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Concept of the Emergency Extraction Kicker System for TESLA

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Introduction

The emergency kickers are part of the Fast Emergency eXtraction Line (FEXL) of the TESLA main linac. If for whatever reasons a clean beam transport from the end of the main linac to the interaction region is not possible, further injection into the linac has to be stopped as fast as possible. Nevertheless up to this moment a certain fraction of the bunch train will still run down the main linac. To prevent destruction of machine or detector components, this fraction of beam will be extracted right behind the main linac by means of the fast emergency extraction kickers and sent down the fast emergency extraction line towards the main beam dump. A similar scheme will be applied at the end of the FEL transfer lines in order to protect the undulators and related collimators from intolerable beam losses.

Combination of a very short rise time with a long flat top of the kicker pulse as well as a high level of reliability, make this abort kicker system to be a rather difficult task. Below we consider the emergency kicker system as required for the fast emergency extraction line of the upgraded main linac running at 400 GeV, which is the most challenging case.

On that basis a similar but down-scaled system will be used for the fast emergency extraction in the 13 to 50 GeV regime as relevant for the FEL facility to protect the undulators.

Requirements of the Kicker System

The required parameters of the kicker system for the 400 GeV main linac fast emergency extraction line are summarized in table 1. For a clean emergency extraction these kickers have to be built up their field between subsequent bunches, which requires

maximum beam energy	400 GeV
total deflection angle	0.2 mrad
integral field at 400 GeV	0.266 Tm
kick pulse rise time	0.1 µs
kick pulse flat top duration	80 µs
total kick stability, in time (within pulse and pulse to pulse) and space	±2.5%
allowed missing kick when 1 out of N modules does not contribute	-3.5%
diameter of free aperture	∅ 20 mm
diameter of good field region	∅ 3 mm
available space for kicker installation	≈ 30 m

Table 1: Requirements of the fast emergency kicker system for the 400 GeV main linac

a rise time in the order of 100 ns. Due to finite information transmission time between recognizing a failure situation and stopping the injection into the main linac, these kickers have to maintain a flat field for about 80 µs before no more beam will arrive at the end of the main linac. The required total kick of 0.2 mrad has to be stable within ±2.5% [1]. As discussed in the following sections this error takes into account a ±2% ripple on the flat top part of the kicker pulse and a ±0.5% pulse to pulse stability. Since the kicker has a full aperture of 20 mm in diameter, the spatial inhomogeneity of the kicker field within the required area for the beam (≈3 mm diameter around the kicker axis) is negligible.

In order to achieve a high level of reliability and safety, the total kick will be distributed amongst N independent modules. Nevertheless neither non-firing of one out of N modules nor erratic firing of one module can be excluded. That is why in addition to the ±2.5% kick stability a missing kick of -3.5% is tolerated in the layout of the FEXL [1]. Therefore a number of 30 modules has been chosen. In that case erratic misfiring of one module is not harmful either, i.e. the passing beam, that receives 1/30 of the total kick from the misfiring module, will still make it through the IP towards the regular beam dump [2]. Each module has a length of 1 m in order to fit into the available space of 30 m.

Design of Kicker Magnet

Emergency kicker magnets may be built in- or outside of the beam vacuum chamber. The variant inside of vacuum chamber has to be preferably built without a magnetic (ferrite) yoke to avoid beam induced high RF losses in the ferrite, which as a consequence leads to a considerable amount of gas desorption. The outer kicker approach requires a ceramic vacuum chamber coated with a high resistive material at its inner walls. In this case a ferrite yoke can be used without difficulties. The latter variant requires less excitation power, but special ceramic chambers and ferrite makes it relatively expensive and technologically complicated. The kicker built inside the vacuum pipe is much simpler and about three times cheaper. Although its excitation power is higher than for the ferrite kicker, it is still moderate in our particular case. Thus for the following considerations a vacuum kicker without a magnetic yoke is chosen.

