BEAM INTENSITY MONITORING AND MACHINE PROTECTION BY TOROIDAL TRANSFORMERS ON THE TESLA TEST FACILITY

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Abstract

In the framework of the TTF now under construction at DESY, we have developed beam intensity monitors using the technique of toroidal transformers. The particular time structure of the beam (0.8 ms pulse length, 10 Hz) and the need for a large beam aperture imposes particular constraints on the design. The machine protection relies on differential comparison of the signals originating from several pairs of these monitors placed at different locations along the machine. 100 kHz samples as well as integrated signals are compared. The maximum tolerated average loss will be 0.8 μA over the 64 μA nominal machine current.

1 INTRODUCTION

TTF is a superconducting linac [1,2] that, in its first construction phase, is composed of a 250 keV electron gun, a preinjection beamline, a separate cryostat for the capture cavity, a low energy analyzing station, one 8-cavities cryomodule, a bunch compressor, 2 more cryomodules and a high energy analyzing station.

The maximum pulse intensity is 8 mA and the pulse length can be varied from 10 to 800 μs.

Monitoring of the beam current macropulse will make use of 7 toroid current transformers placed only in room temperature sections, as shown in Fig. 1. We have a lengthy experience using this technique on the high duty cycle Saclay linac (ALS) and on the MACSE short SC linac. Other examples can be found in references [3,4].

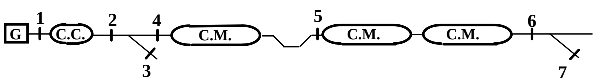

Figure: 1 Schematic of TTF. Numbers 1-7 refer to the locations of the beam current monitors. G:gun, C.C.: capture cavity, C.M.: cryomodule.

These monitors will also serve as part of the machine protection system against excessive beam loss by differential measurement of transmission through various sections.

Due to the potentially long and destructive beam pulses, a fast system for detection of excessive current loss is required to interrupt a pulse before its programmed end. We refer to this as the "fast differential protection" system (FDP).

In order to also fulfill the requirement of an average loss never exceeding the limit of 3 μA, a "slow differential protection" (SDP) was also developed, that works by comparing integrated pulses.

2 BEAM CURRENT MONITORS DESIGN

2.1 Mechanical description

We have designed both CF35 and CF100 versions of the monitors (referring to the size of the beam tube flanges). Locations 1 and 2 (Fig. 1) are of the CF35 type while the other locations will be equipped with the CF100 type to accomodate either dipole dispersed beams or off-axis beam handling.

The toroids are made out of Supermalloy [5] (permeability $\mu \cong 8.10^4$) and are obtained by winding of sheets 0.25 mm thick, 17 mm wide. For CF35 type toroid i.d.=60, o.d.=92 mm and for CF100, i.d.=97, o.d.=157 mm.

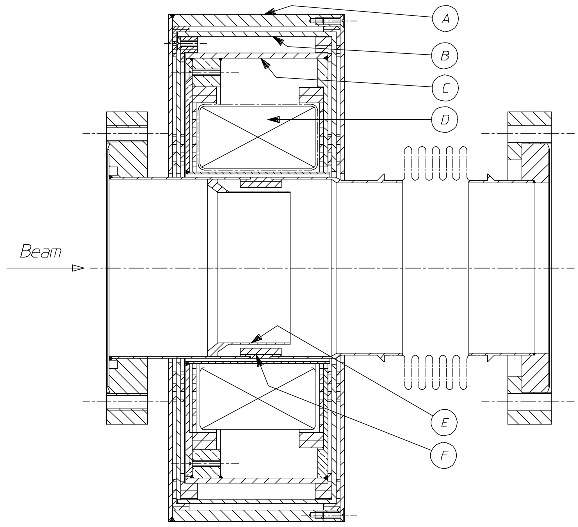

Figure: 2 Mechanical drawing. Shieldings: A- iron, B- Mu-metal, C- copper. D-Supermalloy toroid, E-electron shield, F- ceramic gap.

