Design and construction of standing wave accelerating structures at TUE

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Abstract

Two standing wave accelerating structures have been built for the operation of two AVF racetrack microtrons (RTM). For the first RTM a 3 cell 1.3 GHz on axis coupled standing wave structure has been designed to accelerate a 50 A peak current beam in 9 steps from the injection energy of 6 MeV to a final energy of 25 MeV. The beam will be used as drive beam for the free electron laser TEUFEL. The second structure accelerates a 7.5 mA beam in 13 steps from the injection energy of 10 MeV, to a maximum energy of 75 MeV. This 9 cell on-axis coupled structure operates at 3 GHz and was designed with a relatively large aperture radius (8 mm) in order to avoid limitations on the RTM's acceptance. Design, fabrication and testing of the structures have been done in house. For the design of the structures the combination of the codes Superfish and Mafia has been used. Low and high power tests proved that the structures live up to the demands. With the experiences gained a design for the accelerating structure of the H^- linac of the ESS project has been made. The design of the cells as well as a novel type of single cell bridge coupler will be presented.

Introduction

The Racetrack Microtron Eindhoven (RTME) has been designed to accelerate a pulsed 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, see sec. .

The free electron laser project TEUFEL is a cooperation between the Dutch universities of Eindhoven and Twente. Part of this project is a 25 MeV racetrack microtron which is being built at Eindhoven [2]. The microtron cavity is a standing wave on-axis coupled strucure that consists of three accelerating cells and two coupling cells, see sec. .

The linac of the accelerator based neutron spallation source ESS project will accelerate a 100 mA H^--beam over 660 m length from 70 to 1334 MeV. This paper describes the cell and brigde coupler design in sec. .

The RTME cavity

Fig. 1 depicts the schematic lay-out of the on-axis coupled RTME cavity. Table 1 lists some of the measured and related parameters of this cavity [3].

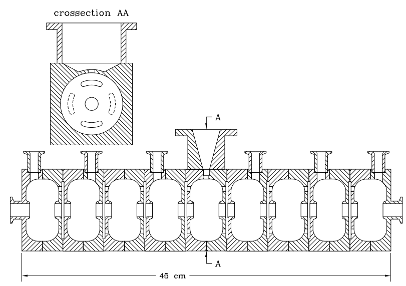

Figure 1: Schematic layout of the RTME cavity.

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

resonant frequency (MHz)	2998.70
stopband (MHz)	-0.06
accelerating voltage (MV)	5.0
coupling coefficient (%)	-4.61
direct coupling coefficient (%)	-0.24
loaded quality factor	4125
coupling ratio β	2.35
cavity length (m)	0.45
eff. shunt impedance (MΩ/m)	62.3
dissipated power (MW)	0.90
beam power (MW) @ 7.5 mA	0.50

The 9 accelerating and 8 coupling cells are formed by stacking 18 accurately fabricated square bricks of OFHC-Cu. These square bricks are used for a repetitive mounting on the lathe and for the alignment of the total cavity in a ridge. Here the pieces are kept together with a force of ~ 3000 N by a multi-spring based clamping mechanism.

For the tuning the parts are mainly stacked in sets of 2 and 4 terminated with plates forming respectively 3 and 5 coupled resonators with 3 and 5 mode frequencies. From the three mode frequencies the accelerating and coupling cell resonant frequencies and the coupling coefficient are obtained. From the five mode frequencies also the direct coupling coefficient for the accelerating cells is obtained.

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 resonant frequency of this structure is adapted to the tuning frequency by adapting the frequency of the end part.

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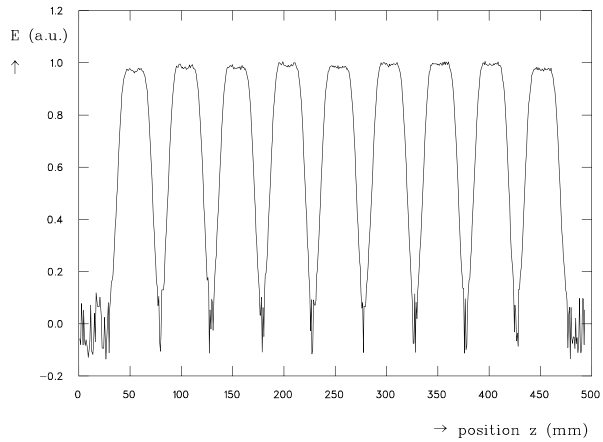

Figure 2: The measured electric field profile in the RTME cavity.

The dimensions of the waveguide-cavity coupling iris are determined by repetitive VSWR measurements in the waveguide.

Since in a perfectly tuned structure there will only flow major RF currents on the outher 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° C has been used. After constitution of the different parts in the ridge no vacuum leaks could be detected.

After the completion of the structure the electric field profile of the $\pi/2$-mode has been determined by means of the pertubating ball method, see fig. 2. The standard deviation in the measured field amplitudes corresponds with 1% of the average amplitudes 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.

The high power tests have been done with a 2 MW EEV M5125 magnetron that was connected to the cavity via a 4-port circulator. By means of an EH-tuner located after the second port of the circulator the amount of power sent to the cavity at the third port could be regulated [3]. At most as much as 1.6 MW of power was sent to the cavity, implying an energy gain of 6.1 MeV for the electrons. This means operation at a maximum field surface strength of 1.17 Kilpatrick field limit. At this field strength hardly any voltage breakdowns occured and no sign of multipacting was observed.

The TEUFEL cavity

The fabrication of the TEUFEL cavity was done similarly as the RTME cavity. Table 2 lists some characteristics of the TEUFEL cavity [4].