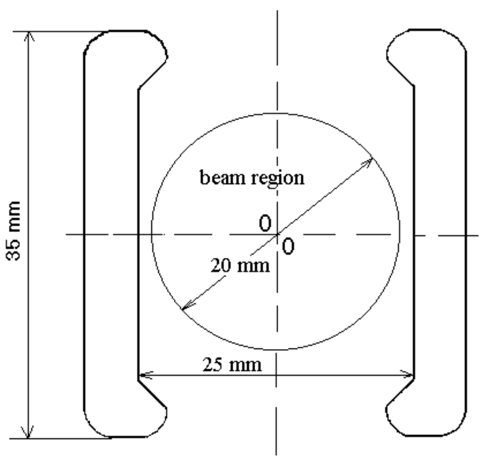


Figure 1a: Geometry of the kicker excitation bars (cross section)

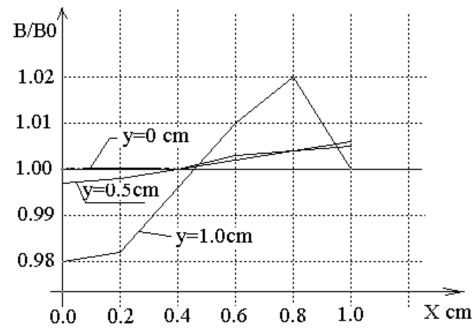


Figure 1b: Spatial variation of the deflecting magnetic field along the horizontal axis at different vertical positions

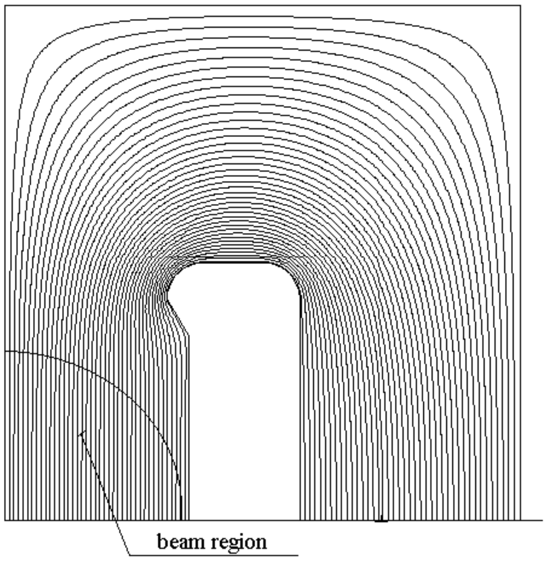


Figure 2: One quadrant geometry of the kicker magnet as used for the Poisson / Superfish calculation and the resulting magnetic flux distribution

The excitation bar geometry of such a kicker is shown in figure 1a. Figure 2 gives the corresponding field distribution (magnetic flux lines) as calculated with the Poisson / Superfish program package. Within the whole aperture (20 mm diameter) the spatial field inhomogeneity, as presented in figure 1b, is about ±1.2%, but for the required beam area of 3 mm diameter around the axis this figure is $\leq 10^{-3}$ and therefore negligible. Furthermore the excitation current and the kicker inductance were calculated by means of the above mentioned programs.

Pulser for Kicker Magnet

The supply requirements for the kicker magnet pulser are summarized in table 2.

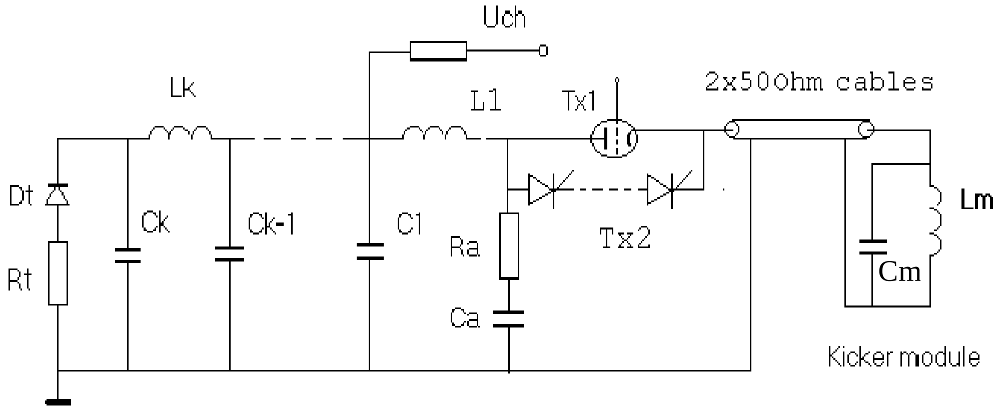
number of modules	30
length of one module	1 m
magnetic field	9.85 mT
excitation current	740 A
module inductance, Lm	0.4 µH
maximum repetition frequency	5 Hz

