DESIGN OF THE TAIL CLIPPER COLLIMATOR FOR CTF3

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Abstract

The CERN CLIC Test Facility (CTF3) aims at assessing the feasibility of the future multi-TeV Compact Linear Collider (CLIC). The CTF3 Tail Clipper Collimator (TCC) will serve to adjust the bunch train length of the beam extracted from the combiner ring, in combination with a fast kicker magnet. In addition, the TCC will operate, when required, as an internal beam dump. The challenge of the TCC design is to meet the requirements of both collimation and dump operational modes for a low energy e^- beam (100-300MeV) of 35A peak intensity. The TCC collimator will be installed in January 2009 in the TL2 transfer line of CTF3. This paper describes the final design of the TCC and the main issues related to its integration in the line.

INTRODUCTION

The CTF3 facility [1] is a demonstrator of the technical feasibility of the key concepts of the novel CLIC RF power source, e.g., generation of high-charge, high-frequency electron bunch trains by beam combination and operation with a fully-loaded drive-beam accelerator. The CTF3 facility includes a 70 m long linac followed by a 42 m delay loop, an 84 m combiner ring (CR) and a CLic EXperimental area (CLEX). The TCC is a combined collimator/dump and will be installed in the transfer line from the CR to the CLEX. It will serve to shorten the pulse length of the accelerated beam for 12 GHz RF generation in the CLEX (collimation mode). A fast kicker magnet [2] will deflect vertically an adjustable fraction of the pulse length. The TCC will absorb the deflected pulse while the rest will be transferred to the CLEX. The TCC will also serve to intercept the full beam (dump mode) for safe installation work in the CLEX. The main beam parameters considered for the design of the TCC are summarized in Table 1.

Table 1: CTF3 Beam Parameters Relevant for the TCC Design

Particles	e^-	
Beam energy @ TCC	150	MeV
Repetition rate	0.8 – 5.0	Hz
Incoming pulse duration	140	ns
Peak beam pulse current	35	A
Beam size range (rms, 1σ)	σh=2-5; σv=1	mm
Beam deflection @ TCC	>6	mm
Average beam power	3.7	kW

THE TCC DESIGN

Thermo-Mechanical Considerations

The dump mode of the TCC represents the most demanding case of operation from the thermo mechanical point of view and it has been considered as the determining condition for the design. The TCC will intercept a 150MeV e^- beam of average power equal to 3.7kW. In the collimation mode, the absorbed power will be less than this.

In order to determine the most appropriate material for the TCC jaw, detailed studies with the Monte-Carlo code FLUKA were performed for assessing the amount of energy deposited on the TCC. Fig. 1 shows the temperature profile (instantaneous) in the jaw after one pulse impact (beam: 150MeV, 5 pulses/s, 3.7kW) for Aluminium, Graphite and Glidcop® jaws.

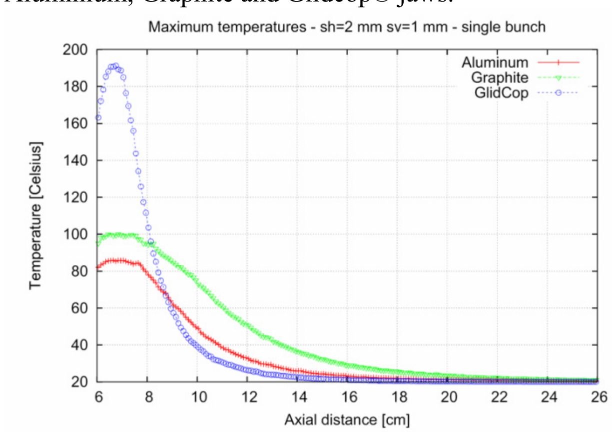

Figure 1: Temperature profile in the TCC jaw after one pulse impact for the studied materials.

Previous thermo-mechanical studies [3] have concluded that, structurally, the most critical case of impact occurs during an impact placed below 1.3mm from the jaw surface. The thermal loads calculated with FLUKA were given as input to an ANSYS® FE model of the TCC jaw, reproducing this particular case. The results obtained are summarized in Table 2.

Table 2: Temperature and Internal Stresses Obtained by ANSYS Simulation for the Studied Materials

e^- beam (σh=2 - σv=1, mm), 150Mev, 3.7kW, 5 pulses/s	Al	Glidcop	Graphite
Yield Strength (MPa)	55	255	30
ΔT (140ns) (ºC)	58	166	78
Maximum stress (140ns) (MPa)	79	265	2

The instantaneous increase of temperature (ΔT) due to the pulse impact originates high internal stresses in the jaw. Graphite was considered as the most convenient material for the jaw since the maximum stress is well below the yield strength value.