They are placed (Fig.2) inside 3 coaxial cylindrical shielding envelopes made respectively of, iron, Mu-metal and copper. The outer box od's are respectively 161 mm and 245 mm. The assembly is mounted on beamline tubes respectively 165 and 216 mm long, comprising flanges, a bellow and a ceramic gap. To prevent the latter from charging up, a piece of stainless steel tube, welded on one side only , is placed inside. The effective aperture to the beam is thus reduced to 25 and 75 mm respectively (instead of 35 and 100 mm).

2.2 Electrical description

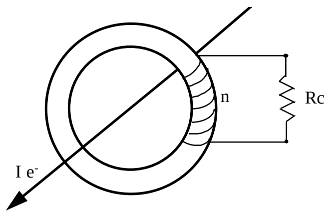

Figure: 3 Electrical schematic

The choice of the number n of turns (Fig. 3) results from a trade off between the need for a sufficient level of output signal (given by U=Rc.I/n) and for a large time constant L/R_c , where L scales like μn^2, to ensure a good current pulse reproduction. The value of n has been choosen different for each version, in order to obtain the same droop in the pulse response. We have choosen n_{CF35}=110 and n_{CF100}=300. The amplitudes are made equal by different amplifiers gains. R_c is equal to 1 kΩ. This way, the pulse droop is less than 10%.

2.3 Associated electronics

Each toroid signal is amplified by an individual amplifier placed close to the beamline. Gains of the order of 40 and 120, are adjusted to provide a 2 V signal for a 10 mA current, matched to a 50 Ω impedance.

The signal resolution, (2 times the noise level), is 50 µA. Risetime is 0.8 µs.