Table 2: Requirements on the pulser, to supply one kicker magnet module

In the following paragraphs three different possible pulser schemes (Type I to Type III) are discussed.

Type I - PFN Pulser

The traditional PFN based pulser may be used as a power supply for individual kicker modules. A ±2% flat top variation is achievable with such a pulser. The schematic circuit diagram and relevant parameters are indicated in figure 3. In order to



<u>Figure 3:</u> Type I - PFN pulser circuit diagram,
Ra=Rt=25Ω, Ca=0.12µF, C1-Ck=0.1µF, L2-Lk=62.5µH, k=18, L1=112µH, Cm=0.3nF

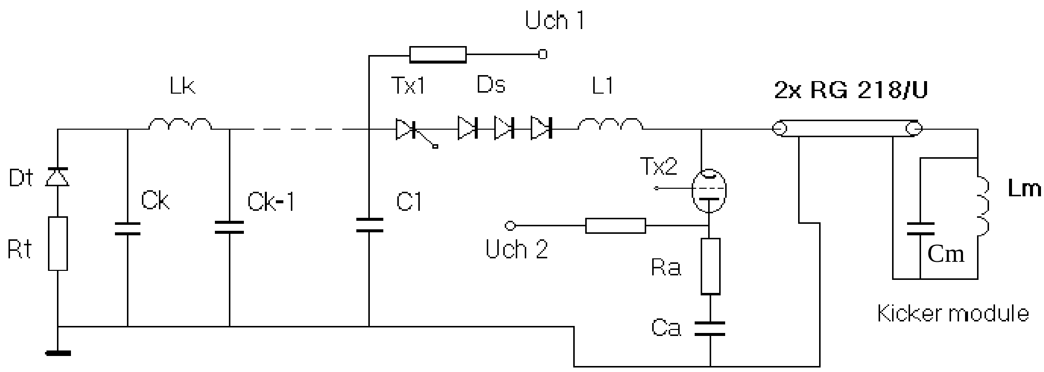
achieve the required rise time of 100 ns, contributions from PFN, thyratron, cable attenuation and magnet connections, which are significant compared to the small magnet inductance, have to be taken into account. Therefore a 25 Ω impedance of the pulser was chosen to be rather conservative. The PFN runs at about 20 kV. Power dissipation at Rt will reach 2 kW and charging power is going to be more then 4 kVA for one module. It has to be mentioned, that hydrogen thyratrons are not capable to conduct high ∫ I dt integrals, i.e. high charge transfer as required here because of the very long pulse. Thus a kind of solid state switch as Tx2 should bypass the thyratron.

Type II - Modified PFN Pulser

To economize the power and simplify the switch it seems reasonable to separate rising of the pulse (100ns) and long flat top generation between different pulser circuits as it is proposed in figure 4a. The pulser contains two circuits:

1. High voltage thyratron circuit to generate short rise time.
2. Low voltage PFN with thyristor switch to produce the long flat top of the pulse.

High voltage circuit charging voltage is about 20 kV and the low voltage PFN needs ten times less, i.e. 2 kV. The PFN has an impedance of 2.6 Ω and consists of k=16 cells.