The Active Part - Jaw

The active part of the TCC will be made of a high-density graphite jaw held inside a water-cooled copper vacuum chamber. The high outgassing rate of graphite makes it critical to limit its increase of temperature in order to respect the vacuum requirements of the line (10^{-8} mbar).

A first solution with the graphite block shrink-fitted inside the copper was considered too risky. In fact, in order to limit the temperature increase and avoid dangerous internal stresses in the graphite, the tolerance of the shrink fitting obtained by a coupled thermo-structural simulation in ANSYS was in the range of 10-20µm. A hypothetical sudden thermal contact between graphite and copper could compromise the integrity of the graphite due to the high internal stresses generated by the thermal gradient. An alternative solution was selected, forcing a gap between the graphite and copper and creating a continuous thermal contact by means of a copper foil acting as a spring. Fig. 2 shows the design of the active part of the TCC.

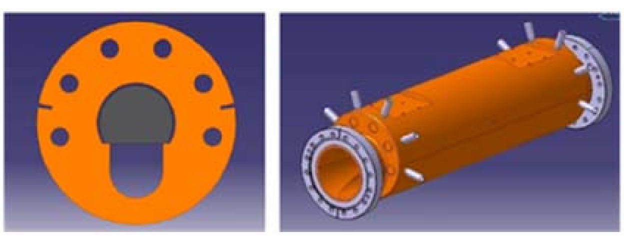

Figure 2: Front view (left) and isometric view (right) of the active part of the TCC.

Even though the thermal contact is not as efficient as a direct contact, the temperature of the graphite will be well under control. The maximum temperature in the graphite is 112°C (in steady state) as shown in Fig. 3.

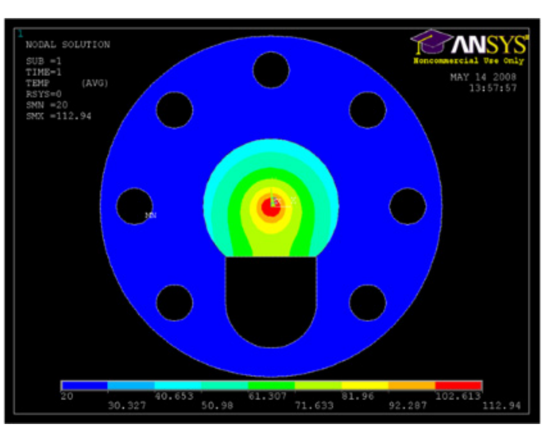

Figure 3: Temperature distribution in TCC active part during dump operation.

Wakefield Calculation

The possible presence of wake fields induced by the beam passing through the TCC has been computed with GDFIDL [4], which provides the time domain computation of a wake generated by a single bunch. By combining the results with the appropriate delay it is possible to see if a multi-bunch beam could generate a build-up of the wake; see Fig. 4.

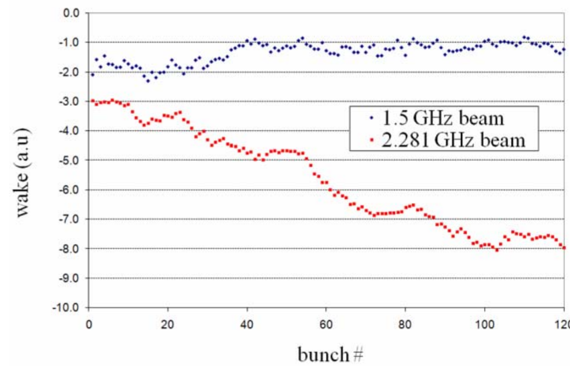

Figure 4: The wake seen by different bunches. The value for bunches with a spacing of 1.5 GHz (real operation) is constant. An artificial bunch frequency of 2.281 GHz served to validate the method; in this case the build-up is evident.

For a frequency of 1.5 GHz or multiples the wake does not build up. A successive FFT of the wake has provided the impedance of the device, and no indication of a resonance at a multiple of 1.5 GHz has been found. Anyhow the presence of a dipole mode at 2993 MHz required a careful study. The impedance of the mode (R=300 Ohm) was computed with HFSS [5]. For a 3 GHz beam of 100 MeV and a current of 35/4 A the normalized transverse kick induced by this mode is only 0.06 mrad.

Actuator System

In the collimation mode, the jaw must be movable, in the vertical plane (plane of deflection of the beam), between +20 and -10 mm, with respect to the reference beam trajectory. In the dump mode, the jaw must completely block the beam aperture. In addition, the TCC is a fail-safe mechanism and the dump position can be reached by cutting the electrical current.

