections at 2.45 GHz and the other with 4×2 sections at 4.90 GHz. Another 4.90GHz section-pair is necessary for longitudinal matching on the HDSM injection path. The sections had to be built with on axis coupled π/2-mode biperiodic geometry [2], because of the relative simplicity of fabricating this type of structure and its excellent operational reliability at MAMI during the past 25 years. For the 2.45 GHz sections, to have a quick start of production, it was decided to make them as approximate copies of the nine sections built in-house at IKPH in the 1980´s [3]. The only changes were an adapted length (33 accelerating cells (AC) instead of 29) and, taking into account the experiences of another initial manufacturer [4], extended final tuning possibilities (4 tuning plungers instead of two and tunable end cells). The technique of bolting together these 2.02 m / 160 kg structures from two long side parts and a middle input coupler by a special vacuum/rf-sealing flange was kept. For the 4.90 GHz sections, the scaled 2.45 GHz resonator profile was changed to get a larger cell to cell coupling, i.e. more ample relative tuning tolerances, and by a larger beam hole [5]. For these 1.07 m / 33 kg sections the two side parts were brazed to the input coupler. To clear out any risk of the high power operability of this new structure and also to verify the calculated power presets for resonance frequency ν_0 and passband gap g, the prototype section was built at IKPH and successfully tested [6]. As the next step ACCEL and PMB [7] both delivered a satisfactorily working demo-section; the latter company unfortunately with a too great delay.

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The nominal power presets for ν_0 and g were +0.35 MHz / +1.30 MHz and +0.1 MHz / -1.4 MHz (cf. Fig. 5 & 6) at 2.45 GHz / 4.90 GHz respectively. The max. deviations IKPH demanded for ν_0 and g are noted in Fig. 1. Great care had to be taken for the symmetry of the sections. LOOP [8] calculations showed, that for a good stability of field flatness and low field in the coupling cells (CC) the difference in ν_0 and gap g between the right and left long side part must be as low as possible (Fig. 1). An AC-field flatness of <±3% at standard position and <±10% for the full range of the tuners was demanded; the first value requires a high precision machining of the coupling slots and the second would be e.g. violated by strong mistunings of single AC or CC (tuning goal ±1 resp. ±4 MHz for 4.90 GHz). Finally, Q-values of ≥15000/10000 were prescribed to guarantee shunt impedances of 67 / 81 MΩ/m; and a coupling factor β=1.13±0.05 was demanded for matched operation of the sections at 43×50 µA beam load. An important specification was a good alignment of the resonator discs; the common projection of the beam holes had to be constricted less than 0.5 mm below their 14 / 10 mm diameter.

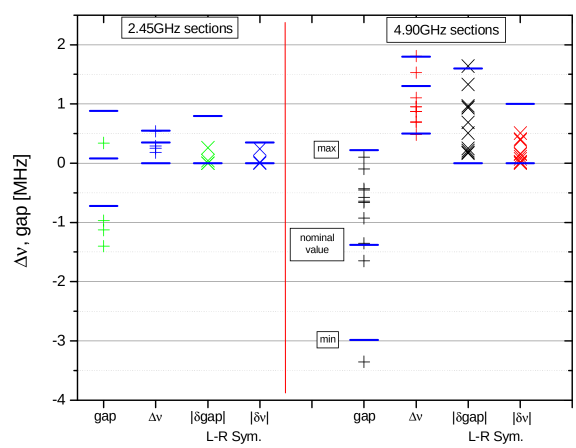

Fig. 1: Statistics of section manufacturing.

MANUFACTURING AND RESULTS

The resonator discs made of OFHC-Cu were pre-machined with 0.5 mm oversize before the final turning and milling was done with 0.02 mm tolerance of the cell dimensions and a surface quality Ra of 0.4 µm. All resonator discs were then annealed to prevent geometry i.e. frequency changes by the later brazing process.

