SEGMENTED BEAM DUMP FOR TIME RESOLVED SPECTROMETRY ON A HIGH CURRENT ELECTRON BEAM

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Abstract

In the CLIC Test Facility 3 (CTF3), the strong coupling between the beam and the accelerating cavities induces transient effects such that the head of the pulse is accelerated twice as much as the rest of the pulse. Three spectrometer lines are installed along the linac with the aim of measuring energy spread versus time with a 20ns resolution. A major difficulty is due to the high power carried by the beam which imposes extreme constraints of thermal and radiation resistances on the detector. This paper presents the design and the performances of a simple and easy-to-maintain device, called 'segmented dump'. In this device, the particles are stopped inside metallic plates and the deposited charge is measured in the same way as in Faraday cups. Simulations were carried out with the Monte Carlo code 'FLUKA' to evaluate the problems arising from the energy deposition and to find ways to prevent or reduce them. The detector resolution was optimized by an adequate choice of material and thickness of the plates. The overall layout of the monitor is described with special emphasis on its mechanical assembly. Finally, limitations arising at higher beam energies are discussed.

INTRODUCTION

In CTF3 an electron pulse of 3.5A and 1.5µs is accelerated using fully loaded 3GHz accelerating structures [1]. The resulting energy spectrum shows a strong time dependency with higher energies in the first 10-50 nanoseconds of the pulse, followed by 1.35µs of steady behaviour. Time-resolved spectrometry is therefore an essential beam diagnostic to correctly set the phase of the accelerating structures. Several spectrometer lines are installed along the CTF3 linac for this purpose. They consist of a bending magnet, which provides horizontal deflection to the electrons, followed by a transverse profile monitor measuring the beam position and its transverse width. The beam lines are classically equipped with an optical transition radiation (OTR) screen [2] observed by a CCD camera for the setting up of the line, and a novel segmented beam dump for time resolved measurements.

The latter is a device composed of parallel metallic plates designed to stop the incident particles. By measuring the deposited charge in each segment, the beam profile can be reconstructed. The material and the dimension of the segments must be optimized depending on the beam parameters. In particular, they need to be long enough to stop the particles. On the other hand, the segment thickness must be chosen to optimize the spatial resolution which will tend to degrade due to multiple Coulomb scattering [3]. Moreover, because of the high power carried by the beam, thermal changes must be considered as a crucial issue as well as radiation effects that will influence the long term behavior the detector.

In 2004 a first version of the segmented dump was built and implemented in the machine [4]. The design consisted of 24 water-cooled 2mm thick tungsten plates spaced by a 1mm thick insulator. In this first design it was not possible to find an insulating material with an adequate radiation resistance, since ceramics are very difficult to braze directly on tungsten. Thus, the insulator had to be replaced after only one year of operation. The electrical connections were realized by directly converting the current in each segment into a voltage through a 1Ω resistance to ground and 50Ω in series. The presence of overshoot and undershoot effects at the beginning and the end of the pulses indicated a bandwidth limitation to 20MHz. This was interpreted as the signature of a beam inductive coupling because in this design 1/3 of the beam was not stopped in the plates and thus propagated through the device to the iron blocks located 20cm downstream.

Recently a new study was initiated to overcome the observed limitations. The final goal will be to maximize the spatial resolution of the segmented dump while optimizing its mechanical design in terms of long-term reliability and in particular radiation hardness.

FLUKA SIMULATION

In order to find out about the deposited energy on the dump, simulation studies with the Monte Carlo code FLUKA [5] were performed.

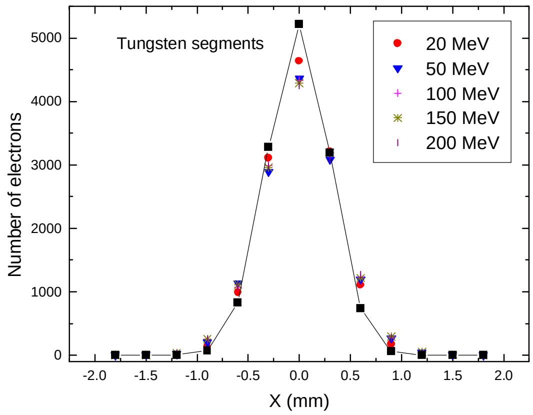

Figure 1: Simulated profile measurements on a tungsten segmented dump for different beam energies.

