The Accelerating Cavity of the TEUFEL Racetrack Microtron

W.J.G.M. Kleeven[*] J.I.M. Botman, J.E. Coppens, J.L. Delhez, H.L. Hagedoorn,
J.A. van der Heide, M.H.M. Knoben, R.W. de Leeuw, C.J. Timmermans
Eindhoven Univ. of Technology, Cyclotron Lab., P.O. Box 513, 5600 MB Eindhoven, Netherlands
A.F.M. Bouman and J.W.J. Verschuur
Univ. of Twente, Department of Applied Physics, P.O. Box 217, 7500 AE Enschede, Netherlands

Abstract

As part of the free electron laser project TEUFEL, a 25 MeV racetrack microtron is under construction. The fabrication and testing of the microtron cavity has been completed. Details of the cavity construction are given and results are presented on tuning and brazing, measurement of the field profiles, quality factor and shunt impedance, matching of the input impedance and on the high power rf tests.

1 INTRODUCTION

The free electron laser project TEUFEL[1] is a cooperation between the Dutch universities of Eindhoven and Twente. A part of this project is a 25 MeV racetrack microtron[2] which is being built at Eindhoven. The present status of this machine is given in Fig. 1. The microtron cavity is a standing wave on axis coupled structure that consists of three accelerating cells and two coupling cells. In previous papers we presented experimental and numerical results obtained for a scale 1:1 aluminium model[3] and also the results of equivalent circuit simulations of the cavity[4] and of the beam loading problem[5, 6]. In this contribution results are presented of the final fabrication and tuning of the structure and the succesful rf tests that have been performed.

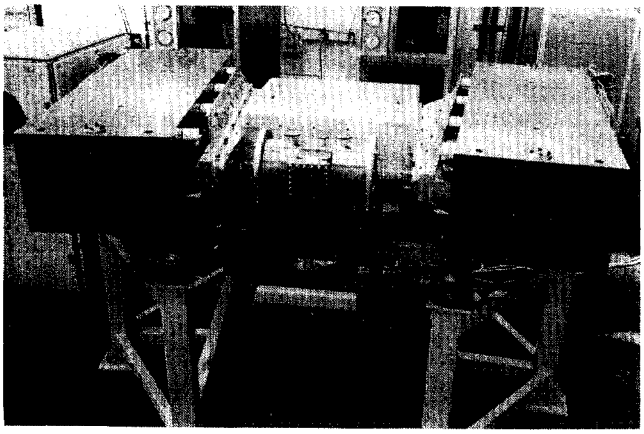

Figure 1: Present status of the TEUFEL microtron

Figure 2: The six cavity half-cells and waveguide input coupler before brazing

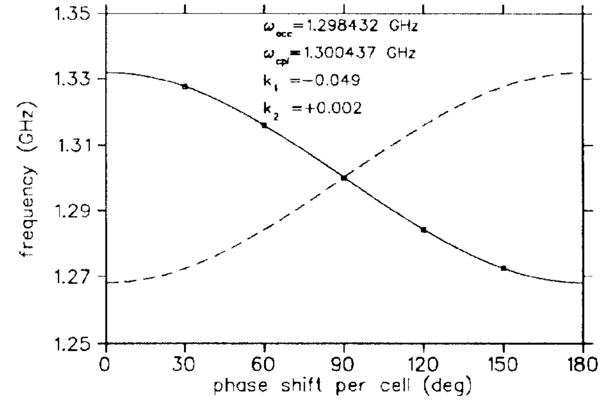

Figure 3: Biperiodic 5-cell equivalent circuit fit of the accelerating cavity dispersion diagram

2 CONSTRUCTION AND TUNING

The photograph in Fig. 2 shows the six half-cells of the cavity before brazing. Because of convenience and also because of vacuum oven space restrictions, only the separate accelerating cells were brazed and rubber O-rings were used to seal the coupling cells. The quality of the cavity does not suffer from this, because the $\pi/2$-mode has empty coupling cells. Furthermore, the required vacuum is only of the order of 10^{-6} torr so that beaking at high temperature is not necessary. An additional advantage of the construction is, that a possible detuning of one cell caused by brazing, can be compensated by re-tuning one of the remaining cells. This detuning varied between −15 kHz and −200 kHz per cell. Brazing was done at a temperature of 780 °C with Cusil (Ag/Cu–72/28). Assem-

