# The Accelerating Cavity of the Racetrack Microtron Eindhoven.

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*Abstract*

The bi-periodic standing wave on axis coupled cavity of the Racetrack Microtron Eindhoven accelerates the 7.5 mA 10 MeV injected electron beam in 13 steps to the final energy of 75 MeV. The 45 cm long, 3 GHz structure consists of 9 accelerating and 8 pancake- like coupling cells and has been designed and constructed in-house. The fabrication and testing of the structure has been completed. Due to the fact that a standard NC lathe was used for the production of the constituting parts special attention has been given to the tuning procedure. This paper presents details on the cavity construction and brazing. Measurement results are presented on the field profiles, the quality factor, the shunt impedance, the generator to resonator coupling and on the high power RF test.

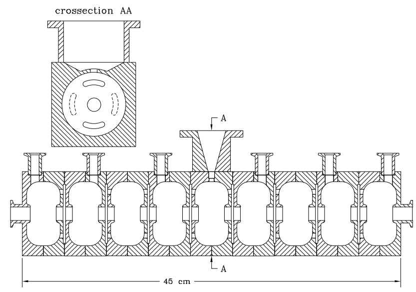


Figure 1: Schematic layout of the cavity.

## 1 INTRODUCTION

The Racetrack Microtron Eindhoven (RTME) has been designed to accelerate a 7.5 mA electron beam from the injection energy of 10 MeV to the final energy of 75 MeV [1]. The acceleration is achieved in 13 subsequent passages by a 5 MeV, 3 GHz standing wave on-axis coupled cavity. This cavity was designed[2] and built in-house, see sec. 2. In sec. 3 the measured parameters of the completed cavity are described. For the commissioning of RTME, it is advantegeous to inject the electron beam at lower energy, subsequently the energy gain in the cavity has to be lowered for synchronous acceleration. In sec. 4 the consequences for the generator and reflected powers are described. Sec. 5 gives some concluding remarks.

## 2 FABRICATION AND TUNING

Fig. 1 depicts the schematic lay-out of the RTME cavity. The 9 accelerating and 8 coupling cells are formed by stacking 18 square bricks of OFHC-Cu. In order to facilitate a number of repetitive machining cycles it was decided to cut the two cell halves in accurately fabricated square bricks and to utilise some special made tools that position the bricks in a repetitive manner on the lathe. Due to the machining, stress will be built up in the material, which will lead to deformation of the copper and as a consequence changes in resonance frequency during the brazing process. To avoid these changes a carefull production sequence was adapted.

For the tuning the parts are stacked in sets of 2 and 4, terminated with plates forming respectively 3 and 5 coupled resonators with 3 and 5 mode frequencies.

When the numbered parts are measured in pairs, from the 3 measured mode frequencies the $\pi/2$-mode frequency, $\omega_{\pi/2}$, the coupling cell frequency $\omega_c$ and the coupling constant $k_{ac}$ are obtained. By forming different combinations the individual $\pi/2$-mode resonance frequencies of the individual parts are determined.

When a set of 4 parts is stacked together, the 5 coupled resonators yield 5 mode frequencies, one is $\omega_{\pi/2}$. With a fit to the dispersion relation for a bi-periodic chain $\omega_a$ and $\omega_c$, $k_{ac}$ and the direct coupling constant $k_{aa}$ are determined, $k_{cc}$ has been put zero.

The radius of the coupling cells is increased from 35 mm to the final value of 35.5 mm in two steps. Measurements point out that the resonance frequencies of the coupling cells after these adjustments are equal within a few MHz.

The initial frequencies of the accelerating cells are too high, therefore they are brought down in frequency by an enlargement of the volume. The frequencies of the individual parts were determined by multiple measurements of the parts in pairs. All the parts, except the 2 terminating ones and the 2 middle ones that house the iris are tuned this way. After this tuning procedure the $\pi/2$-mode frequencies of the accelerating cells were scattered around the tuning frequency within a band of $\pm 0.2$ MHz.

To tune the end parts they are stacked with their two tuned nearest neighbour parts. This structure is covered with a plate. The $\pi/2$-mode resonance frequency of this structure is adapted to the tuning frequency by adapting the frequency of the end part.

The dimensions of the coupling iris are determined by reflection measurements in the waveguide. After fabrication

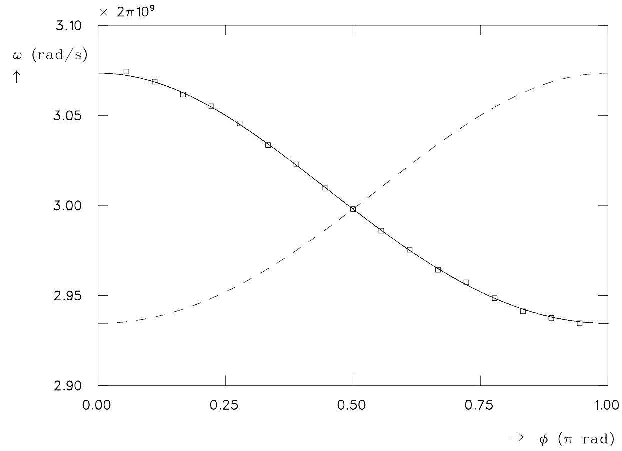


Figure 2: Measured dispersion relation of the cavity.

of the coupling iris, the frequency of the middle cell was determined by stacking it with another already tuned pair of parts and subsequently determining the $\pi/2$-mode frequency of the middle cell. Due to the coupling iris the resonance frequency of the middle cell was initially lower than the tuning frequency. The frequency was adjusted by an enlargement of the gap between the nose cones.

