CTF3 DRIVE BEAM ACCELERATING STRUCTURES

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Abstract

The 3 GHz drive beam accelerator of the CLIC Test Facility CTF3, currently under construction at CERN, will be equipped with 16 novel SICA (Slotted Iris – Constant Aperture) accelerating structures. The slotted irises couple out the potentially disruptive induced transverse HOM energy to integrated silicon carbide loads (dipole mode *Q*'s below 20). The use of nose cones for detuning allows a constant inner aperture (34 mm). The structures will be 1.2 m long and consist of 34 cells. A first 6-cell prototype structure has been tested successfully up to power levels of 100 MW (nominal: 30 MW), corresponding to surface electric field levels of 180 MV/m.

1 INTRODUCTION

The power generation in the CLIC two-beam scheme, described in detail in [1], relies on drive beam accelerators (DBAs) operated at 937 MHz (30 GHz/32). The CLIC test facility CTF 3, which will demonstrate the CLIC power generation scheme, has a DBA operating at 3 GHz [2]. This allows re-use of the S-band equipment from the decommissioned LEP injector. To maximize RF power generation efficiency, the drive beam accelerator will operate at almost 100 % beam loading, i.e. over the length of each accelerating structure, the accelerating gradient will decrease to almost zero.

The CTF 3 DBA consists of 16 accelerating structures, each of 32 inner cells plus 2 coupler cells with a total length of 1.22 m. It will operate in the $2\pi/3$ mode with a moderate accelerating gradient of 6.5 MV/m under the nominal beam loading conditions (98 %). The unloaded gradient is 10.9 MV/m.

The approach taken for the design of the accelerator structures for the DBA was described in [3]. Two different concepts were followed at that time, the Tapered Damped Structure (TDS) and the Slotted Iris–Constant Aperture (SICA) structure. The initial test results of the SICA prototype structure which led to the decision to endorse this solution for the entire DBA are reported here.

2 PROPERTIES OF THE SICA STRUCTURE

The SICA structure channels out dipole modes by means of radial slots in the irises, which do not interfere with the accelerating mode. These slots continue radially into ridged waveguides (Fig. 1). The tapered silicon carbide (SiC) loads are mounted in these ridged waveguides. This geometric mode separation has the advantage that the accelerating mode is well isolated from the loads.

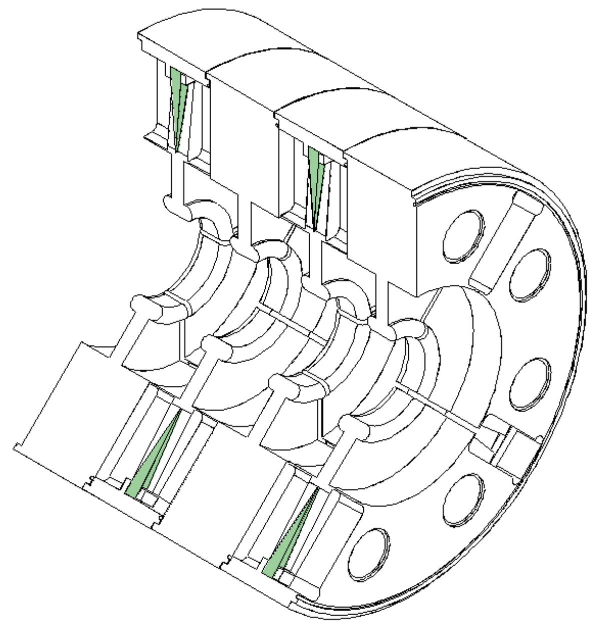

Figure 1: Cut-away view of the SICA structure geometry

A second feature of the SICA structure is the modulation of the group velocity by nose cones of varying size along the structure (cf. Fig. 1). This allows a constant, relatively large inner aperture, which minimises the short range wake field.

Possible issues for slotted iris structures are *i)* the danger of so-called "slot modes", *ii)* the risk of field enhancement at the edges of the slots and *iii)* the lack of any damping of higher order longitudinal modes. All these issues have been studied in detail and found to be of no harm for the operation of the DBA [4]. Using HFSS, the slot modes were found to have resonance frequencies around 2 GHz, *Q*'s of below 10 and very low kick factors (5 % of that of the first dipole mode), which is considered acceptable. The field enhancement at the edges of the slots was reduced to an acceptable value of 1.4 by rounding the edges to a radius of 0.5 mm by NC milling. The higher-order longitudinal modes were included in beam dynamics simulations and found to do no harm, in particular since the are widely detuned.