For the pre-braze tuning of all accelerating and coupling cells the frequencies of disc-pairs and disc-staples were measured with the etalon method described in [6]. The frequency correction from ambient conditions to vacuum was calculated with the code CONVERTF (LANL Code Group), the frequency spectrum was analysed by fitting a simplified biperiodic coupled cavity model, taking into account first and second neighbour coupling, to the dispersion curve to get the passband gap g resp. $\Delta\nu_{CC}$. Due to the precise manufacturing of the discs the frequency offsets $\Delta\nu_{AC}$ were 1.5 MHz / 5-10 MHz at 2.45 GHz / 4.9 GHz, which could be tuned by increasing the cell diameter in one or two steps.

The input coupling β of the sections was measured by stacking the complete section consisting of two brazed half-sections and the non-brazed centre cell, and then tuned by iteratively increasing the length of the input coupling slot.

Coming out of the vacuum furnace a He-leaktest of the section was done, especially for a tightness < $1\cdot10^{-9}$ mbar l/s from the 20/12 cooling channels to the interior, and a careful wide-angle technoscopy of all AC and CC for discolourations and contaminants followed. The straightness was controlled by measuring the well tolerated outside height of a section over a plane surface for two 90° shifted azimuthal angles and turned out to be better than 0.3 mm. The specified max. deviations in ν_0 and g were nearly always fulfilled (Fig. 1); and for the 2.45 GHz-gap the overstepping was moderate enough for a good prognosis of a nevertheless satisfactorily working section. All resonance frequency deviations could be easily compensated by the two fixed tuners, without touching the end cells. For all sections the Q-value fulfilled the specification (15960/10350 average at 2.45 GHz resp. 4.90 GHz with < ±1% deviations). The coupling factors β were between 1.04 and 1.24, because of the great sensitivity of β to the length l of the input coupling slot ($\beta\sim l^5$, [6]). Typical bead pull curves for a 2.45 GHz and 4.90 GHz section are shown in Fig. 2, and the two section types, already equipped at IKPH with rf-windows, tuners and antenna probes, are displayed in the photo Fig. 3.

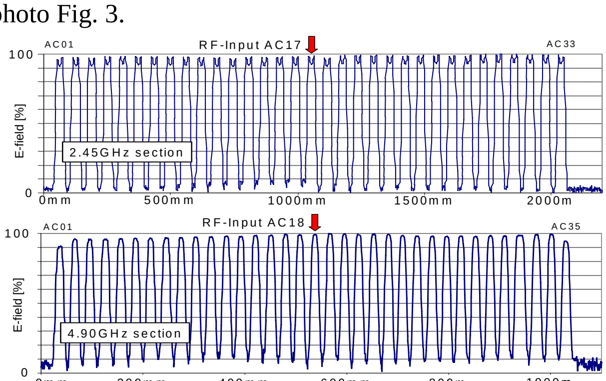

Fig. 2: Bead pull measurement of typical E-field of 2.45 GHz (top) and 4.90 GHz section (bottom).

A surprise was the result of a precise (±0.1 mm) length measurement of the sections by a 2m-calliper. The 2.45 GHz-sections were by 1.9 mm and the first six 4.90 GHz-sections by 1.0 mm too short on the average; a 1.0 mm length error means a phase slip of 2.94° resp. 5.88°. For the beam dynamics of highly relativistic electrons this effect does not matter. As the cause for this error it was found out by a pressing experiment with 4.90 GHz half resonator discs [9], that the force of 1.4 tons on these Cu-discs stapled for rf-tuning measurements had been too high. The 800°C annealed copper was loaded with a stress of 2.4 kp/mm^2, which was beyond its yield strength. For the second series of 4.90 GHz sections the pressing force was reduced to 0.86 tons, just enough for reliable ν- and Q-measurements of the staples, and the thickness of the half resonator discs enhanced by 0.01 mm. As a result these sections had now precisely the correct length.

