Development of a Planar Accelerating Structure

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Abstract

A planar 30 GHz constant impedance travelling-wave structure was designed, constructed and tested under high power. Accelerating gradients of around 50 MV/m were achieved at pulse lengths of 16 ns. In order to fulfill the CLIC requirements a very strong suppression of transverse wakefields, by a factor of 100 within less than 1 ns (20 cm), is necessary. This can be achieved in two ways: Damping waveguides in every cell in horizontal and vertical direction, or, damping waveguides only in horizontal direction and detuning of the structure.

1. Introduction

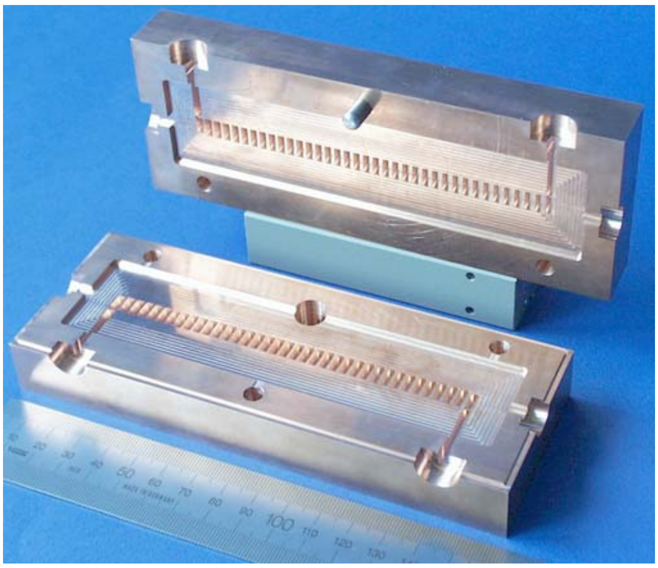
Planar structures are very different as compared to round structures. The accelerating mode has RFQ fields with transverse forces depending on the longitudinal and transverse position. The short-range wakes in horizontal direction are much lower and favor the acceleration of flat beams. Their fabrication by high precision inline milling may reduce the costs considerably. And finally, side openings represent a good vacuum pumping channel.
A planar 30 GHz constant impedance travelling-wave structure with $2\pi/3$ phase advance per cell was designed and constructed. High power tests at CERN included breakdown, dark current, high gradient holding capability and the proof of principle to accelerate a round beam.
In a next step, the power couplers were redesigned as symmetric double couplers in order to reduce the peak electric field and corners on the irises were rounded.
Finally, measures were investigated to heavily damp higher order modes. Damping wave-guides had to be introduced in every cell in both directions, horizontally and vertically. In case of a detuned structure it was sufficient to have damping waveguides only in horizontal direction.

2. Design and Fabrication

The planar structure is a 37-cell travelling-wave, constant impedance structure at 29.986 GHz. The $2\pi/3$-mode results in a period length of 3.332 mm. The iris thickness has been fixed to 0.7 mm. The detailed description of the geometry and the RF parameters are given in [1], [2]. The structure is shown in Fig. 1 and the main RF parameters are listed in Table1.

Table 1: Numerically determined RF-parameters for the structure in Fig. 1.

Oxygen free CuSn2,	$\kappa = 18.4 \cdot 10^6\ \Omega^{-1}\ \mathrm{m}^{-1}$		
$r/Q_0 = 23.1\ \mathrm{K\Omega/m}$,	$Q_0 = 2095$,	$r = 46.4\ \mathrm{M\Omega/m}$	
$\upsilon_g/c_0 = 11.9\ \%$,	$\alpha = 1.27\ \mathrm{m}^{-1}$,	$L = 123.28$ mm,	$T_f = 3.47$ ns



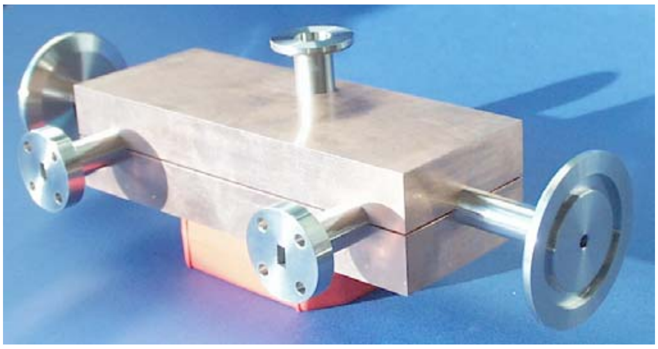


Figure 1: Interior and exterior of a 37-cell planar structure.

The structure consists of two identical pieces which were machined with high precision CNC milling, and no special surface finish. The two halves were aligned by 3 dowel pins. Frequency tuning were achieved before brazing by drilling centered holes in the bottom of each cell. In a first brazing cycle the two halves were bonded together and in a second, lower temperature cycle all flanges were brazed.

