DESIGN AND HIGH POWER TEST OF A 30 GHZ PLANAR ACCELERATING STRUCTURE

R. Merte, H. Henke, Technische Universitaet Berlin, Germany
D. Yu, DULY Research Inc., CA, USA

Abstract

The paper presents[1] the design of a planar R-Band accelerating structure and results of a first high power test. The structure is a traveling wave, constant impedance structure, with 37 cells operating in the 2π/3-mode. It consists of two halves which were fabricated by high speed, high precision CNC milling. The two halves and all flanges were brazed at high temperature in a two step procedure. The high power test was done in the CLIC Test Facility II at CERN [1]. The structure was powered with 30 GHz power extracted from the CTF drive beam. Power ratings were between 80 and 40 MW in pulses from 4 to 16 ns long. No evidence of breakdown could be observed. The cavity which is slightly out of frequency accelerated a probe beam with an effective gradient of 23 MV/m after manipulating the CLIC drive beam and thus shifting the frequency upwards by 150 MHz.

1 INTRODUCTION

Planar structures are very different as compared to round structures. The accelerating mode excites transverse forces which depend on the longitudinal and transverse position. The excitation of higher order modes is expected to be much weaker, and the surface quality and the shaping of the irises are different. This will affect the power handling capability and the beam dynamics. Therefore and because planar structures have never been used to accelerate particles, it was decided to build a fully engineered cavity and to test it under real conditions at the highest possible frequency.

At present the upper frequency limit for high power sources is 29.986 GHz available at CERN. A fully engineered 37-cell prototype operating in the 2π/3-mode at the CLIC frequency, was fabricated by CNC milling. The design includes in- and output couplers, a cavity geometry such that $|F_x| = |F_y|$, vacuum flanges and beam pipe flanges. All connections of the prototype are compatible with the CLIC test facility (CTF) at CERN. In a collaboration with the CLIC team at CERN in summer 1999 some experiments are done. Firstly, the cavity was driven by the beam and spectra were observed. Secondly, the cavity was powered with RF pulses between 40 and 80 MW and pulse lengths between 16 and 4 ns, respectively.

2 GEOMETRY OF THE STRUCTURE AND RF PARAMETERS

The planar structure is a 37-cell traveling wave, constant impedance structure at 29.986 GHz. From the wavelength of 9.997 mm follows a period length of p = 3.332 mm for the 2π/3–mode.

The iris thickness has been fixed to t = 0.7 mm. The length of one cavity in beam direction is $g = p - t$ = 2.632 mm. A detailed description of the geometry of the structure is given in [3].

The basic RF parameters are determined numerically with GdfidL [2] and listed in table 1. A test model should have a small number of cells, but it should be large enough to present a measurable impedance. We chose 37 cells for the prototype.

Table 1: Numerically determined RF-parameters for oxygen free CuSn2.

$$\kappa = 18.4 m / \Omega mm^2$$
$$L = 123{,}28 \text{ mm}, \quad r/Q_0 = 23{,}1 \text{ k}\Omega\text{/m},$$
$$Q_0 = 2095, \quad r = 46{,}4 \text{ M}\Omega\text{/m}$$
$$v_g/c_0 = 11{,}9\ \%, \quad \alpha = 1{,}27\text{/m}, \quad T_f = 3{,}47 \text{ ns}$$

3 MECHANICAL DESIGN

A 37-cell accelerating section has been modeled, consisting of 35 accelerating cells with equal transverse forces property and terminated with two coupling cells. The input and output couplers are matched with a cut iris. The matching procedure has been done in the time domain with GdfidL [2]. The structure was produced by CNC milling with an accuracy of 0.004 mm. The machining by inline milling has the disadvantage that cavity corners are rounded with the radius of the milling cutter (R = 0,5 mm). The rounded corners cause a frequency shift and detune the match, as recently seen in measurements of X-band models. In order to take account of these effects all simulations are made with rounded corners. The structure is fully engineered for a high power experiment in vacuum. The design includes ports for vacuum, RF and beam pipe. Figure 1 shows a picture of the manufactured structure and figure 2 the mounted structure with RF-, beam pipe- and vacuum-flanges, ready for brazing. The brazing was done at CERN. Thermal control for cooling and tuning is also planned. Cooling tubes will be glued on the top and the bottom of the structure, if necessary.

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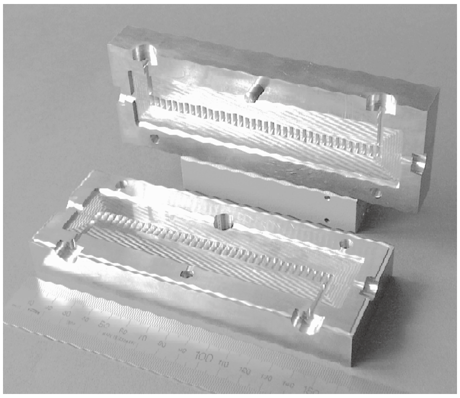

Figure 1: Manufactured 37-cell structure.