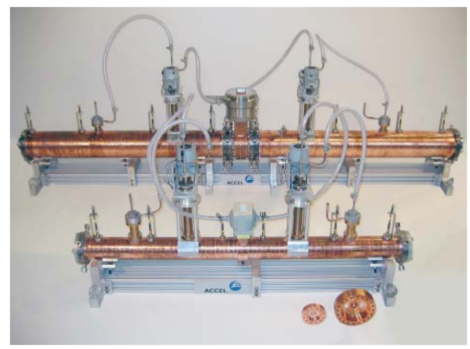

Fig. 3: Photograph of 2.45 GHz and 4.90 GHz MAMI C sections manufactured by ACCEL Instruments.

TEST PROCEDURE AND RESULTS

The main features of the test setup are shown in Fig. 4, the procedure has been described in [6]. The mass spectrometer was very useful for discriminating external leaks (e.g. bad In-sealings at the tuners and the many probes) from internal outgassing; for leak tight operation masses 18 and 28 (H_2O, CO) were clearly dominant. The rf-interlock threshold of the getter pumps was set to 5×10^{-6} mbar resp. 1×10^{-5} mbar at the vacuum window and the section ends. The two -50 dB antenna probes there were connected to a ratio powermeter to watch any irregular jumps in field flatness. The most important parameter of a biperiodic structure is, apart from a correct

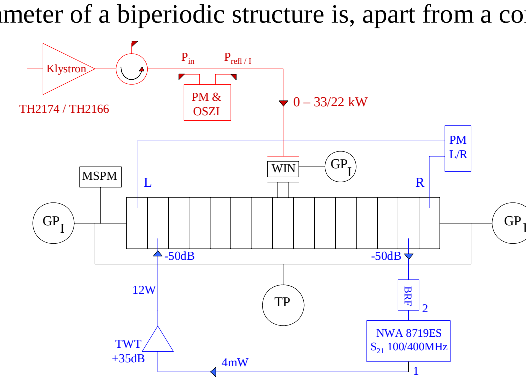

Fig. 4: Basic rf-powertest setup at IKPH (GP/TP - Getter-, Turbo-Pump / MSPM - Mass Spectrometer / PM - Power Meter / BRF - narrow Band Rejection-Filter, < -30dB for ν_0 ±2.5 / ±5 MHz / I - rf-Interlock).

resonance frequency, the passband gap g. The permanent change of g was carefully controlled when rising the max. input power, and exemplarily also its dynamic reversible change was measured again. The results are compiled in Figs. 5 and 6, together with the results for the IKPH-made 2.45 GHz and 4.90 GHz sections ([3],[6]). (Note: The dynamical 4.90 GHz-curve here differs from that published in [6]; there a zero point error occurred). Noteworthy is, that the permanent and the dynamic change in passband gap have opposite sign at 2.45 GHz, but the same sign at 4.90 GHz, in spite of the quite similar geometry of the two structures [5].

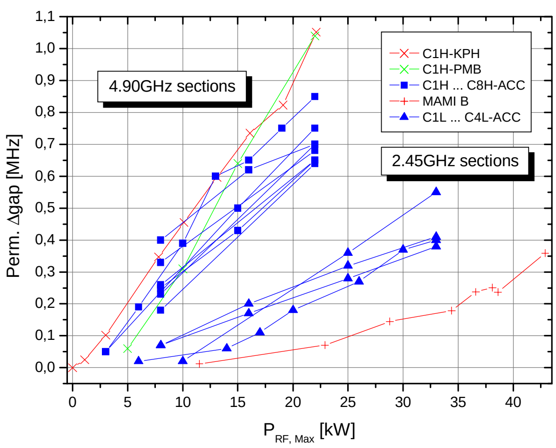

Fig. 5: Permanent change of passband gap with max. applied rf-power (L - 2.45 GHz, H - 4.90 GHz sections).

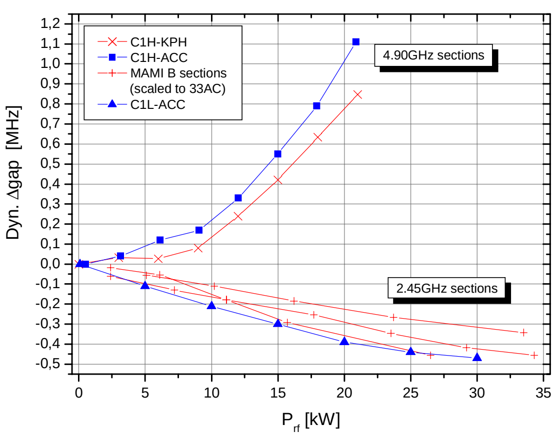

Fig 6: Dynamic change of passband gap with rf-power.