Since in a perfectly tuned structure there will only flow major RF currents on the outer surface of the accelerating cells, it was decided to only join the two halves of the accelerating cells by brazing, whereas the two halves of the coupling cells are joined by O-rings.

As brazing material $Ag_{72}Pd_{0.2}Cu_{27.8}$ with a melting temperature of $780^\circ$ C has been used. The frequency changes of the individual accelerating cells due to the brazing were limited to $\pm 250$ kHz, with an average value of -55 kHz. After brazing, the $\pi/2$-mode frequency of the structure at $25^\circ$ C was 2997.8 MHz, only 0.04 MHz below the tuning frequency. The operation temperature of the cavity, $35^\circ$ C, is controlled via a closed cooling water circuit.

The precise outer dimensions are also used to carefully align the bricks, that form the cavity, in a special ridge. Here the pieces are kept together with a force of $\sim 3000$ N by a multi-spring based clamping mechanism. After constitution of the different parts in the ridge no vacuum leaks could be detected.

## 3 MEASURED PARAMETERS

Fig. 2 depicts the measured dispersion relation of the 17 cell cavity. The squares denote the resonance frequencies of the individual modes, the solid line is the least square fit of the dispersion relation for a bi-periodic chain to the measured data. The results of this fit are listed amongst other data in table 1.

The electric field profile of the $\pi/2$-mode has been determined by means of the perturbating ball method, see fig. 3. The standard deviation in the measured amplitudes corre-

Table 1: Measured and related quantities of the RTME cavity, $T_{Cu} = 298$ K.

| | |
|---|---|
| $f_{\pi/2}$ (MHz) | 2998.70 |
| stopband (MHz) | -0.06 |
| $k_{ac}$ (%) | -4.61 |
| $k_{aa}$ (%) | -0.24 |
| loaded quality factor | 4125 |
| $\beta$ | 2.35 |
| unloaded quality factor | 13820 |
| cavity length (m) | 0.45 |
| $r_{eff}$ (MΩ/m) | 62.3 |
| $R_{sh}$ (MΩ/m) | 28.1 |
| $P_{cav}$ (MW) | 0.90 |
| $P_{ref}$ (MW) | 0.06 |
| $P_b$ (MW) @ 7.5 mA | 0.50 |

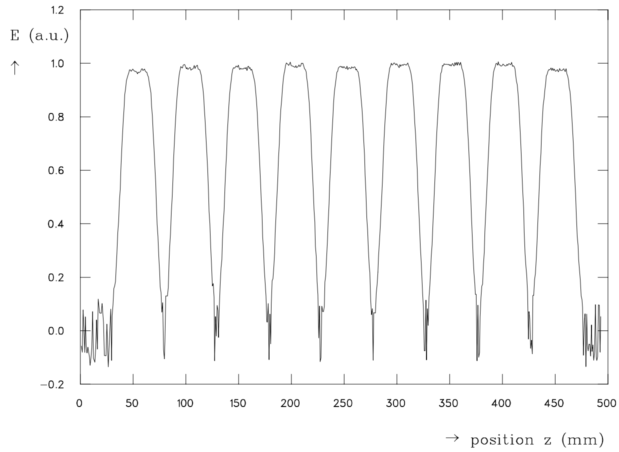


Figure 3: Measured electric field profile in the cavity.

sponds with 1% of the average amplitude in the cells, indicating that the structure is properly tuned. It is not possible to quantify the magnitude of the electric fields in the coupling cells.

From the measured field profile, the shunt impedance $R_s$ of the structure is calculated [3]:

$$R_s = \frac{4Q_{\pi/2}}{\pi\varepsilon_0\omega_{\pi/2}\delta_0^3}\left[\int\left|\frac{\Delta f}{f_0}\right|^{1/2} ds\right]^2 , \qquad (1)$$

$\delta_0$ = 5 mm is the diameter of the ball, $\Delta f/f_0$ the relative frequency shift due to the ball and $Q_{\pi/2}$ the quality factor of the $\pi/2$-mode. This yields a shunt impedance $R_s = 28.1$ MΩ, which gives $r_{eff} = 62.3$ MΩ/m: 78% of the value calculated with Superfish.