3 LOW POWER TESTS

To verify the validity of the SICA approach, a short prototype (4 inner cells plus 2 coupler cells) was built and tested at CERN. Due to the reduced length, the geometry

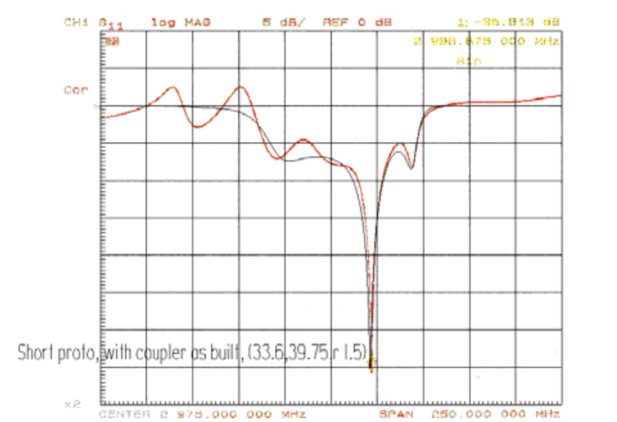

Figure 2: simulated (black) and measured (red) frequency response of $|s_{11}|$ of the 4+2 cell prototype.

of the nose cones varies more drastically from cell to cell than in the final 32+2 cell structure. A machining error in the input coupler cell compromised somewhat the pass band of the structure, but as can be seen in Fig. 2, the measured input reflection corresponds well to the HFSS

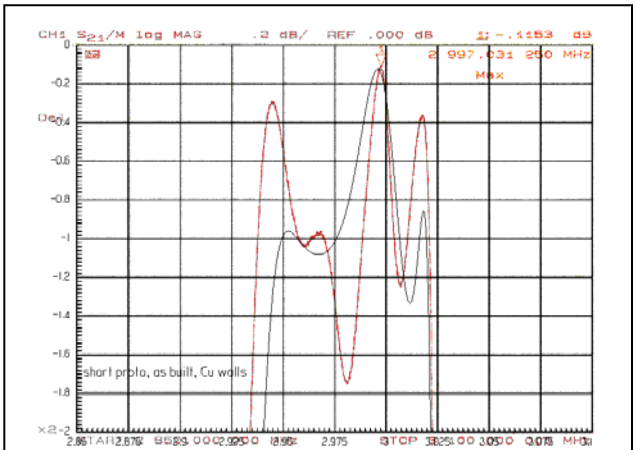

Figure 3: : simulated (black) and measured (red) frequency response of $|s_{21}|$ of the 4+2 cell prototype.

simulation which gave confidence to this simulation tool. The obvious measurement errors at the low and high ends of the frequency span, where $|s_{11}| > 1$, are due to an imbalance of the 3-dB hybrid used in this measurement which could not be calibrated out.

The transmission was also measured and corresponds well to the simulation (cf. Fig. 3).

Computer hardware limitations did not allow a simulation of the full size (32+2 cell) accelerating structure, so Fig. 4 shows the simulated reflection curves for two 16+2 cell structures, one consisting of all even cells, the other of all odd cells. This is believed to give a good verification of the overall design, and in particular the matching of the couplers.

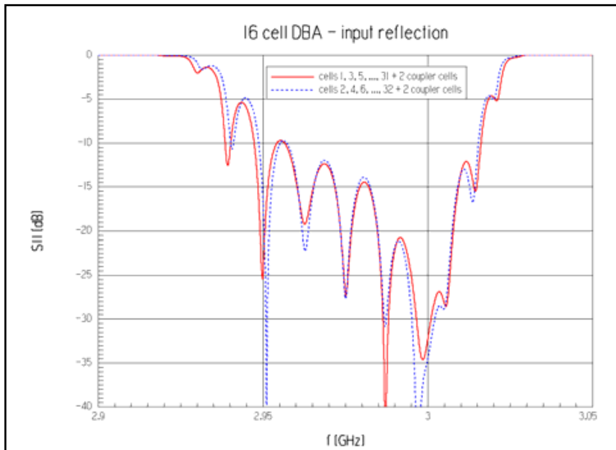

Figure 4: HFSS simulation of the $|s_{11}|$ response of two different 16+2 cell assemblies: odd cells (red solid) and even cells (blue dashed)

4 HIGH POWER TESTS

After installation in part of the CTF3 tunnel, the short prototype structure was evacuated and baked out at 150 °C. The initial conditioning with pulse lengths of 2 µs allowed to reach the power limit of the klystron (35 MW) within 2 days without any major breakdowns in the structure. The conditioning strategy was to keep the vacuum level at the gauges below 10^{-7} mbar, permanently readjusting the input power level accordingly.

As a next step, the pulse compression system LIPS with a 180 ° phase flip (resulting in a triangular shaped, short pulse) was used and conditioning was continued up to a peak power level of 100 MW, until again limited by the available power from the klystron, and again with no breakdowns in the structure. Comparing this power level with HFSS simulations, the peak electric field at the

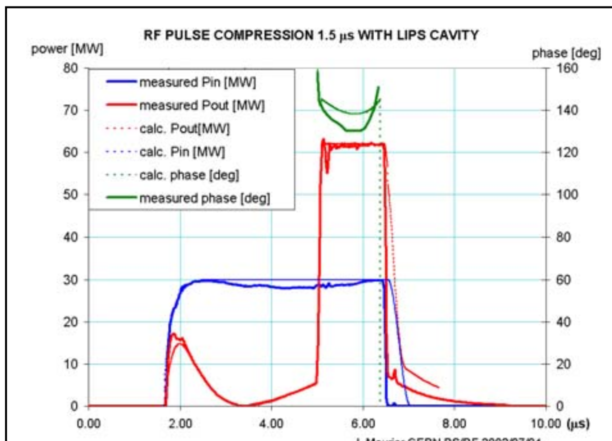

Figure 5: Using a phase modulation program, a rectangular pulse of up to 63.5 MW, 1.5 µs was input to the accelerator structure.

edges of the slot in the last iris was estimated to have obtained approximately 180 MV/m.