Due to the high peak currents in the cavity the structure will operate under high beam loading conditions. Therefore the coupling ratio is relatively high, $\beta = 6.7$. The precise beam current to be accelerated in the microtron is not known yet. The generator and reflected power in dependence of the macro pulse current is depectid in fig. 3. This was calculated with formula[5]

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

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 RF frequency and ϕ is the accelerating phase.

Table 2: Accelerating cavity parameters

resonant frequency (MHz)	1300
stopband (MHz)	0.8
accelerating voltage (MV)	2.22
coupling coefficient (%)	−4.9
direct coupling coefficient (%)	+0.2
loaded quality factor	2380
coupling ratio β	6.7
cavity length (m)	0.425
eff. shunt impedance (MΩ/m)	15.9
dissipated power (MW)	0.31

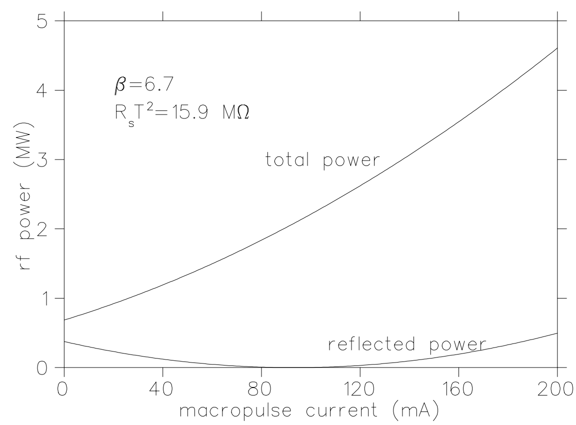

Figure 3: Required RF generator power and reflected power as a function of the average macropulse current for the TEUFEL cavity

The ESS linac

The proposed lay-out of the linac of the European Spallation Source (ESS) project [6] has two front ends, each with a H^- source (70 mA, 50 kV, 10% d.c.), low energy beam transport, an RFQ, a beam chopper and a second RFQ. Funneling is at 5 MeV. A drift tube linac (DTL) operating at 350 MHz accelerates the beam up to 70 MeV. In the reference design a 700 MHz normal conducting side coupled cavity linac (CCL) further accelerates the beam to 1.334 GeV to feed the rings [7].

In the CCL a single 2 MW klystron will feed 2 tanks connected via a bridge coupler. The tank length is determined by limiting the peak power per tank to 0.75 MW. It than varies from 1.27 (16 cells at 70 MeV) to 1.95 m (10 cells at 1.334 GeV), short enough to allow constant cell length in one tank (the phase slip per tank is 4 deg.). The intertank gaps have a length of $5/2\beta/\lambda$

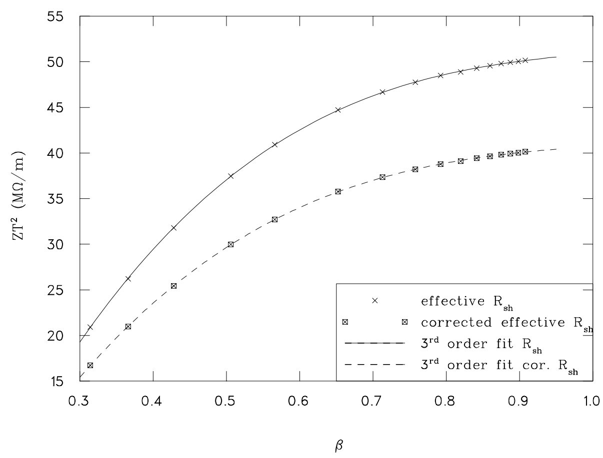

Figure 4: Calculated shunt impedance as a function of the velocity β. The lower curve represents the values for the shunt impedance lowered by 20 %.

and 3/2 β/λ. Over the shorter gap the two tanks are connected via a bridge coupler.

In the design of the CCL first the shunt impedance and the transit time of the individual cavities is maximised. Various parameters determining the shape of a cell are of importance. The shunt impedance increases with decreasing bore hole radius, web thickness between cells and nose cone thickness.

Fig. 4 depicts the values for the shunt impedance as optimised with Superfish. It is reasonable to lower this values by 20 % to account for the losses due to the coupling slots between accelerating and coupling cells and manufactoring imperfections. In previous designs of long side coupled CCL's the outher diameter of the cells has been kept constant in order to minimise fabrication costs. With modern machining techniques, as programmable lathes, this is no longer necessary. The extra costs due to the variating outher diameter will not imply a significant cost increase. The diameter will be kept constant within a single tank.

For the calculation of the cell geometries we have the availability of the accurate 2D code Superfish and the less accurate 3D code Mafia. For the calculation of the coupling coefficient between the accelerating and coupling cells we need accurate 3D results. Therefore for this calculation the combination of the codes Superfish and Mafia has been used as described in ref. [8]. By varying the offset of the symmetry axis of the coupling cells to the symmetry axis of the accelerating cells the coupling coefficient can be varied between 2 and 8 %.

Due to the varying length of the bridge couplers a number of higher order modes in these bridge couplers are within the passband of the accelerating tanks [9]. At lower energies the TE_{111} mode crosses the passband. This mode can easily be expelled from the passband by placing two round disks with a diameter of about half the coupler diameter at the end of the coupler at the locations where the electric field is maximum. At higher energies the TE_{112} mode crosses the passband. This mode is expellled from the passband by placing two rings in the coupler where the amplitude of the TE_{112} mode is maximum. The rings are large enough to expell the perturbing mode from the passband, but small enough to assure that the resonator still operates as a single cell resonator. Mafia calculations on the combination of two accelerating cells that are connected via coupling cells to the bridge coupler show that the method works. One has to assure however that the shifted mode is well outside the passband to avoid mixing with one of the chain modes.

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