---

[*] present adres: IBA,Chemin du Cyclotron 2, B-1348 Louvain-la-Neuve, Belgium

Cavity frequency f_0 (measured)	1.3 GHz
Operating temperature for 1.3 GHz	34 °C
Accelerating voltage V	2.22 MV
Cavity length	42.5 cm
Shunt impedance $R_sT^2 = \frac{V^2}{2P}$ (MAFIA)	18.6 MΩ
Shunt impedance (measured)	15.9 MΩ
Wall losses (assuming R_sT^2=15.9 MΩ)	310 kW
Transit time factor T (MAFIA)	0.80
Unloaded quality factor Q_0 (MAFIA)	23500
Unloaded quality factor (measured)	18330
Loaded quality factor Q_L (measured)	2380
Generator-cavity coupling β (measured)	6.7
Acc. to coupl. cell coupling k_1 (measured)	−0.049
Acc. to acc. cell coupling k_2 (measured)	+0.0020
Measured frequency spectrum (air, 27 °C)	
$\pi/6$-mode (Q_0 = 1955) (GHz)	1.327506
$\pi/3$-mode (Q_0 = 2175) (GHz)	1.316059
$\pi/2$-mode (Q_0 = 18330) (GHz)	1.299737
$2\pi/3$-mode (Q_0 = 1930) (GHz)	1.284052
$5\pi/6$-mode (Q_0 = 2040) (GHz)	1.272456

Table 1: Accelerating cavity parameters

bly of the complete cavity is done in between two stainless steel flanges that are tightened with three iron studs. The stainless steel waveguide input coupler is also sealed by a rubber O-ring. No mechanical tuning is used. Fine tuning during operation is done by changing the cavity temperature. For this purpose six water cooling channels are made in the cylindrical wall of the cavity.

Tuning of the middle four half-cells was done by measuring appropriate combinations of one half accelerating cell, a full coupling cell and another half accelerating cell. Such a set was stacked between two copper plates that carried two small coupling loops to do transmission measurements. Simple equivalent circuit models were used to obtain the frequency errors in the separate cells from the measured frequency spectrum. A lowering of the cell frequency was done by removing copper from the outer cavity wall; a frequency increase by removing copper from the nose cones. Estimates of the wall material to be removed were obtained with SUPERFISH. Machining of the cavity cells was done on a computer driven lathe which allowed corrections to the contours in the order of 0.01 mm. The frequency errors in the outer two half-cells were obtained by measuring the complete cavity with two thin capacitive wires, placed on the cavity axis. Frequency shifts due to temperature deviations ($\Delta f \approx -20$ kHz/°C) and difference in permeability between air and vacuum ($\Delta f \approx$400 kHz), were taken into account.

The rf input iris was optimized before the tuning was done. This, because changing the iris dimensions would also influence the frequency of the middle cell. In order to avoid any influence from an inhomogeneous field profile (as caused by tuning errors), the iris optimization was done by just measuring the middle cell. Therefore, the measured cavity coupling parameter β, should be three times higher than the required value.