Subsequently the pulse compression system was used with a phase modulation program tailored to obtain rectangular output pulses of the nominal pulse length of 1.5 µs. Under this condition, some breakdowns at power levels of above 40 MW (The CTF3 nominal power level is 30 MW) were observed, but nevertheless conditioning continued to power levels of up to 63.5 MW. Due to the limited bandwidth of the structure, the reflection response on the steep rising and falling edges of the pulse also caused dips in the forward power, as can be seen in Fig. 5.

Finally, the phase modulation program was adjusted to produce even shorter (500 ns) but higher power level pulses. In this mode of operation, a maximum power of 88 MW was obtained, limited by reflections back to the klystron, because now the effect of the narrow bandwidth of the structure became more pronounced.

Following the high power tests, the structure was opened and examined for damage with an endoscope. The colour of the irises had changed from copper red to a more silver colour, notably for those irises where the

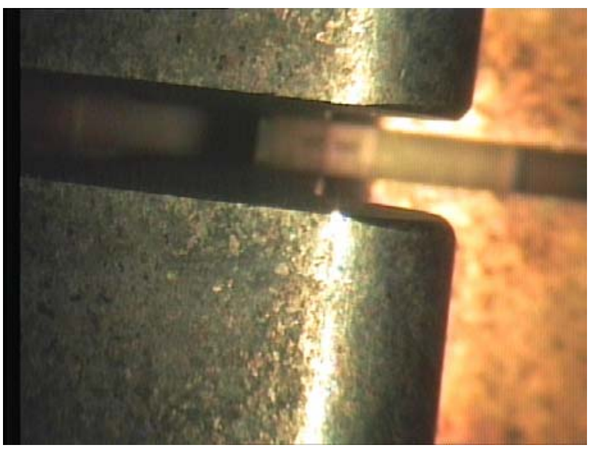

Figure 6: Endoscopic picture looking from the beam axis into the 2 mm wide slot in the last iris. The iris is seen in the foreground, the nose cone is on the right. The slot edges are rounded off mechanically (*R* 0.5 mm). In the background the outer cavity wall can be seen.

electric field had been a maximum. The nose cones were checked for pitting or damage, but apart from the changed colour, no significant modification was found. In particular, the geometry of the irises, nose cones and slots was unchanged. Fig. 6 shows the areas of highest field around the slot in the last cell. The edge of the 2 mm wide slot had been rounded to a radius of 0.5 mm by milling to reduce the field enhancement. Slight traces of pitting can be observed.

5 FULL SIZE PROTOTYPE

The full size prototype is now being prepared for brazing. All the discs have been machined, and the coupler cells have been pre-brazed. To verify the geometry of the individual cells, a single disc test set-up was used to measure the *0* and π modes of all individual discs. The measured frequencies are represented in the f_0–f_π–plane, which allows plotting curves of constant phase advance per cell for a given synchronous frequency. This uses the simplifying formula

$$2f^2 = f_0^2 + f_\pi^2 + \left(f_0^2 - f_\pi^2\right)\cos(\varphi)$$

which has been shown to be valid for the fundamental

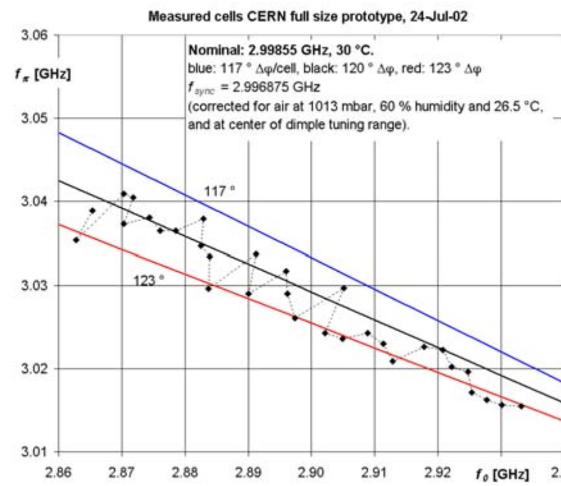

Figure 7

mode. Fig. 7 shows the measured data for all 31 discs together with the margin of error which can be compensated by the dimple tuning capability of ±3 ° in phase. The measured data to be tolerable, in spite of a few discs at the lower frequency limit.

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