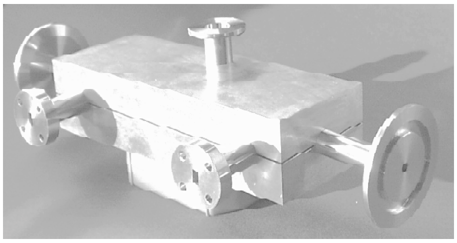

Figure 2: Manufactured structure with flanges.

4 COLD MEASUREMENT

4.1 Frequency scan

The measurements were made with a Hewlett Packard HP-8722C vector network analyzer (NWA), working in the frequency range from 50 MHz up to 40 GHz. The mentioned rounded corners lead to the further problem that the numerical simulation needs a huge amount of RAM and time. Therefore the 37-cell GdfidL simulation was terminated before the steady state was reached. Figure 3 and figure 4 show a comparison of the S-parameters of the measured 37-cell structure with the simulation. There is a very good agreement in what concerns bandwidth *B* and match for the 2π/3-mode. The high losses in the transmission are caused by the material of the structure.

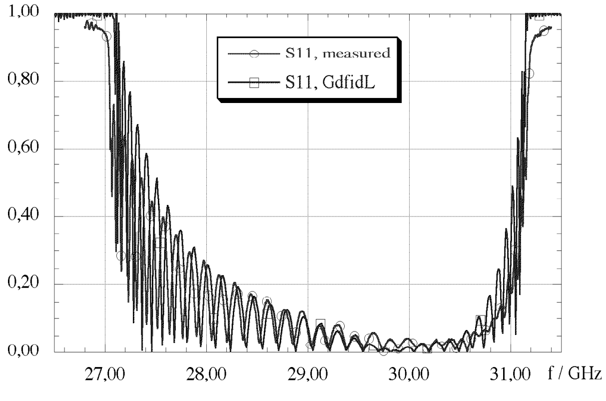

Figure 3: Comparison of the unperturbed reflection with the GdfidL simulation.

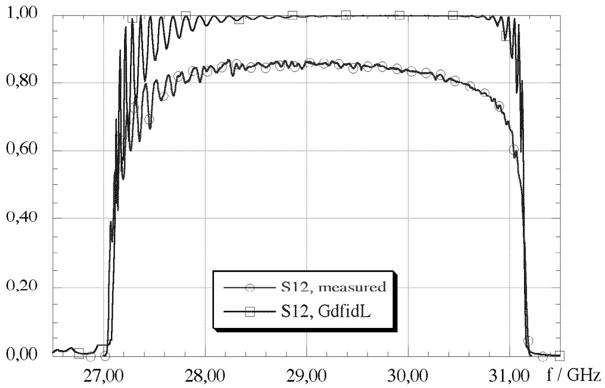

Figure 4: Comparison of the unperturbed transmission with the GdfidL simulation.

The numerical simulation does not consider losses in the time domain. The data of the measured transmission confirms the numerically determined RF-parameters from table 1. The measured RF-parameters are:.

v_g/c_0 = 11,8 %, α = 1,30/m, Q_0 = 2053, T_f = 3,48 ns.

4.2 Bead Pull Measurement

A standard traveling wave bead pull measurement was performed. In order to keep the perturbation of the fiber small, a very thin pure nylon fiber with 0.12 mm diameter was used. The bead itself was a simple knot in the fiber. The measurements were made in an uncalibrated mode of the NWA. All measurements were made with a bead on the beam trajectory (no transverse off sets). The fiber is a perturbation by itself and causes a frequency shift and reflection. A first measurement, with fiber inside but bead outside the structure, takes the unperturbed reflection ($_{up}$) which is the reflection of the fiber. The next run with the bead pulled through the structure measures the perturbed reflection ($_p$). The corrected data results from:

$$\Gamma_{cor}(z) = \Gamma_p(z) - \Gamma_{up} = c\left|E(z)\right|^2 e^{-j2\phi(z)}$$

Figure 5 shows the relative magnitude of the electric field along the z direction. The abscissa indicates the number of sampling points. The characteristics of the bead, such as material, shape and volume as well as input power, represented by the constant c, were not determined.

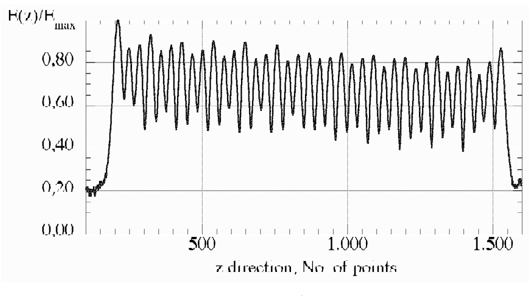

Figure 5: Magnitude of the 2π/3-mode.

