THE INJECTION AND EXTRACTION KICKER CIRCUITS FOR THE ELETTRA BOOSTER

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Abstract

The design, realization and performance of the power circuits for the Booster injection and extraction Kicker magnets are presented. Both circuits have been designed and developed with the goal to achieve reliable working conditions, simple maintenance and fast recovery time in case of failures. The circuits are designed around the same switching unit already adopted in the Kicker system of the Storage Ring injection; this allows storing common spare parts for both circuits and for the Storage Ring Kicker system as well. Beside the analytical analysis, a parametric study of the circuit, performed with the Microsim PSPICE software package, allowed to optimize the performance of the circuit, regarding the parameters which were considered critical for the Booster injection and extraction processes, i. e. the current pulse rise time and fall time.

BOOSTER KICKERS REQUIREMENTS

Injection Kicker

The injection into the Booster ring is an "on axis" process; this will be accomplished with the combined action of one Septum and one Kicker magnet. The injection Septum will provide the main deflection of about 15 deg and the injection Kicker will deflect the beam, of about 4 mrad, in order to put it on the axis of the Booster. Tab. 1 reports the main parameters, which have been considered in designing the injection Kicker circuit.

Table 1 – Main injection parameters

Beam energy	100 MeV
Deflection angle	4.5 mrad
Magnetic core length[1]	350 mm
Current pulse fall-time	~ 100 ns
Max. charging voltage	~ 10 kV

Extraction Kicker

The extraction of the electron beam from the Booster ring is accomplished with the combined action of four Bumpers, one Kicker and two Septum magnets. The Bumpers will shift the beam as close to the Septum shield as possible and then the Kicker will give a further kick in order to drive the beam through the gap of the Septum magnets. Tab. 2 reports the main parameters, which have been considered in designing the extraction Kicker circuit.

Table 2 – Main extraction parameters

Beam energy	2.5 GeV
Total deflection angle	2.24 mrad
Magnetic core length[2]	350 mm
Current pulse rise-time	~ 100 ns
Max. repetition rate[3]	5 pps
Max. charging voltage	25 kV

CIRCUIT DESIGN

Besides the important goals of achieving reliable working conditions, simple maintenance and fast recovery time in case of failures, the following guidelines drove the design of both circuits.

1. The basic circuit, reported in fig. 1, will have a configuration, which relies on the same thyratron switch already adopted for the Storage Ring Kickers [2][3]. The main difference, in this application, is the transmission line *T1*, which is the component that actually forms the square current pulse; the capacitor *C1* is a speed-up component, included for optimizing the current pulse rise-time.

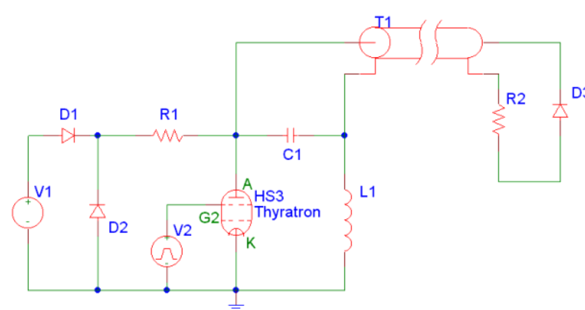

Figure 1 – Booster kicker circuit schematic

2. The same circuit will be used to drive both the Kickers; the injection circuit needs only one transmission line module, whereas in the extraction one, two such lines are connected in parallel, in order to get a lower impedance of the system and to obtain a higher flat-top current for a given charging voltage.

As already mentioned, one important parameter to be optimized is the current pulse rise-time. An analytical analysis of the circuit shown in fig. 1, based on the Laplace transform method, shows that the current pulse

[1] This value has been set designing the magnetic core [1].

[2] The extraction Kicker magnet is made by two core modules, connected in parallel; in this way the beam will experiment their effect in sequence [1].

[3] During routine tests

rise-time obeys the following relationship (in Laplace domain; see also [4]):

$$i(s) = \frac{V}{sL} \frac{s + \frac{1}{CZ_0}}{s^2 + \frac{1}{CZ_0} s + \frac{1}{CL}} \qquad (1)$$

where

L = total inductance seen by the generator
Z_0 = impedance of the transmission line
C = speed-up capacitor

The value of C can be adjusted in order to achieve the best trade-off between the pulse rise-time and overshoot. The following picture shows the behaviour of the pulse waveform (red trace), according to (1) and assuming:

L = 1.04 μH, Z_0 = 25 Ω, C = 0.55 nF.

