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Concept of the Fast Beam Sweeping System for the $e^{\pm}$ Beam Dumps of TESLA

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Introduction

The TESLA collider and FEL project requires beam dump systems, that have to deal with high energy and high intensity 1 ms long bunch trains having a small spot size in the order of ≈ 1 mm^2 . Since thermal diffusion can be neglected in a 1 ms time scale, the energy deposited in the absorber, caused by one bunch train as a result of the electromagnetic shower process, directly translates into an instantaneous temperature rise ΔT_{inst} . For a given bunch train population, beam energy and absorber medium it only depends on the size of the incoming beam.

Typically the natural spot size is not sufficiently large enough to keep instantaneous heating and the related mechanical load below a safe limit. Therefore the effective beam size within the bunchtrain passage time has to be increased by additional means. Although not focussed on here, the beam windows will of course profit as well [1]. One possibility is to distribute all bunches of the train on the dump face along a circular line with a sufficiently large radius by means of a fast sweeping system.

This paper presents the concept and the parameters for such a fast sweeping system as required for the 250 GeV main dump. Therefore 5.64 x 10^{13} particles per bunch train having a natural rms beam size of 1 x 0.4 mm^2 at the dump (in case of the undisrupted beam) are assumed. The parameters of the fast sweeping systems for the 400 GeV main linac upgrade as well as for the 25 GeV and 50 GeV FEL abort systems can be derived from that.

Requirement to the Sweep Radius at 250 GeV Energy

In the main linac each bunch train carries 2.3 MJ of energy. Repeating with 5 Hz this results in an average beam power of 11.3 MW. Thus the main TESLA dump consists of a water absorber [2].

Limitation for the maximum instantaneous temperature jump $(\Delta T_{inst})_{max}$ in water during one train passage is determined as 40 K. Monte-Carlo simulations of electromagnetic shower in the dump show that the temperature jump in water may reach a few hundred degrees for an undisrupted TESLA beam.

Figure 1 shows the maximum energy density as deposited by one incoming particle in water, as a function of beam size for different sweep radii. A round beam with $\sigma_x=\sigma_y=\sigma$ is assumed for the calculation. The Monte-Carlo code MARS-13 has been used for these simulations [3]. From this figure one can see that the maximum energy deposition in water could be reduced 10-100 times depending on the sweep radius.

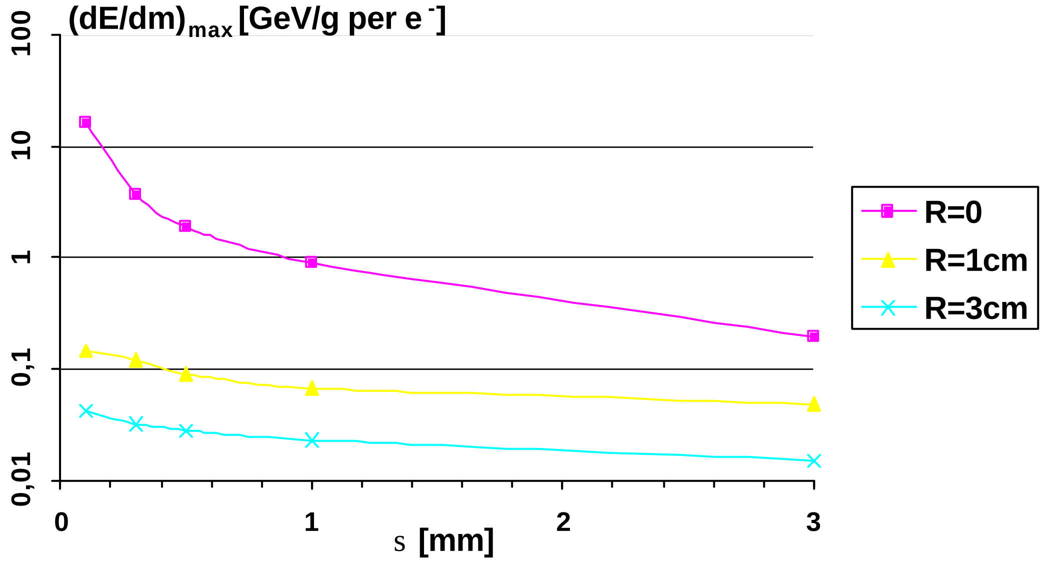

Figure 1: Maximum energy density normalized to one incident particle in water as a function of rms beam size s for different sweep radii R

