EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN - AB Department

CERN-AB-2005-030
CLIC Note 635

30 GHZ POWER PRODUCTION IN CTF3

C. Achard, H. H. Braun, G. Carron, R. Corsini, A. Grudiev, S. Heikkinen, D. Schulte, J. Sladen, I. Syratchev, F. Tecker, I. Wilson, W. Wuensch

CERN, Geneva, Switzerland

Abstract

One of the major objectives of CTF3 (CLIC Test Facility) is the production of 30 GHz power for the high-gradient testing of CLIC accelerating structures. To this end a dedicated beam line, power generating structure and power transfer line have been designed, installed and commissioned. 52 MW of 30 GHz power with a pulse length of 74 ns and a repetition rate of 16 Hz were delivered to the high-gradient test area. This will allow operation of test accelerating structures in the first CTF3 run of 2005 up to the nominal CLIC accelerating gradient of 150 MV/m and beyond the nominal pulse length. The system is described and the performances of the CTF3 linac, beam line and the rf components are reviewed.

Presented at
PAC 2005, Knoxville, USA,
May 16-20, 2005

Geneva, Switzerland
June 2005

30 GHZ POWER PRODUCTION IN CTF3

C. Achard, H. H. Braun, G. Carron, R. Corsini, A. Grudiev, S. Heikkinen, D. Schulte, J. Sladen,
I. Syratchev, F. Tecker, I. Wilson, W. Wuensch, CERN, Geneva, Switzerland

Abstract

One of the major objectives of CTF3 (CLIC Test Facility) is the production of 30 GHz power for the high-gradient testing of CLIC accelerating structures. To this end a dedicated beam line, power generating structure and power transfer line have been designed, installed and commissioned. 52 MW of 30 GHz power with a pulse length of 74 ns and a repetition rate of 16 Hz were delivered to the high-gradient test area. This will allow operation of test accelerating structures in the first CTF3 run of 2005 up to the nominal CLIC accelerating gradient of 150 MV/m and beyond the nominal pulse length. The system is described and the performances of the CTF3 linac, beam line and the rf components are reviewed.

INTRODUCTION

When the combiner ring will be completed in 2007, CTF3 will produce a 35 A, 150 MeV bunched electron beam. This beam will be used to drive scaled CLIC PETS (Power Extraction and Transfer Structures) to produce 30 GHz power for the high-gradient accelerating structure development program. However, in order to produce 30 GHz power sooner (the last 30 GHz tests were made in CTF2 in 2002), a special power generating station has been built which uses the beam produced by the first third of the CTF3 linac. This part of the linac has already been installed [1] and is capable of producing a 70 MeV beam of up to 6.4 A, with 3 GHz bunch spacing and 1 mm bunch length.

The next high-gradient accelerating structure tests will require input powers of about 70 MW [2]. The structures will be tested in a radiation shielded area about 17 m away from the power generating station, thus about 100 MW of rf power must be produced and transported with very high efficiency.

The relatively low current of the driving beam in the linac of CTF3, however makes production of 100 MW quite challenging. The solution which has been adopted consists of a 1.5 m long, travelling wave structure with an internal aperture profiled to follow the simulated waist of the driving beam. A special 'dog-leg' transmission line was built to allow easy switching between 30 GHz rf power production and operation of the rest of the CTF3 facility. The 30 GHz power is transported to the test area via an over-moded power transfer line with a total efficiency of 75%. An overview of design rational, hardware and achieved performance of the system is presented in this report.

BEAM DYNAMICS AND RF DESIGN

A design goal of 99% transmission of the beam through the power generating structure was fixed in order to avoid damaging or excessively activating the power generating structure. The main beam-dynamics issues were to provide adequate focusing for transmission through a rather small and long aperture, allowance for the growth of the beam caused by the nearly 30% loss of energy and avoidance of the potentially very strong transverse wakefields in the high frequency structure. A quadrupole triplet was used to focus the beam through the structure.