The TCC is supported by two movable tables that provide the movement range needed for the collimation and dump modes. The upper table enables the movement for the operation in the collimation mode. The movement is provided by a stepper motor connected to three screw jacks. The motor system gives a positioning accuracy and resolution well within the TCC specification (0.3 and 0.1 mm respectively). The displacement is also monitored by one potentiometer that will serve to detect any motor failure. A pneumatic cylinder attached to the lower table lifts the ensemble to the collimation mode position (up). For dump operation, the compressed air inside the cylinder is released and the TCC reaches the dump position (down) by its own weight.

End switches and mechanical stops limit the maximum and minimum ranges of movements for both collimation and dump operation.

INTEGRATION ISSUES

A detailed FLUKA simulation of the operation in dump mode (150MeV e- beam, 3.7kW, 5 pulses/s) was performed in order to study the effect of the radiation on other components of the beam line.

The TCC will be installed 50cm upstream of a set of quadrupole magnets. Experimental results [6] show an important degradation of the mechanical properties of the insulating resin (Araldite) used in the manufacturing of the quadrupole coils when irradiated above 3MGy. The FLUKA analysis concluded that the absorbed dose in the quadrupole was mainly due to photons. Although the average energy of photons and neutrons are of the same order (9.7MeV for photons and 1.8MeV for neutrons), the fluence of photons at 5Hz is four orders of magnitude higher than that of neutrons (10^{15} $cm^{-2}s^{-1}$ for photons, while for neutrons is 10^{11} $cm^{-2}s^{-1}$). The predicted absorbed dose in the quadrupole magnet was equal to 27MGy after one-year operation (1000 hours at 5 Hz), much higher than the absolute limit of 3MGy.

In order to preserve the integrity of the quadrupole, a combined internal-external shielding of the TCC was foreseen. Inside the TCC assembly, a copper block, as shown in Fig. 5, will shield the graphite jaw.

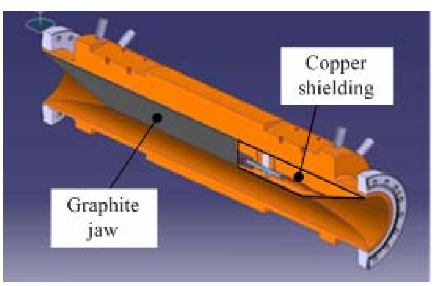

Figure 5: Final bi-material jaw of the TCC.

Fig. 6 shows the final layout of the TCC in the TL2 line of the CTF3 facility.

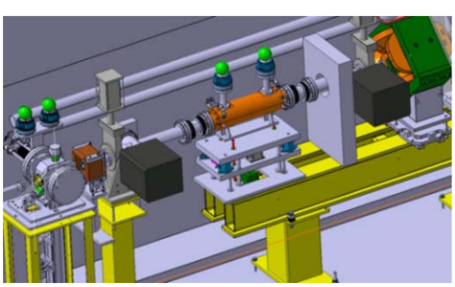

Figure 6: Layout of the TCC in the CTF3 facility.

The external shielding will consist of a 10cm lead plate placed between the TCC and the quadrupole magnet. The predicted absorbed dose in the quadupole in this configuration is equal to 0.1MGy, much lower than the mentioned threshold (Fig. 7).

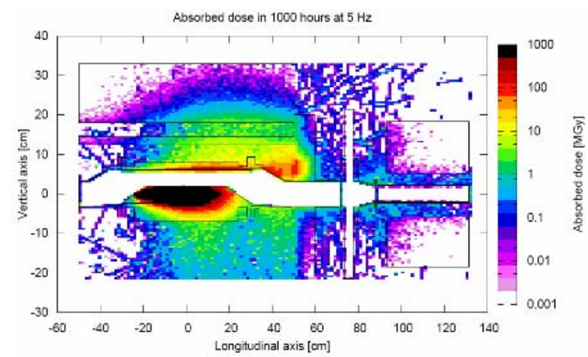

Figure 7: Absorbed dose in the TCC and downstream quadrupole after internal and external shielding.

In addition, the analysis of the ambient dose equivalent rates [7] in the accessible areas surrounding the facility led to the design of an iron local shielding that will fully enclose the TCC in order to respect the radiation protection regulations.

CONCLUSIONS

The TCC will be installed in the CTF3 facility by January 2009 and it will operate in both collimation and dump modes with a 150MeV e- beam of 35A peak intensity. The design of the active part responds to the thermo-structural constraints for both operation modes. The design intends to minimize any degradation of the vacuum quality in the line due to the outgassing of the graphite during the beam impacts. Additional aspects concerning the integration of the TCC in the facility and the impact on the surrounding equipments during its operation have been treated. The adopted multi-shielding solution guarantees the integrity of the equipments and respects the radiation protection regulations in the adjacent accessible areas.

ACKNOWLEDGEMENT

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