<u>Figure 4a:</u> Type II - Modified PFN pulser circuit diagram,
Ra=25Ω, Ca=0.2µF, C1-Ck=1µF, L2-Lk=6.5µH, Rt=2.6Ω, k=16, L1=18µH, Cm=0.3nF

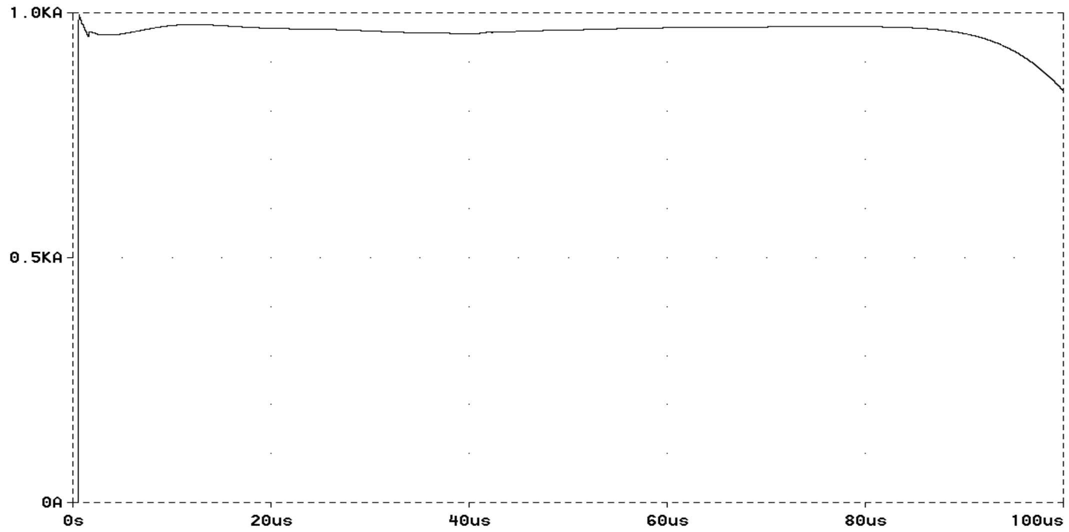


Figure 4b: SPICE result of the kicker current pulse as generated by a type II pulser,
Ca charged to Uch2=25kV, PFN runs at Uch1=2.5kV, flat top variation ±1.5%

We assumed that the kicker is located about 100 m away from the pulser. The resulting kicker current pulse as simulated with SPICE is shown in figure 4b. Besides being quite bulky due to the PFN, the power dissipation in this pulser is still relatively high, namely about 360W (160 W at Rt and 200 W at Ra).

Type III - Modified Crowbar Pulser

A more economical circuit may be considered as shown in figure 5a. This is a kind of crowbar circuit, but modified to work with long kicker to pulser transmission cables. The thyratron circuit provides fast kick rise time. It has a 25 Ω impedance and is therefore matched for reflection. The additional discharge circuit C1-L1 facilitates crowbars action and may be located far enough from the kicker itself. The current pulse of this circuit is slow and therefore impedance match is not important. The big capacitor Cf is charged to a small voltage Uch3 typically 20V to compensate kicker current droop due to the active resistance of the circuit. The recently developed closing and opening switch IGCT (Tx1) is used to activate crowbar action. It will be opened at the end of

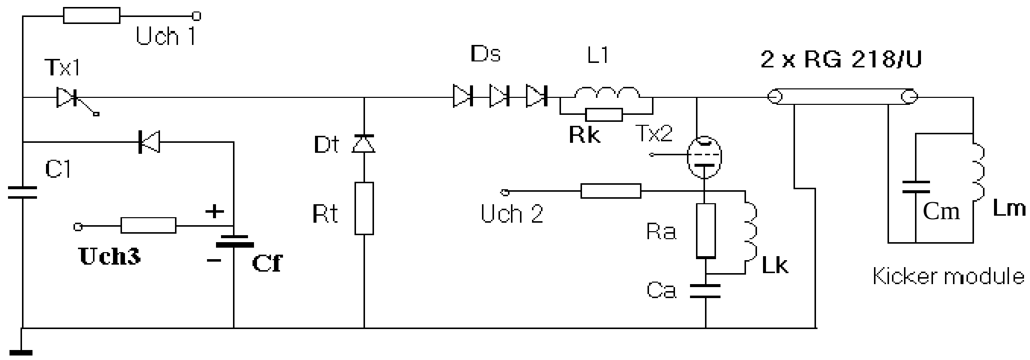


Figure 5a: Type III - Modified crowbar pulser circuit diagram,
Ra=25Ω, Ca=0.2µF, Lk=240µH, C1=4µF, L1=25µH, Rk=200Ω, Cf=0.05F, Cm=0.3nF