For a given maximum instantaneous temperature jump $(\Delta T_{inst})_{max}$ created by a bunch train population of 5.64 x 10^{13} e^- , figure 2 shows the required sweep radius R as a function of the rms beam size σ. The given data is a result of Monte-Carlo simulations. As quoted in the TESLA Technical Design Report the rms beam size will be about 1 x 0.4 mm^2 at the face of the dump. According to figure 2 a sweep radius of about 45-50 mm is required to limit the maximum instantaneous temperature jump at $(\Delta T_{inst})_{max} \leq 40$ K.

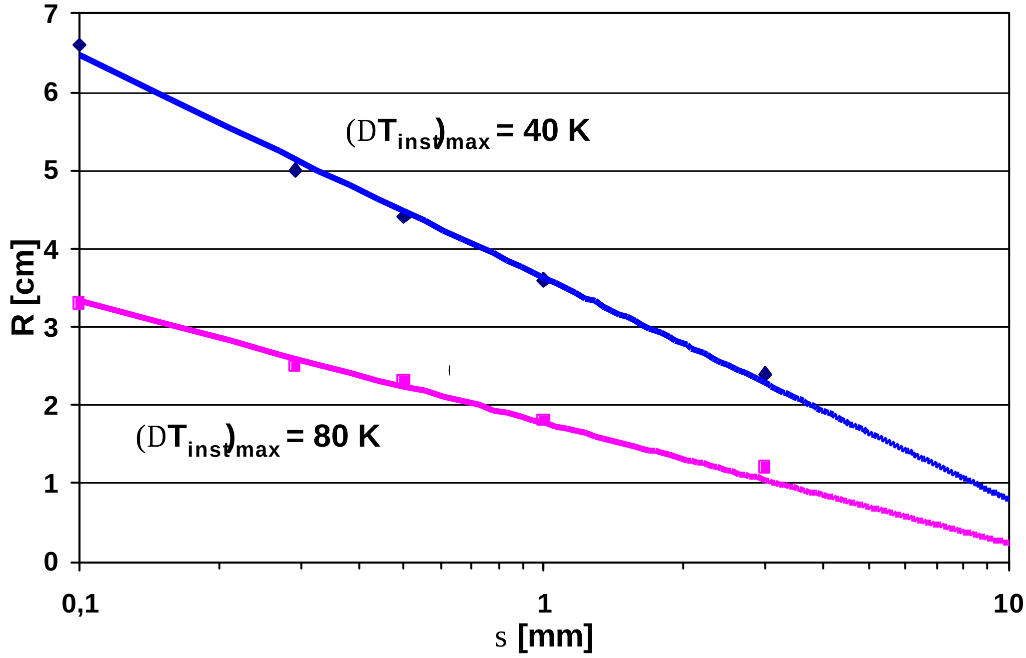

Figure 2: Sweep radius R as a function of beam size s for a given maximum instantaneous temperature rise $(DT_{inst})_{max}$ caused by one bunch train with 5.64 x 10^{13} e^-

Sweeping Kickers for 250 GeV Beam

The sweeping kicker will rotate the beam spot on the dump with a frequency of a few kHz. The low frequency allows to build the kicker magnet around a thin stainless steel beam pipe. In this case transformer steel magnetic yoke may be used for the sweeper modules. It is supposed that a pair of sweepers, horizontal and vertical, are located about 120 m upstream from the dump. Supplied by the sinusoidal current, phase shifted 90 degree between horizontal and vertical, the pairs of sweepers will rotate the beam spot along a circle with a radius of 50 mm at the dump face.