A polar chart with phase information is presented in figure 6. The structure is terminated with coupling cells, which have a different resonance frequency. This mismatch causes errors of the field phase and magnitude.

Considering the frequency shifts caused by the fiber and air, the frequency of an empty and evacuated structure is determined as 30,246 MHz.

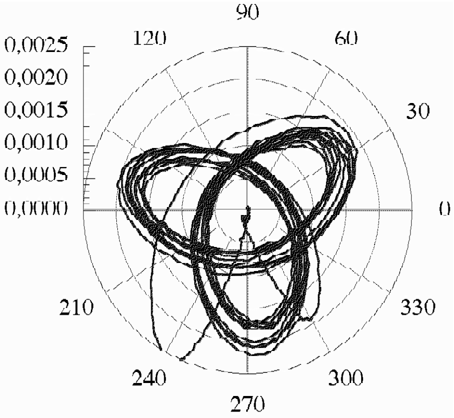

Figure 6: Polar chart of the 2π/3-mode.

5 HIGH POWER TEST

A bunch with 1/3 nC charge was sent through the structure and the generated RF pulse was measured with the CTF diagnostic equipment. The spectrum is centered at a frequency of about 30.250 GHz, which is 260 MHz higher than the CTF II frequency. It confirms also the frequency shift measured with a bead pull.

Next, the structure was powered with the 30 GHz RF generated by the drive beam in one of the CTF Power Extraction and Transfer Structures (PETS). The power level was adjusted by changing the drive beam bunch charge and the pulse length by changing the number of bunches in the drive beam train. The power is measured at the output of the PETS and there is an attenuation of -1 dB in the wave guide between the PETS and the accelerating structure. The maximum power, 80 MW, see figure 7, was limited by the available drive beam charge. The tests did not show any indications that breakdowns were occurring inside the structure. No abrupt increase of the reflected power was observed.

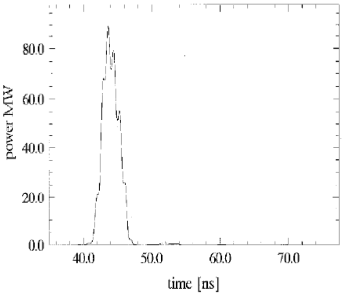

Figure 7: 80 MW power pulse of 4 ns pulse length at 30 GHz feed to the structure.

At 29.986 GHz no acceleration was observed because of the large frequency shift. In order to reduce the frequency error of the structure, the frequency of the power generated in the CTF II was up-shifted by changing the bunch repetition frequency of the drive beam bunch train. With the large energy spread the pulse length was limited to 4 ns and the power to 30 MW at 30,150 GHz. The left over frequency error was then around 100 MHz. Figure 8 shows the probe beam energy spectrum before and after acceleration in the planar structure. The energy gain is about 2.8 MeV corresponding to 23 MV/m average gradient. The expected gradient is 33,6 MV/m, where we have taken into account the 1 dB waveguide damping, the 100 MHz off tune and the pulse rise time of 1,5 ns which allowed for a structure filling of three quarters only.

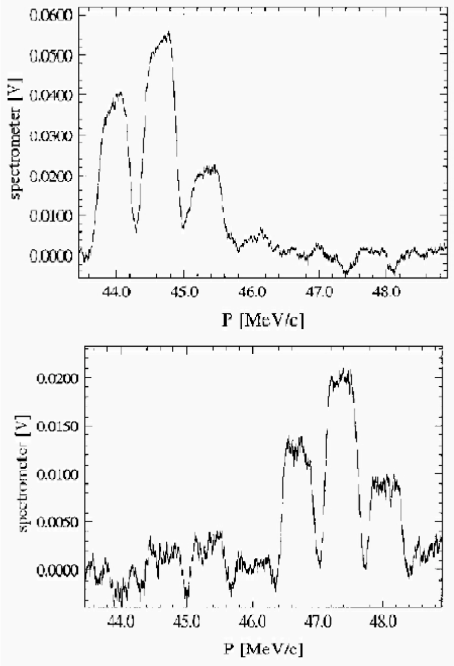

Figure 8: Probe beam energy spectrum before and after acceleration. The energy gain is about 2,8 MeV.

ACKNOWLEDGEMENT

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REFERENCES

[1] M. Valentini, H. Braun, W. Wuensch, “Test of a 30 GHz Planar Accelerating Structure in the CLIC Test Facility II”, CLIC Note 413, CERN, CH, 1999.

[2] W. Bruns, “GdfidL: A finite difference program for arbitrarily small perturbations in rectangular geometries, IEEE Trans. Magn. Vol. 32, No. 3 May 1996.

[3] R. Merte, H.Henke, „Development And Test Of A Planar R-band Accelerating Structure“, PAC 1999, New York.