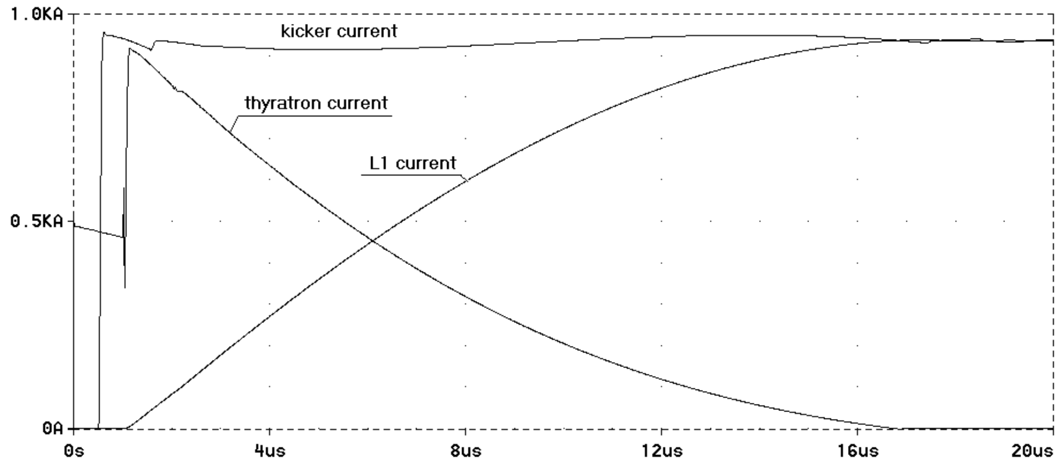


Figure 5b: SPICE result of the modified crowbar pulser type III,
Ca charged to U_{ch2}=24kV, C1 is charged to U_{ch1}=2.4kV, flat top variation ±1.5%

kicker flat top to produce the fall of the kicker pulse.

In this case we will have 40 W power dissipation at the crowbar circuit elements and 200 W at Ra, i.e. 240 W total, which is 120 W smaller compared to the modified PFN pulser of type II. Simulated with SPICE, figure 5b shows the kicker current pulse and its compositions generated by this kind of pulser.

The above mentioned power dissipation is mostly due to the energy stored in the capacitors Ca and C1. The values of those capacitors mainly depend on the cable length and flatness tolerances of the kicker pulse. This means that with shorter cables and looser tolerances, the capacitor values and power dissipation can be diminished and vice versa.

Conclusion

The electrical characteristics of all three types of pulser scheme for 250 GeV and 400 GeV linac energy are summarized in the following table 3.

Energy [GeV]	Magnet current [A]	Charging voltage [kV]	Power dissipated per one mudule [W]		
			Type I	Type II	Type III
250	500	12.5	800	144	96
400	800	20	2000	360	240

Table 3: Electrical characteristics of the three considered pulser schemes for the fast emergency extraction system

Comparing the three different pulser schemes as presented in this paper, we can conclude as follows:

- It is feasible to build the fast emergency extraction kicker system, meeting the requirements as specified in table 1.
- Schemes according to type II and type III are more economical, but is perhaps more complicated in operation due to additional charging power supplies. Their voltages have to be very well set in a fixed relation with respect to each other. Otherwise the flatness of the kicker pulse will suffer.

- For reasons of rise time, the pulser to kicker distance must not exceed 100m.
- The final choice of the pulser will be done after prototyping of all three schemes.
- The fast emergency extraction system for the 50 GeV FEL regime will use the same concept. The energy is 8 times less but the aperture is twice larger. This means that 4 times shorter modules can be built using the same pulse generators as described above.

References

[1] O. Napoly, J. Payet, N. J. Walker, Emergency Extraction High-Energy Beam Line for TESLA, November 2000, DAPNIA / SEA-00-14, TESLA Report 2001-13

[2] N. J. Walker, private communication