The primary issues for the rf design were to provide a rather high, 2 MΩ, total impedance and to limit the surface electric field to below 130 MeV/m for 100 MW output power. This surface field limit was chosen so that the power generating structure has half the surface field of an accelerating structure under test - in this way conditioning time of the PETS is minimized compared to the accelerating structure, and a copper PETS, see below, can drive accelerating structures made from materials with a higher surface-field threshold such as molybdenum [2]. The structure geometry was also constrained by the beam dynamics requirement that the lowest dipole-mode frequency be as far away from harmonics of 3 GHz, the bunch spacing of the driving train, as possible to minimize the coherent growth of dipole-mode fields. This dependence of beam loss on dipole-mode frequency, expressed as increased beam loss inside the PETS as a function of the aperture of a specific scaled geometry is shown in Fig. 1.

The solution which best met the aforementioned design objectives was to make the PETS in three 500 mm long segments with internal iris apertures chosen to follow the waist of the focused beam. With the additional constraint on the synchronous dipole-mode frequency, the three segments were chosen to have internal apertures of 9, 6.7 and 9 mm respectively.

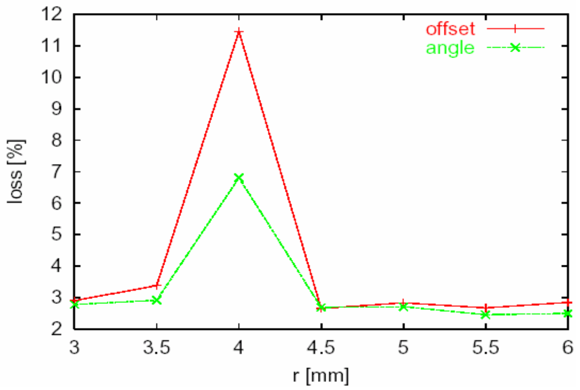

Figure 1: Dependence of beam loss on iris aperture, and thus on synchronous dipole mode frequency. The peak in the beams losses corresponds to a resonant excitation of the dipole mode frequency.

PETS AND HIGH POWER LINE

An early decision in the PETS design process was to construct the extremely long 1.5 m PETS out of brazed diamond-machined copper disks, a technique used successfully for CLIC accelerating structures. The use of higher-potential-performance materials such as molybdenum, has been left for an eventual retro-fit because of higher technical difficulty. With the choice of technology fixed, the detailed rf designs of the periodic structures were made. Selected rf properties of each of the segments are summarized in Table 1. Both types of segments have a $2\pi/3$ phase advance and are over-moded at 30 GHz. The resulting computed power flow as a function of distance along the structure for an equivalent driving current of 4.5 A is shown in Fig. 2.

Table 1: PETS segment rf parameters

	6.7 mm aperture	9.0 mm aperture
R'/Q	11.26 kΩ/m	5.87 kΩ/m
v_g/c	.243	.398
Synchronous f_{dipole}	34.01 GHz	32.46 GHz

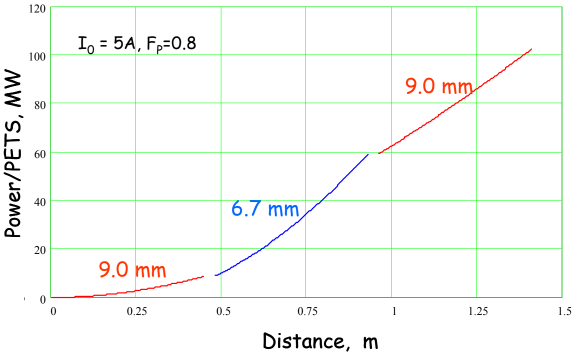

Figure 2: Power flow as a function of distance along the PETS – the beam travels from left to right.