Fig. 4 depicts the measured incident (generator) and reflected power at the cavity, as well as the power built up in the cavity. This measurement has been performed with a tunable 2.0 MW magnetron as power source. The magnetron and cavity were connected via a 4-port circulator. If the magnetron is at port 1, the cavity is at port 3 of the circu-

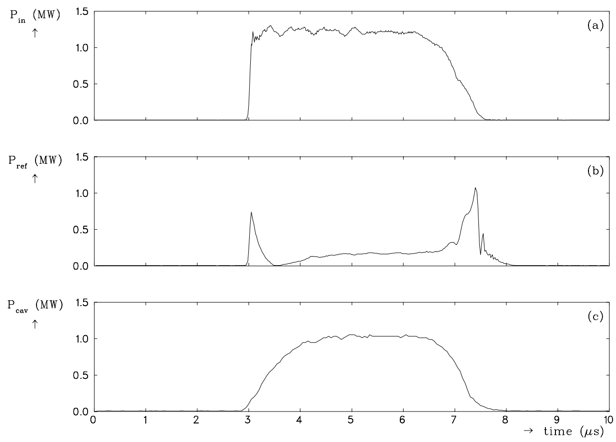


Figure 4: a) Incident, b) reflected and c) power built up in the cacity.

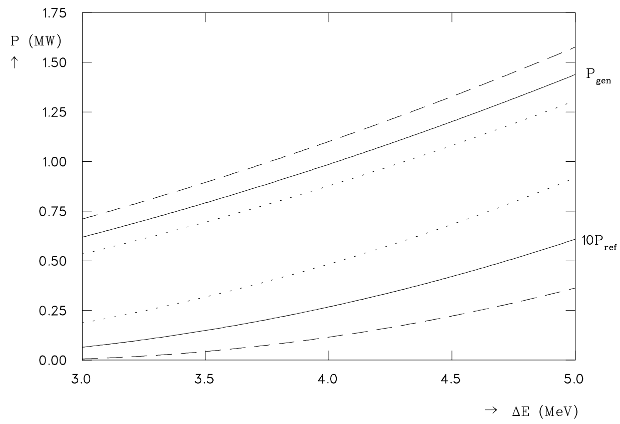


Figure 5: The required generator power and 10 times the accompanying reflected power at the cavity as a function of the energy gain per passage, for different single pass beam currents: 10.0 mA (- - -), 7.5 mA (——), 5.0 mA (· · · · ·).

lator. The amount of power that is send towards the cavity is regulated by means of a high power magic T at port 2 of the circulator. The power levels are measured by means of a calibrated chrystal detector, this method is accurate if the magnetron power is constant and known.

In fig. 4.b in steady state approximately 14% of the incident power at the cavity is reflected. In good agreement with eq. 3, which yields an amount of 15% of the generator power that is reflected.

At most as much as 1.6 MW generator power was sent to the cavity, meaning an energy gain $\Delta E = 6.1$ MeV. This implies operation at a maximum surface field strength of 1.17 Kilpatrick field limit. At this field strength hardly any voltage break downs occured.

## 4 VARIABLE ENERGY GAIN

The required generator power for a certain dissipated beam power, $P_b$, and cavity power, $P_{cav}$, is given by [4]:

$$P_{gen} = \frac{P_{cav}}{4\beta}\left(1 + \beta + P_b/P_{cav}\right)^2 . \qquad (2)$$

Also the reflected power can be written as a function of the beam and cavity power:

$$P_{ref} = \frac{P_{cav}}{4\beta}\left(1 - \beta + P_b/P_{cav}\right)^2 , \qquad (3)$$

where $\beta$ is the generator to cavity coupling coefficient. With these equations the required generator and reflected powers for the cavity can be calculated as a function of energy gain and beam current, see fig. 5. The energy gain $\Delta E = 5$ MeV in the figure corresponds to the proposed 10-75 MeV mode of operation for the microtron. The energy gain range of 3 - 5 MeV is of particular interest since it corresponds with all possible modes of operation of the microtron, that can be realised with the present injector linac.

## 5 CONCLUDING REMARKS

The low and high power tests point out that the RTME cavity is properly tuned and is able to accelerate the electron beam by as much as 6.1 MeV per passage. At this energy gain, or any other energy gain between 0.5 and 6.1 MeV, no sign of multipacting was observed.

From the tests it can be concluded that the accelerating structure lives up to the demands and it is expected that it will function well as accelerating structure for the Racetrack Microtron Eindhoven over a broad range of energy gains.

## 6 REFERENCES


[1] Webers G.A., *Design of an electron optical-system for a 75 MeV racetrack microtron*, Ph.D. Thesis, Eindhoven University of Technology (1994).

[2] Leeuw de R.W. et al., *Design study for the accelerating cavity of the racetrack microtron Eindhoven*, Proc. Eur. Part. Acc. Conf. London (1994), 2092-2094.

[3] Kleeven W.J.G.M. et al., *The accelerating cavity of the TEUFEL racetrack microtron*, Proc. Eur. Part. Acc. Conf. London (1994) 2095-2097.

[4] Theeuwen M., *The accelerating cavity of the racetrack microtron of the TEUFEL-project*, MSc. Thesis, Internal report VDF/NK 91-28, Eindhoven University of Technology (1991).