According to the layout of the normal abort line of the main linac, table 1 gives the requirements for the horizontal and vertical sweepers. In order to minimize the variety of the sweepers it is desirable to design only one type of sweeper module, which can be installed horizontally or vertically and may be used in the other abort systems as well. Therefore the magnet aperture has been chosen for a round beam pipe of 110 mm inner diameter.

	horizontal sweeper	vertical sweeper
beam energy	250 GeV	
mean distance to dump	125 m	115 m
deflection angle for 5 cm sweep radius	0.2 mrad	0.8 mrad
required integral field at 250 GeV	0.17 Tm	0.65 Tm
required aperture for beam (hor. x vert.)	110 x 50 mm^2	90 x 77 mm^2
sweep frequency	1 kHz	
available space	20 m	

Table 1: Sweeping kicker requirements for the 250 GeV main linac abort system

Table 2 shows the electrical and magnetic parameters of such a module. It is assumed that the sweeping frequency is 1 kHz, which corresponds to 1 turn of the beam spot at the dump entrance. With a magnetic length of 0.8 m this module creates a field integral of 0.0448 Tm, when powered at 1000 V peak voltage. The overall length was assumed to be 1 m, which takes the installation of flanges, pumping ports and bellows into account. In order to achieve the required total kicks, 4 of these 1 m long modules are necessary for horizontal deflection and 15 vertically.

Since the absence of fast sweeping is very harmful to absorber and windows of the

magnetic field	0.056 T
magnetic length	0.8 m
field integral	0.0448 Tm
physical length	1 m
magnet aperture	sufficient for ∅ 110mm (inner dia.)beam pipe
excitation current	180 A
# of windings	30
inductance	880 μH
impedance at 1 kHz	5.5 Ω
peak voltage	1000 V
repetition frequency	5 Hz

Table 2: Sweeper module parameters

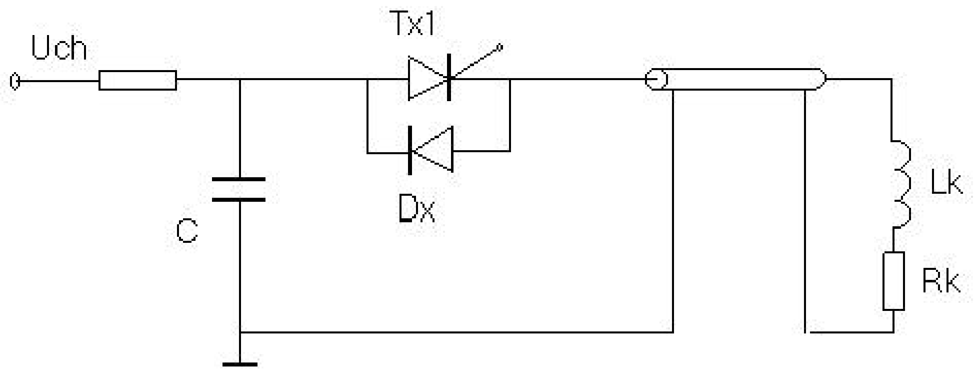

Figure 3: *Scheme of the pulsed power supply for the sweeper module*

dump system, one has to control the proper functioning of this system and create a "Sweeper-OK" signal, which enables or inhibits injection of beam into the main linac. Additional safety arises from distributing the deflection amongst several modules, which still provides sufficient total kick, even if one module fails.

There are two possible solutions for the beam sweeping power supply. The sweeping kickers may be continuously supplied by means of SIN and COS wave generators. In that case the "Sweeper-OK" diagnostics can check the system permanently. The big disadvantage of this approach is the considerable amount of power consumption. It is easy to derive from the numbers above, that one module develops 180 kVA of reactive power and at this low frequency the Q-value can not be very high (expected Q is in the order of 10, which gives about 18 kW of power dissipation).