3. Bench Measurements and High Power Testing

Tuning procedure and bench measurements are given in detail in [2]. Excellent agreement between numerically obtained S-parameters, from GdfidL [3], and measurements existed. A bead-pull measurement, Fig. 2, shows phase and amplitude of the electric field of the $2\pi/3$-mode.

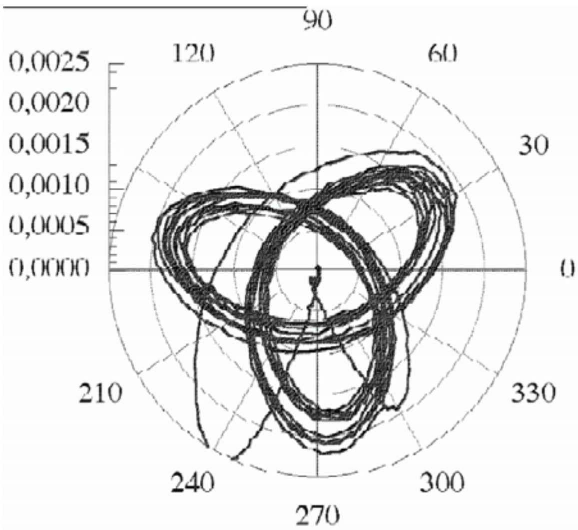


Figure 2: Polar chart of the $2\pi/3$-mode from a bead-pull measurement.

High power tests were performed using the CLIC Test Facility (CTF II) [5]. The incident, transmitted and reflected power were measured via directional couplers, down converted to 500 MHz and digitised with a fast oscilloscope. Wall current monitors on each side of the structure measured spontaneous electron bursts emitted during breakdown and dark currents. For the structure conditioning RF pulses of 8 ns were used. A typical RF pulse is shown in Fig. 3.

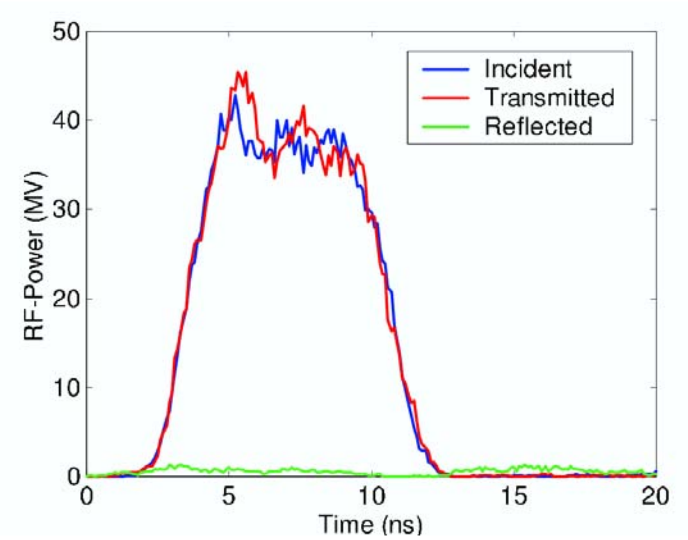


Figure 3: Typical measured incident, transmitted and reflected RF pulse during

Breakdown events accompanied by massive electron emission, 100 m A and 300 ke V, happened at an average accelerating gradient around 60 MV/m. No dark current was observed. One of the objectives of the test was the demonstration of synchronous electron acceleration. Simulations with GdfidL predicted an energy gain of $\Delta E/MV = 1.2. \sqrt{P_{in}}/MW$. Excellent agreement between the measurement and the prediction was shown up to 60 MV/m using 8 ns pulses, Fig. 4.

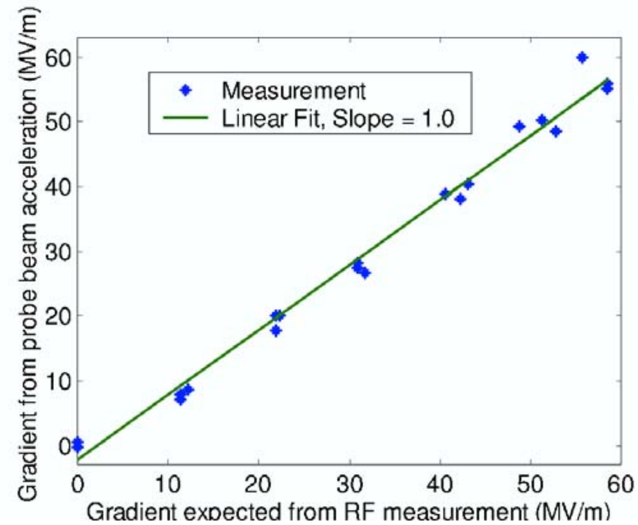


Figure 4: Electron acceleration versus measured

4. Structure Modifications

Breakdown in an RF structure is determined by the peak electrical field and an important parameter for high gradient operation is the ratio of peak electrical field to average accelerating gradient. Two modifications of the structure were undertaken to reduce this ratio. Firstly, a symmetric power coupler was designed in order to reduce both peak electrical field in the input cell and magnetic field on the coupler iris. The second measure relieves the pulsed heating problem. Secondly, the corners on the irises were rounded leading to a ratio of around five.