As a first step of the optimization process, the original geometry of the device built in 2004 was used, i.e. with

2mm thick plates spaced by 1mm. The deposited energy inside the device and the individual tracks of the particles are recorded for each simulation. In order to get a reasonable statistics, the simulation uses $2 \cdot 10^4$ electrons. Two different materials (tungsten and iron) were considered and simulations were performed for 20, 50, 100, 150 and 200 MeV electrons. The transverse size of the beam is assumed to be Gaussian with a typical width of σ=3mm. From the single particle tracks, the measured beam profile can then be reconstructed as shown in fig. 1. Each point represents the number of particles stopped in a given plate. The black curve represents the initial beam profile at the entrance of the beam dump, while the different points indicate the transverse profile measured for different beam energies. Gaussian profiles were then fitted through these points. The errors made in these profile measurements are summarized in table 1.

Table 1: Error made in the beam profile measurement for iron and tungsten plates at different beam energies

Beam energy (MeV)	20	50	100	150
Error (%) for tungsten plates	10	21	23.5	28
Error (%) for iron plates	61	78	82	82

Errors larger than 60% for iron plates illustrate the strong effects of multiple scattering. The spatial resolution is degrading rapidly for low Z and low density materials. For tungsten, the error remains relatively small for low energy electrons, but increases rapidly with beam energy. Therefore it needs to be subtracted in the data analysis.

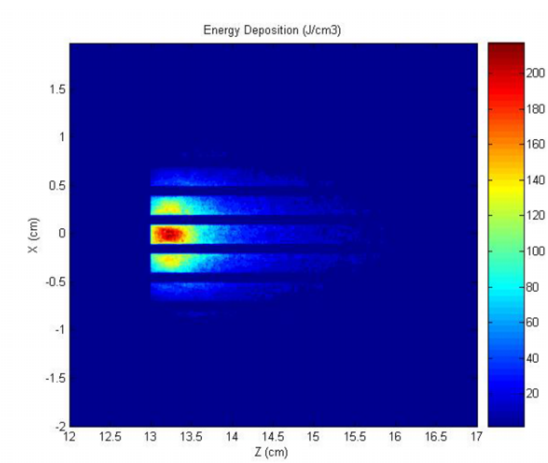

Figure 2: Energy deposition in tungsten plates for a 50MeV electron beam.

The energy deposition along the dump is presented in fig. 2 in form of an XZ surface plot. This example corresponds to 50MeV electrons stopped in tungsten. The maximum local temperature and the total power absorbed by the dump can be calculated using the deposited energy. The corresponding values are given in table 2. The maximum local temperature remains low enough to prevent any damage to the tungsten plates. However, the power deposited in the dump still needs to be dissipated, in particular to minimize the mechanical stress induced on the electrical connections.

Table 2: Temperature and power in the dump

Beam energy (MeV)	20	50	100	150	200
Maximum ΔT (K)	92	93	118	145	165
Total power (W)	88	219	434	639	847

The performance of the first option of direct water cooling of the dump segment turned out to degrade rapidly due to strong radiation effects. A second design was thus based on the use of a multi-slit collimator installed just upstream of the segmented dump. Its role is to capture as much beam power as necessary to ensure a good signal, but keep the deposited power low enough so that the segmented dump does not require direct water cooling anymore. In this scenario, radiation hard ceramics can be used as insulating material. The mechanical assembly of the multi-slit collimator and of the segmented dump are depicted in fig. 3.

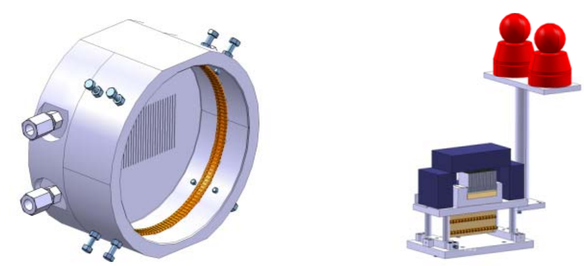

Figure 3: (a) Multi-slit collimator, (b) segmented dump.

From the construction point of view, thin slits have to be machined over few centimetres long distances precisely enough to guarantee good positioning, constant thickness and high parallelism between them.

Simulations were performed to study the impact of the slit width on the spatial resolution of the measurements. The difference is less than 5% for slit widths varying between 200μm and 1mm and this independently from the initial beam energy. A slit width of 400μm, stopping 75% of the incident electrons, was thus chosen as a good compromise between mechanical tolerance and collimation performance. In order to keep the costs reasonably low, an iron collimator was used.