The second solution is a pulsed power supply, as shown in figure 3. This circuit may generate any arbitrary number of harmonic oscillations depending on how long the

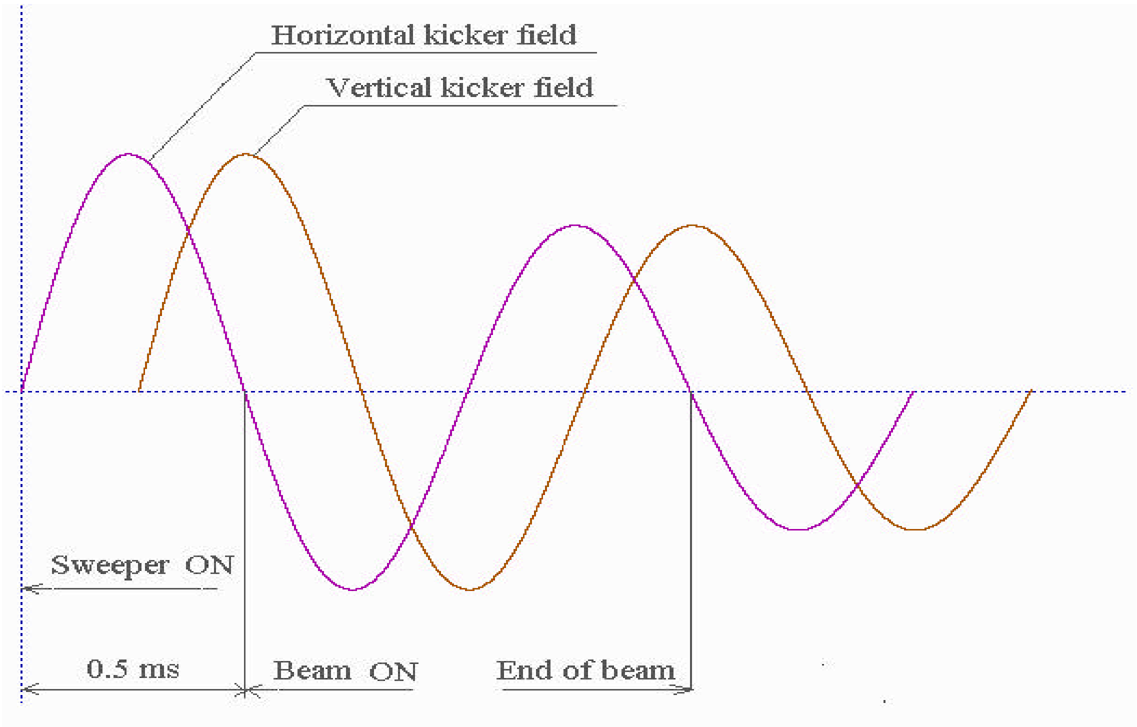

Figure4: *Sweeping kicker timing scheme allowing functioning check in order to inhibit beam operation in case of failure*

thyristor switch Tx1 is closed. In our case 2 periods (see figure 4.) are used. The switch Tx1 will be closed early enough before a beam pulse. During the first period the "Sweeper-OK" diagnostic will check the system. If a failure (missing current etc.) is detected at this moment, it is still possible to inhibit injection of the next macropulse into the main linac. Assume the sweeper to be all right, then the second period of the current will be used for sweeping the beam.

For the 50 GeV abort line at the TESLA FEL facility a kick of 0.23 mrad ⇔ 0.04 Tm @ 50 GeV is required in both planes to result in a sweep radius of 16 mm. One of the presented sweeper module would be sufficient in each plane to provide the necessary beam circulation.

Conclusion

For safe and reliable operation of the TESLA beam abort systems fast beam sweeping is applied. Several identical horizontal and vertical sweeper modules provide the distribution of the pulse of each bunch train on the face of the absorber along a circular line with a radius of 50 mm. Thus the related maximum instantaneous temperature jump $(\Delta T_{inst})_{max}$ in the water absorber does not exceed 40 K, even in the case of a failure of one of the modules. To reduce the power dissipation in the magnets pulsed power supplies are applied. For “Sweeper-OK” diagnostic advanced period of triggering of the pulsers is foreseen.

References

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