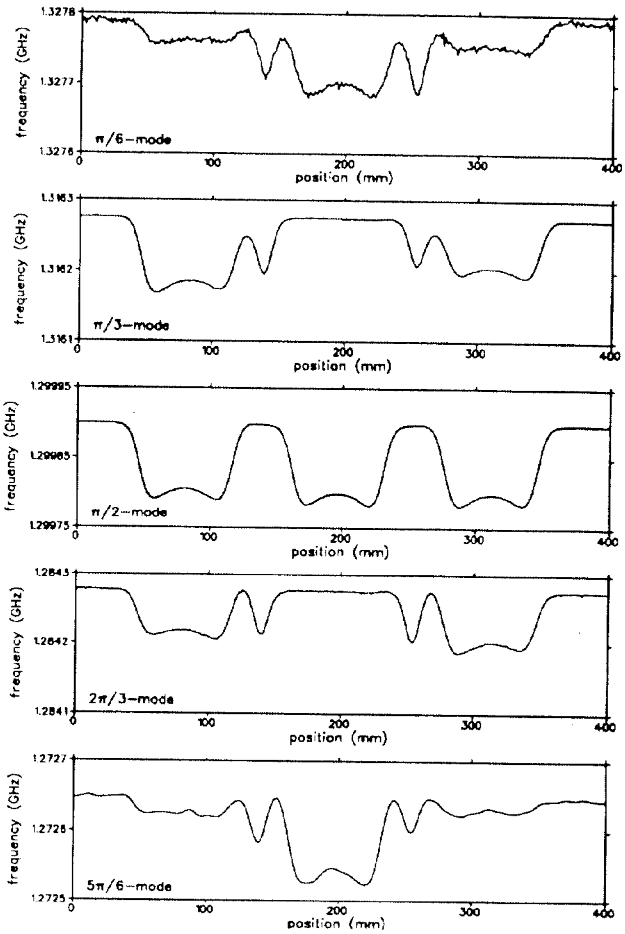

Figure 4: Profiles of the five ground modes, measured with a 5 mm diameter copper perturbation ball

3 MEASUREMENTS

All measurements were carried out with a computer controlled sweep oscillator (HP 8341) and network analyzer (HP 8510B). Approximately 25 iterations were needed to achieve the correct contours of all six cavity half-cells. The final frequency of the brazed cavity (1.3 GHz at 34 °C) agreed very well with the design value (1.3 GHz at 35 °C). Some results of measurements as well as calculations are given in Table 1. From the measured mode spectrum a dispersion diagram was obtained (Fig. 3) by fitting with a biperiodic 5-cell equivalent circuit model in which first and second neighbour coupling as well as two different frequencies for the accelerating cells and coupling cells were assumed. The small stop band of only 800 kHz underlines the proper relative tuning of the cells w.r.t. each other.

Field profiles were measured with the perturbation ball method. For a metal sphere with diameter δ, the electrical field profile E on the cavity axis is related to the measured

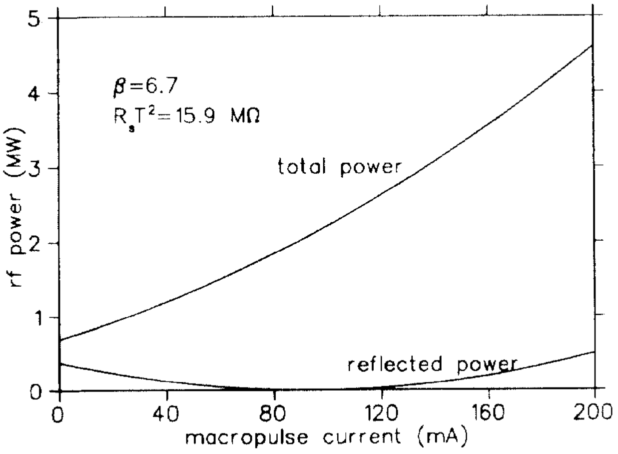

Figure 5: Required rf generator power and reflected power as a function of the average macropulse current

frequency shift by

$$\frac{\Delta f}{f} = -\frac{\pi\delta^3}{8W}\epsilon_0|E|^2, \qquad (1)$$

where W is the stored energy. Results of these measurements are given in Fig. 4. The flatness of the $\pi/2$-mode once more indicates proper tuning. The shunt impedance in Table 1 is obtained from the measured profile via the formula

$$R_s = \frac{4Q_0}{\pi\epsilon_0\omega_0\delta^3}\left[\int(\frac{\Delta f}{f})^{1/2}ds\right]^2, \qquad (2)$$

where ω_0 is the angular frequency and s is the path length along the cavity axis.