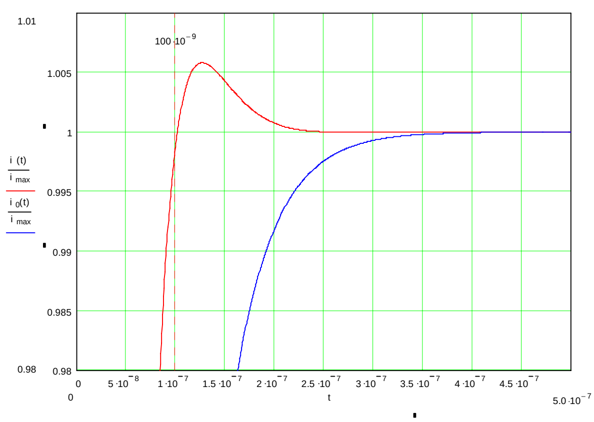

Figure 2: Pulse waveform (analytical relationship)

In fig. 2 is also reported, for comparison, the graph of the exponential response (blue trace) of the current pulse when a voltage step is applied across the same inductance L. A parametric study of the circuit with the above parameters L, Z_0 and C, performed with the MicroSim PSPICE software package, showed similar results (see fig. 3 and fig. 4).

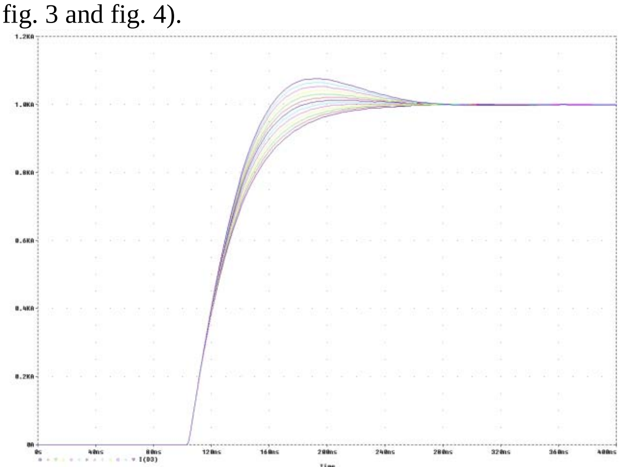

Figure 3: Current pulse waveforms vs. capacitor values

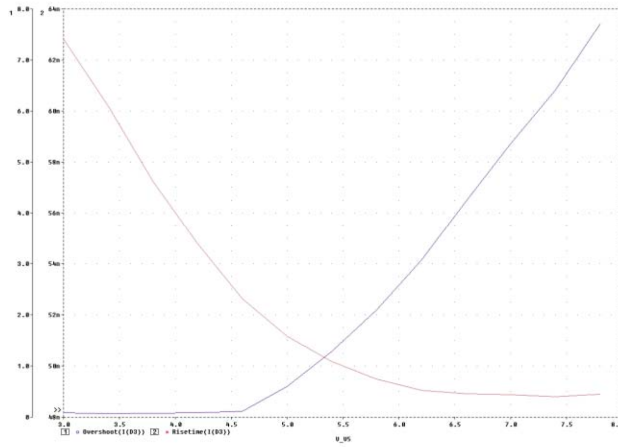

Figure 4: Pulse overshoot (blue) and rise-time (red) vs. capacitor values

In particular, this analysis showed that a capacitor value of C = 0.53 nF should give a rise-time of 92 ns and an overshoot of 0.5 %.

The thyratron chosen for the circuit realization is the well known CX 1154 from E2V, already adopted for the Kicker circuits of the Elettra storage ring; the transmission line modules are realized with suitable lengths of selected RG 214 cable, terminated with 49 Ω non inductive power resistors KANTHAL 888 AS 490 JDS of. These resistors have a tubular ceramic support, inside which a chain of 3 fast power diode VMI K 100 UF, impregnated in resin, has been inserted; the electrical connections have been made in such a way to realize a coaxial assembly of the termination. The speed-up capacitors are from the AVX HP series.

MEASUREMENTS

The first tests have been performed using a dummy load in order to verify the performance of the extraction system layout (circuit and inductive load), since this circuit is the most demanding one. The length of the transmission lines (two connected in parallel) has been set in order to obtain a pulse length of 500 ns and the inductive load was a coil of about 1.0 μH. The circuit has been tested up to 30 kV and a typical pulse waveform is reported in fig. 5 (following page).