Each signal is then carried through a coaxial pair to a

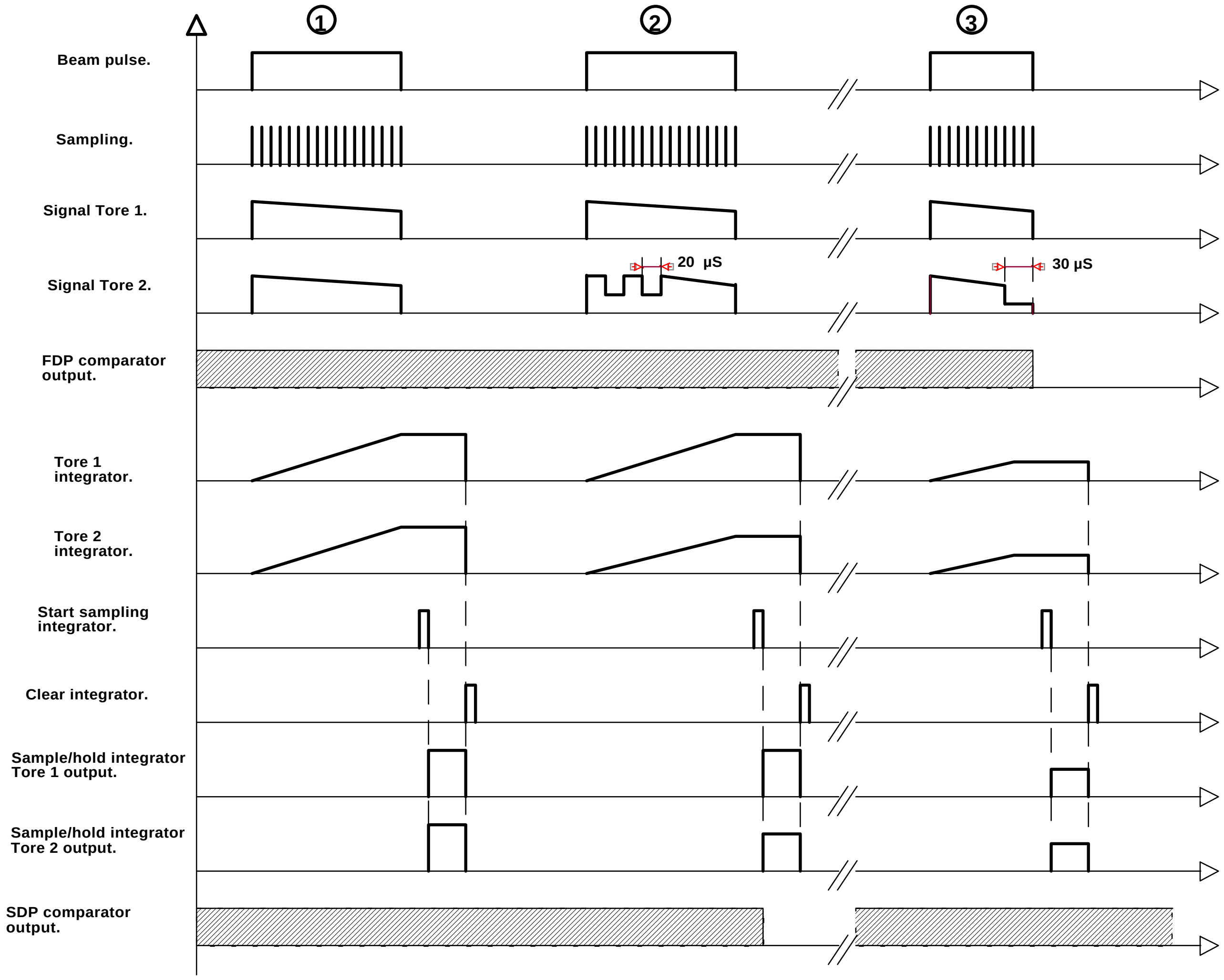

Figure: 4 Differential protection system. Behaviour of different signals in case of ①-no beam loss, ②- small and long current loss, ③-intense and short current loss.

follower module placed in a central crate that allows one to deliver 5 signal copies for different applications.

3 DIFFERENTIAL PROTECTION

Damage to beamlines or to cavities can be envisaged as being caused either by a permanent low current loss, e.g. at the 10 Hz maximum repetition rate, or by a an intense current loss occuring in the course of one single pulse. The tolerable loss in each case depends on beam emittance and/or the material on which beam impinges, and is not discussed in this paper.

Our design has been based on a limit of 3 µA for the average current loss, and 50 µs for the maximum duration of a total loss of current.

3.1 Fast Differential Protection

Both signals to be compared are delivered by the follower module to the FDP module. Each signal is sampled at 100 kHz. If a difference greater than 0.1 V (i.e. 500 µA) between corresponding samples is found 3 consecutive times, a trip signal is delivered. The condition of 3 consecutive events is to eliminate spurious trip. For the same reason we have not amplified the difference of the signals.

This way, the loss of 8 mA during 30 µs is tolerated in one single machine pulse only. A loss of 8 mA during 20 µs at 10 Hz will not be detected, but is acceptable as representing only 1.6 µA in average. The permanent loss of 500 µA over 800 µs pulses at 10 Hz (4 µA average), that this scheme also permits, has justified the following additional protection.

3.2 Slow Differential Protection

In the SDP module, the 2 signals compared are integrated during the machine pulse and their levels are then compared. If the difference is found to be greater than a threshold corresponding to a charge quantity of 800 µs*0.8 µA, (i.e. 80 nC), a trip signal will be issued. The maximum possible constant loss during a pulse is thus reduced to 100 µA i.e. at the maximum regime, an average loss of 0.8 µA.

3.3 General organization

As far as the machine protection is concerned, the different current monitors are coupled into 6 pairs, namely, in using the numbers of the Fig. 1 :

1-2 2-3 2-4 4-5 4-6 4-7

For each couple there is one FDP and one SDP module. They are installed in the same crate as the follower modules.

FDP trip signals are sent directly to the gun pulser in order to ensure the fastest reaction. They are also sent to a programmable logic controller (PLC) that manages the different beam regime authorizations and communicates with the Control System. SDP signals are only sent to the PLC, which in turn can send an order to the gun pulser, before the occurrence of the next pulse.

Figure 4 summarizes the behaviour of different signals in the 3 cases where no loss occurs, a small long beam loss occurs or a large short beam loss occurs.

CONCLUSION

Beam current monitors have been designed that reproduce the machine macropulse with a 10% droop and a resolution of 50 µA.

In the present stage of development, TTF protection against beam losses will be ensured by 6 differential current measurements. The average beam loss will be limited to 0.8 µA and the duration of a maximum current loss will not exceed 50 µs.

Aknowledgement

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