A section was considered to be satisfactorily conditioned, when without interlock (vacuum, rf-reflection) at nominal power (25.5 / 15 kW) the tuners could be moved over their full range (≅ 0.8 / 2.0 MHz for two symmetrical tuners) and at standard tuner position an input power of 33 / 22 kW was possible. Then the section was flooded with air, to somewhat simulate its behaviour in case of the accident of a broken ceramic rf-window, and two of the moveable tuners were replaced by fixed plungers with appropriate length. In most cases the second rf-conditioning then took only 1 h. All 4.90 GHz sections behaved very good natured and were conditioned to full power in 1 to 2 days. For the 2.45 GHz-sections, however, in two cases multipactor problems arose. They manifested in strong oscillating reflections, jumps of flatness up to 20%, and could be localized by an asymmetric behaviour of the three ion getter pumps and precisely by observing the deformation of a blue plasma cloud, visible through two glass windows at the sections ends, when moving a strong permanent magnet along the sections outside wall. In one case the problem

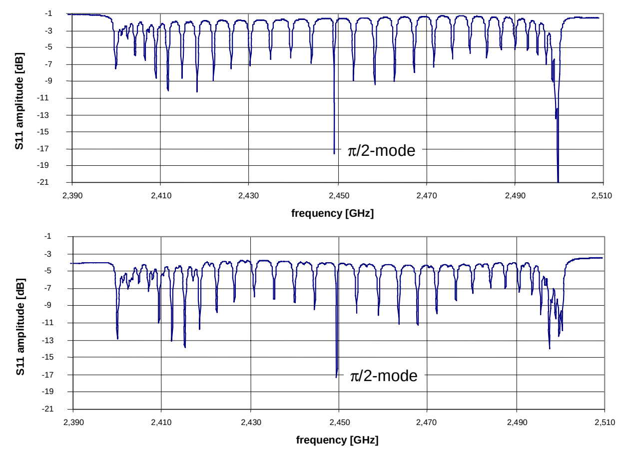

Fig. 7: Frequency spectra of the multipacting 2.45 GHz section C4L-ACC before and after high power test.

was overcome by approx. 1 week of conditioning. In the second case the effect was very strong and deformations leading to a detuning of the multipacting side part developed, as can be seen by comparison of the two frequency spectra of Fig. 7. The lower one indicates by small intermediate resonances a deterioration of symmetry. The section was two times overworked at ACCEL: First the demounted side part was heated in the vacuum furnace up to 760°C, which diminished but did not remove the multipacting. As second attempt a chemical cleaning by chloric and citric acid was done and then again the 760°C annealing; and this made the section working without any problems. The reason for these 2.45 GHz multipacting difficulties is still unknown, the visible surface quality of both types of sections was clearly equal. Evidently the 4.90 GHz-geometry is distinctly less sensitive to this effect

REFERENCES

[1] A. Jankowiak et al., Proc. EPAC02, Paris, p.1085
[2] S.O. Schriber, IEEE Trans. NS-22 (1975), p.1343
[3] H. Euteneuer et al., Proc. LINAC86, SLAC, p.508
[4] A.S. Alimov et al., Instruments and Experimental Techniques, Vol. 48, No. 1, p. 11, Moscow 2005
[5] H. Euteneuer et al., Proc. EPAC00, Wien, p.1930
[6] A. Jankowiak et al., Proc. LINAC04, Lübeck, p.842
[7] PMB, F-78531, Buc Cedex, France
[8] S.O. Schriber, Proc. LINAC02, Gyeongju, p.231
[9] H. Euteneuer, Internal Report MAMI 2/2005