The cavity coupling coefficient β=6.7 was obtained from the loaded and unloaded quality factors. The result was confirmed however, by Smith-card measurements of the reflection close to resonance. In Fig. 5 we give the required generator rf power and the reflected power in dependence of the average macropulse beam current This was calculated with the formula[6]

$$r = \frac{(1+p-\beta)^2}{4\beta} + \frac{(1+\beta)^2}{4\beta}(\tan\psi - \tan\psi_0)^2, \qquad (3)$$

where r is the normalized reflected power (normalized w.r.t. the wall losses), p is the normalized beam power, $\tan\psi = -2Q_L(\omega-\omega_0)/\omega_0$, $\tan\psi_0 = -p\tan\phi/(1+\beta)$, ω is the angular rf frequency and ϕ is the accelerating phase.

4 HIGH POWER RF TEST

The high power rf test was done at the university of Twente where a 20 MW, 1.3 GHz klystron (Thomson, TH 2022C) is in use for the injector linac. The rf pulse duration could be varied between 0 and 18 μsec and the pulse repetition frequency between 0 and 2 Hz. Forward and reflected power were measured with a calibrated six-port reflectometer. A small pickup loop was applied to measure the voltage signal in the cavity. A regulated closed water circuit was used to warm the cavity to 34 °C in order to achieve resonance at 1.3 GHz. It was found that the water pressure should not be too high in order to avoid small mechanical resonances. The cavity was evacuated to a pressure of 10^{-6} torr with a turbomolecular pump and ion getter pump placed in parallel.

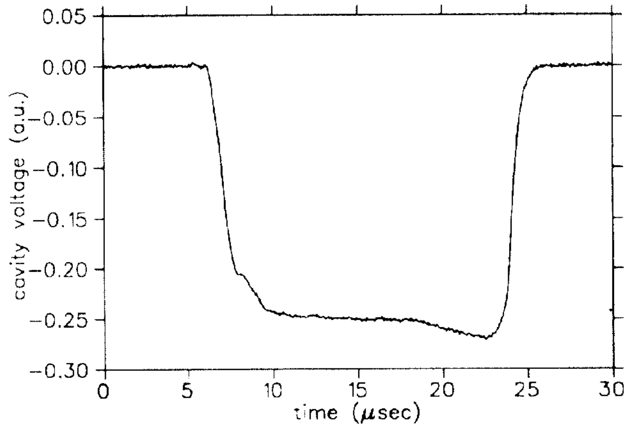

Figure 6: Typical cavity voltage pickup signal measured during the high power rf test

The maximum power level in the cavity achieved after one week of conditioning was around 550 kW, which should be compared with the 310 kW needed for 2.22 MV accelerating voltage. At 450 kW cavity power almost no electrical break-throughs were observed. These break-throughs could be visualized with a remotely controlled camera that looked through a perspex window in one of the vacuum ports. About 50 % of the input power reflected at the cavity entrance, as is in good agreement with the measured β-value. A typical cavity voltage pickup signal is given in Fig. 6. The slight rise during the second half of the pulse is due to a non-constant modulater voltage.

5 REFERENCES

[1] G.J. Ernst et. al., Nucl. Instr. Meth. A318(1992)173.

[2] J.I.M. Botman et. al., Developements on the TEUFEL Injector Racetrack Microtron, to be publ. in the Proc. of the 1993 FEL conference, The Hague, Netherlands.

[3] W.J.G.M. Kleeven et. al., Nucl. Instr. Meth. B68(1992)87.

[4] W.J.G.M. Kleeven and M.E.H.J. Theeuwen, Equivalent Circuit Simulation of a 5-cell Biperiodic Accelerating Structure, Eindhoven University of Technology, Cyclotron Lab., Internal Report VDF/NK 91.25, 1991.

[5] W.J.G.M. Kleeven et. al., Proc. 3rd Europ. Part. Acc. Conf. (EPAC), Berlin, 1992, pp. 813.

[6] W.J.G.M. Kleeven and J.A. van der Heide, Equivalent Circuit Analysis of Beam Loading in an Accelerating Cavity, Eindhoven University of Technology, Cyclotron Lab., Internal Report VDF/NK 91.21, 1991.