The maximum temperature and power stopped in the collimator and the segmented dump are presented in table 3. In these simulations, we assumed a 4cm long collimator. These values must then be compared with the ones shown in table 2: At 20MeV the collimator is highly efficient, the temperature in the dump decreases by a factor 2 and the power by a factor 4. This is in perfect agreement with what one can await from the slit geometry. However, with increasing beam energies, showers induced by the particles stopped in the collimator start to contribute significantly to the deposited energy in the segmented dump. At 200MeV the efficiency of the collimator reduces to only 28%. A longer collimator, where the shower is better absorbed, might improve on this situation.

Table 5: Temperature and power collimator and dump

Beam energy (MeV)	20	50	100	150	200
Max ΔT_{Coll} (K)	22	22	22	28	31
Total $Power_{Coll}$ (W)	115	234	371	467	538
Max ΔT_{dump} (K)	51	60	68	86	116
Total $Power_{dump}$ (W)	21	74	217	404	614

From energy deposition simulations, one can extract the estimated radiation dose that will be received by the device. An example is shown in fig. 4 where the segmented dump is assumed to be used one hour per day, 10 days a year at a repetition frequency of 1Hz.

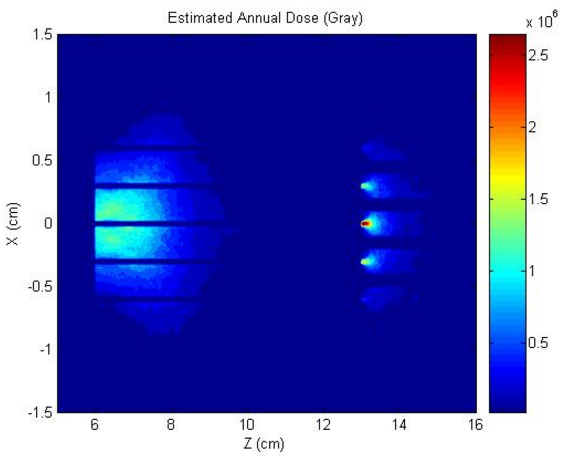

Figure 4: Energy deposition in the iron multi-slit collimator and the tungsten segments for 50MeV electrons.

It can be seen that the ceramics, located in between the metallic plates but shifted downwards by 2 cm from the beam position, receives an annual dose between 0.8 and 2MGy, depending on the initial electron energy. In radiation tests [6], it has been observed that alumina has not suffered any noticeable damage even if exposed to doses of 100MGy.

INSTALLATION AND MEASUREMENT

A test device was constructed in January 2006 and installed in a spectrometer line in April as shown in fig. 5. Typical beam energies at this spectrometer line range from 20-40MeV. In the meantime, the electronics was modified, and now the current of each segment is read directly with 50Ω impedance to ground.

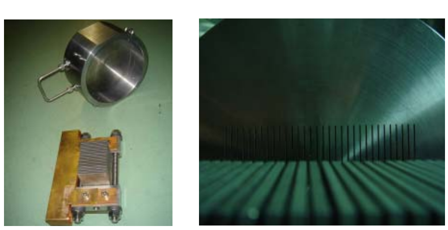

Figure 5: Photos of segmented dump and collimator in the lab (left) and installed in the beam line (right).

The first energy spectra measured recently are shown in fig. 6. The parasitic overshoot and undershoot have disappeared and the bandwidth is now limited only by the 100 MSa/s sampling rate of the ADC.

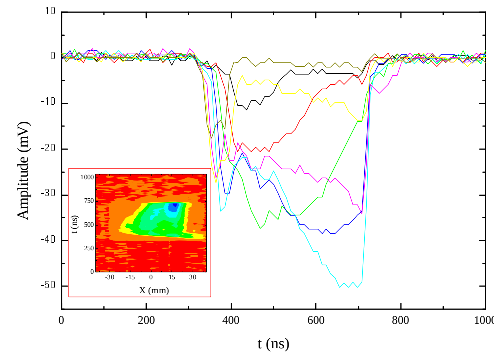

Figure 6: Time signals and time resolved spectra.

CONCLUSION

A radiation hard segmented dump was designed and commissioned successfully with beam. The output signal bandwidth, better than 50MHz, satisfied the requirements.

FLUKA simulations were carried out to estimate the spatial resolution of the device and deposited power on the different segments. Errors, which need to be subtracted, result from multiple Coulomb scattering and lead to increased profiles in the order of some percents.

The input collimator absorbs most of the beam power (~80%) and works very well for low-energy beams. However, its efficiency decreases with beam energy and other devices should be considered at energies above ~100 MeV [7].

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