The full PETS was assembled from three separate brazed segments (the complete structure is 400 cells long) each with a constant aperture. Power flow from one segment to the next, and thus between 6.7 and 9 mm apertures, was made using a phase adjusted 10 mm diameter circular waveguide to maintain the correct rf to beam phase from one segment to the next. Special matching cells and irises provided the impedance match between the periodic structures and the circular interconnecting waveguide.

The need to maintain beam clearance constrained the smallest diameter aperture in the coupler to be larger than 9 mm. This meant that the beam pipe in the coupler was well above cut-off and a standard coupler design could not be used. Instead a resonant grove was used to reflect 30 GHz power flowing down the beam pipe, and concentrate fields in the region of the two symmetrical output waveguides. More details on the design principles of such a coupler are presented in [3]. The power from the two arms of the coupler was then combined in a 90º H-plane hybrid.

Each of the three PETS sections were individually tuned using a reflecting plunger. The standard tuning procedure was however made more complicated because the structures are over-moded. High Q resonances of the lowest dipole band trapped between the plunger and the coupler perturbed measurements. This problem was overcome by smoothing the tuning over the entire length of the segments. The segment to segment phase was also measured using a reflecting plunger.

Each of the cells in the PETS was pumped by four 1.0 mm diameter, 12 mm long radial pumping holes. Cooling was made via pairs of cooling blocks clamped to the outside of each segment. The cooling blocks also provided the transverse positioning of the structure. The entire three-segment assembly was placed in a vacuum tank. The structure and output waveguide system in the tank is shown in Fig. 3.

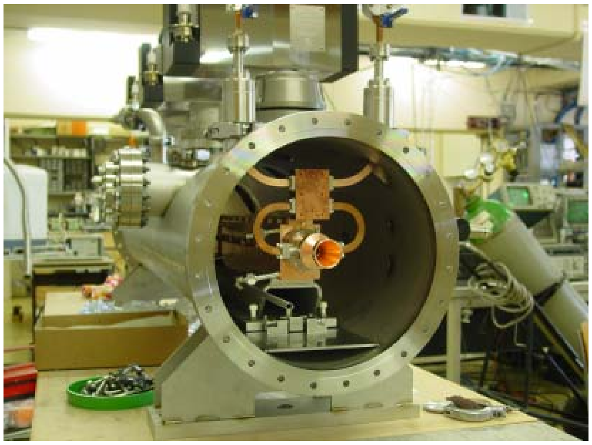

Figure 3: The complete three-segment PETS under low-power rf measurement.

The 30 GHz accelerating structures will be tested in a shielded tunnel, which previously housed the CTF2 complex, so that accelerating structures can be changed without interrupting CTF3 operation. The PETS and accelerating structure test area are consequently separated by about 17 m - standard rectangular waveguide could not be used to transfer rf power from one to the other because of excessive losses (about 0.5 dB per meter). Instead a specially designed quasi-optical waveguide system was purchased from the firm Gycom, Nizhny Novgorod. The waveguide system, including transitions to and from WR-34, three 90º bends and about 17 m of waveguide, has a measured power transfer efficiency of 87%. A photograph of the high power line during pre-assembly is shown in Fig. 4. A very useful side-effect of the 17 m, 54 ns, long transmission line is the time delay it produces between when the PETS and the accelerating structure under test are powered. In this way power reflected from the test area arrives in the PETS after power production is over for pulse lengths over 100 ns.

Figure 4: The over-moded line with three mitred bends and converters to WR-34 waveguide.

HIGH-POWER OPERATION

The objectives for the CTF3 2004 run were to commission the PETS beam line and to condition the rf system to the highest possible power with a load installed in the future position of test accelerating structures. The main challenge was to accomplish both objectives at the same time, since the two are fundamentally interconnected. A number of effects occur when the beam current is raised to increase the rf power: beam loading in the drive linac increases lowering the beam energy [1], the lower energy changes the transport through the PETS and the energy drop across the PETS also increases changing the transport further. Studying, scanning beam-line parameters and setting up compensation for these dependencies were complicated by the need to simultaneously control the rf power level. The beam transmission achieved with an incoming current of 5 A was approximately 90%. This is lower than the computed transmission, however this may have been due to a 1.4 mm misalignment, which was found after the run, in the upstream end of the PETS with respect to an upstream collimator. The highest rf power was achieved with an incoming current of 6.4 A and a transmission of 65%.