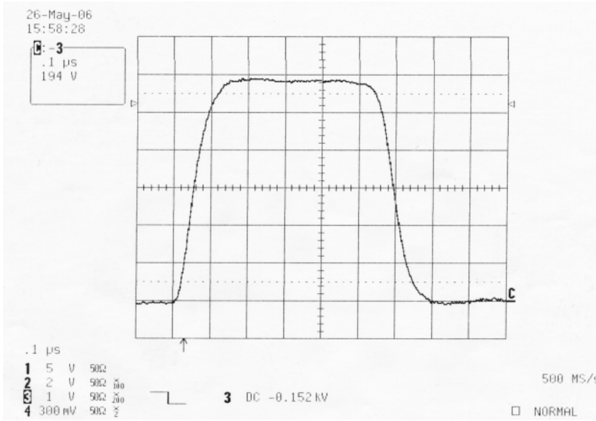

Figure 5: Extraction circuit current pulse Vert. scale: 194 A/div
V_{charge} = 30 kV; L ~ 1 µH, C = 482 pF

In the final installed layout, the length of the transmission lines of both circuits has been reduced in order to match the Booster revolution period (ΔT = 394 ns). The final length of the current pulse of both Kickers has been set at about 350 ns (transmission line length l = 35 m). The circuits have been connected to the real loads, i. e. the magnets already installed in their vacuum chamber. Some adjustments of the capacitor C have been necessary in order to correct the pulse overshoot, mainly due to the additional inductance introduced by the connections. Routine tests consisted in more than 5 days of continuous operations at maximum charging voltage (higher than 10 kV for the injection Kicker and 22 kV for the extraction Kicker). A suitable interlock based on a waveform mask, a feature available in most of the LeCroy digital oscilloscopes, gave the possibility of switching off the circuit power supply. Namely a real time pass-fail test monitored all the waveforms and was able to trigger the interlock as soon as any waveform was not within the set mask.

Fig. 6 shows a typical current waveform of the extraction Kicker current pulse, once the whole system has been installed in the Booster ring and fig. 7 shows a typical jitter figure of the same current pulse.

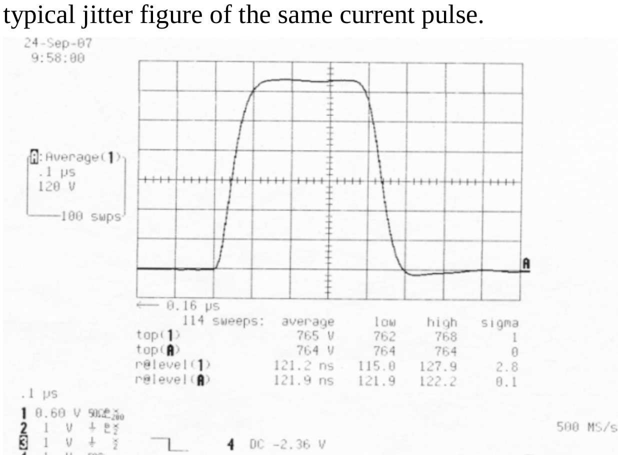

Figure 6: Extraction kicker current pulse V_{charge} = 20 kV, C = 0.595 nF

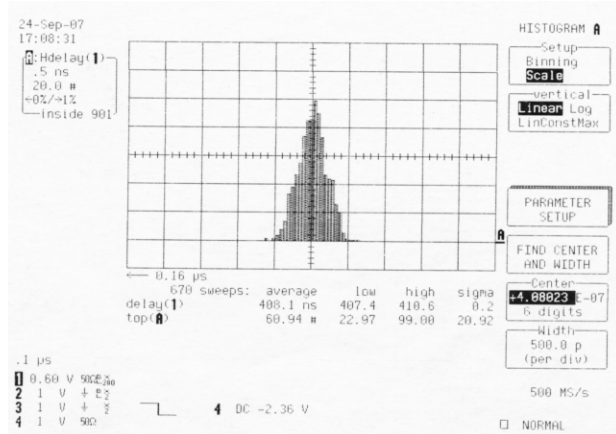

Figure 7: Extraction kicker pulse jitter hor. axis: 0.5 ns/div

CONCLUSIONS

It was possible to realize the power circuits driving the pulsed Kicker magnets, using an already adopted technology. Usually the layout for such applications uses the thyratron connected in a floating configuration, while the transmission line has the shield connected to ground; this would have forced the development of a new biasing unit of the tube switch. Instead we successfully explored the possibility to develope the circuits, based on the cathode-grounded switch layout.

On the pros side we can mention:

– a wide set of components shared between other installed systems, namely the storage ring Kickers;
– a convenient circuit layout, composed by well defined modules; each one can be easily dismounted an serviced in laboratory.

On the cons side we can mention the transmission line in a floating configuration that, even if it was not noticed in this particular case, could need additional shielding due to the impulsive regime of the circuit.

REFERENCES

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