5. Damping of Higher Order Modes

A particular feature of CLIC is a very short bunch distance and extremely tight limits on the admissible transverse kicks acting on the bunches. These requirements translate into a necessary suppression of transverse wakefields by a factor of 100 within 20 cm. Requirements which are hard to fulfill for a longitudinally very open structure like the present planar structure. The reasons are that the structure has many higher order modes which are synchronous with the beam and which are at cut-off in the side-opening. That is, they do not transport energy into the side-openings and act all coherently. A detailed study of the different ways to interrupt the coherence and to damp the modes is given in [6] and [7]. Two ways were found to fulfill the requirements. One approach is based only on damping of every cell. Waveguides with loads are placed in horizontal as well as vertical direction, Fig. 5.

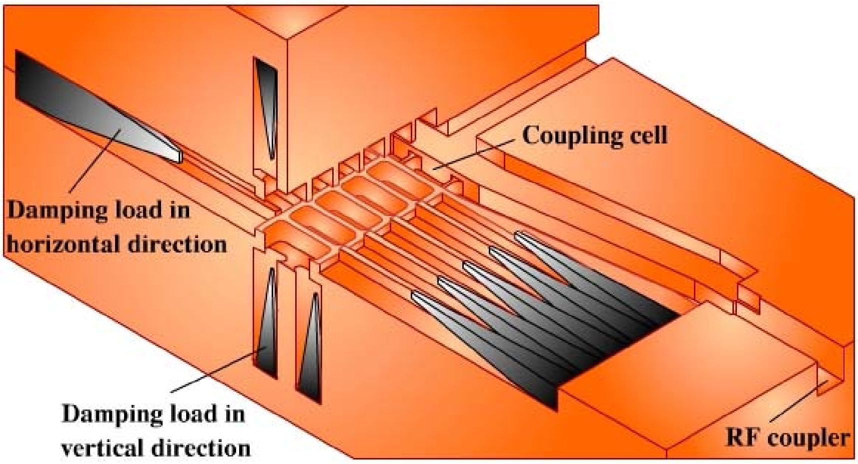


Figure 5: Structure with loaded waveguides in horizontal and vertical direction.

The coupling to the waveguides is chosen such that the fundamental mode is only slightly damped, less than 5 %. As shown in Fig. 6 the transverse wakefields, calculated with GdfidL, decay by a factor of 100 well within 20 cm.

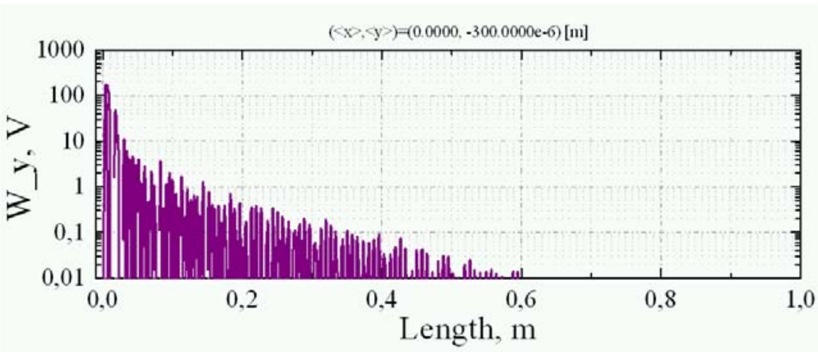
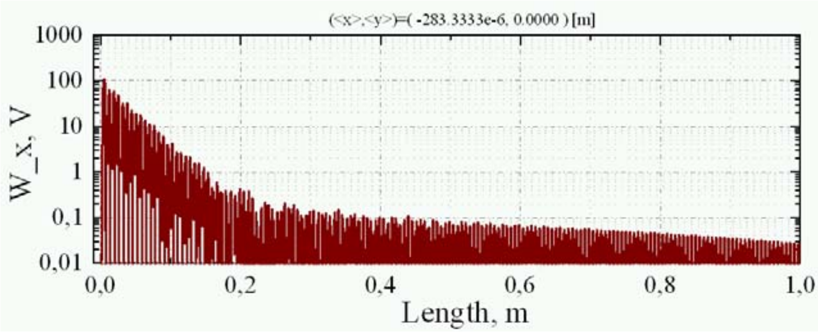


Figure 6: Transverse wakefields of the structure in Fig. 5.



In order to verify the numerical results a scaled-up 10 GHz aluminum model was built, Fig. 7. Excellent agreement between calculated and measured S-parameters and impedances was found.

Figure 7: 10 GHz aluminum model with damping waveguides and loads.

The second solution uses damping waveguides in horizontal direction only and detuning of the cells. The width of the cells varies by about 10 % and the depth is adjusted in order to keep the fundamental mode frequency constant. Again, the wakefields decay as required. This second solution is mechanically much easier. It can be fabricated by simple inline milling and may present an alternative solution to a closed round structure.

6. References

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