It is not possible to draw detailed conclusions about the conditioning behaviour of the rf system because of the interposed beam-line commissioning. Very generally, a best performance of 71 MW (which corresponds to 52 MW delivered to the test area) with a pulse length of 73 ns was produced after about 40 h of rf conditioning in a repetition rate range of 5 to 16 Hz. A sample pulse is shown in Fig. 5. It was quite clear that raising the power at short pulse lengths was much easier than lengthening the pulse. During the conditioning, pulse shortening with a decay time of about 40 to 80 ns was observed along with breakdown events with a decay time of a few ns. The long-decay activity dominated the early stages of conditioning. The short-decay activity appeared more frequently in the later stages of conditioning and was qualitatively similar to the breakdowns observed in previous short pulse testing [2].

Based on rf and vacuum signals, most of the activity occurred in the components at the beginning and end of the rf line – in the PETS and WR-34 waveguide components and not in the over-moded line itself. Visual inspection of rf surfaces after the run showed evidence of extensive rf activity on both the high electric field regions of the downsteam irises of the PETS (which have the highest power flow) and inside the WR-34 rectangular waveguides (the circular waveguides were not opened for inspection after the run). The maximum surface electric field in the PETS at the final power level was 101 MV/m and the surface fields in the waveguides were about a factor of two lower. That the waveguides were breaking down at such low surface fields may have been caused by insufficient pumping of the small cross-section 30 GHz waveguides causing gas rather than vacuum discharge.

How close the demonstrated power level was to the ultimate value is not know as testing was stopped when CTF3 entered a scheduled shutdown. The beam transport had already dropped to 65% at the maximum current however the 1.4 mm misalignment has since been corrected and a somewhat higher transmission is expected in the coming run. On the other hand, the poor condition of the high surface field regions in the PETS and a conditioning curve which seemed to have begun to saturate indicate that the structure was nearing its limit. A better control of the conditioning process, improved pumping of the waveguides and the use of molybdenum will be incorporated for future runs.

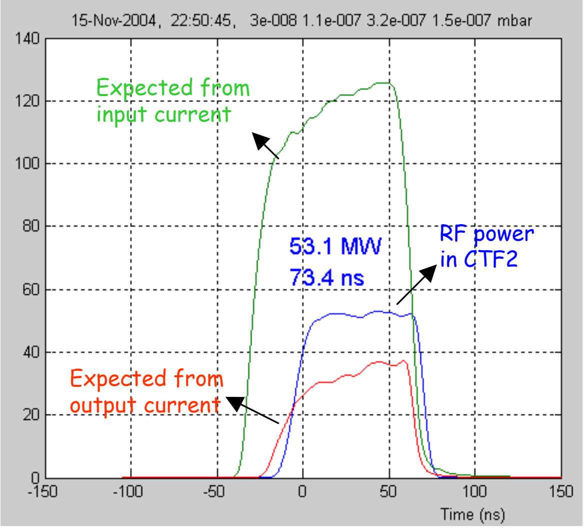

Figure 5: The highest power and pulse length achieved during the run.

REFERENCES

[1] R. Corsini et. al. “First Full Beam Loading Operation with the CTF3 Linac CTF3”, EPAC2004.

[2] C. Achard, H. Braun, S. Döbert, I. Syratchev, M. Taborelli, I. Wilson, W. Wuensch, “A Demonstration of High-Gradient Acceleration Paper”, PAC2003 and CERN-AB-2003-048.

[3] S. Doebert, J-Y. Raguin, I. Syratchev, W. Wuensch, “Coupler Studies for CLIC Accelerating Structures”, EPAC2002