High current, high voltage pulser for the ELETTRA kicker magnets.

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Abstract

The design of the pulsers for the kickers of the 2 GeV electron storage ring ELETTRA is presented.

The high magnetic field to be produced requires devices able to switch 8.5 kA, 14 kV pulses. The choice among different thyratron switches and different circuit configurations is investigated, and the results of the relevant tests are presented and discussed.

1. INTRODUCTION

The injection system of ELETTRA consists in two septum magnets and four kicker magnets. Four kicker magnets will be symmetrically arranged around the mid point of a single straight section. This solution allows us to have four identical magnets.

Due to space requirements, a high peak magnetic field has to be produced by the kickers (Table 1).

Table 1. Main parameters of the kicker magnets.

Energy of the electron beam	2 GeV
Deflection	22 mrad
Magnetic length	600 mm
Peak magnetic field	0.22T
Free aperture	90Hx48V mm
Magnet inductance	1.5 μH
Peak current	8.5 kA
Peak voltage	14 kV
Pulse duration	4 μs

The required pulsed magnetic field was obtained with a 0.1 mm Permalloy-C laminated magnet. A detailed description of the magnet system for injection can be found elsewhere [1].

The power pulse circuit is of the capacitor discharge type. A capacitor is charged up to the full voltage, then it is discharged on the magnet by means of a switch which is triggered when the pulse is required. The resulting half sine wave shaped current should last not more than 4 μs, in order not to produce unwanted oscillations of the electron beam.

As the kicker magnet system is a vital part of the machine, a safe long term operation is required. Therefore a relatively low voltage supply (14 kV) has been chosen, resulting in a very high peak current (8.5 kA). Other solutions, such as higher voltages and lower currents, where rejected because a so compact magnet, operating in air, would show long term problems due to degradation of the insulation characteristics. Moreover a multiturn coil would be much more difficult to make for such voltages and with a so compact design, resulting in a very expensive manufacture.

The pulsed power circuit makes use of thyratrons as power switches. The use of two thyratrons connected in parallel is often used which such high peak currents [2], but the compact design of the injection section, the problem of correctly sharing the two currents without increasing the jitter, and easy of complete assembly, suggested to investigate the possibility of using a single thyratron.

2. PULSE POWER CIRCUIT

A typical capacitor discharge like circuit, with the magnet inductance L and a resistive recovery path is shown in Figure 1. It represents the basic circuit configuration which has been investigated.
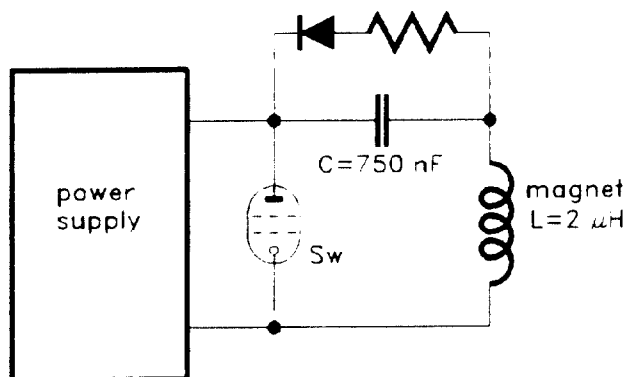

Figure 1. Basic capacitor discharge circuit.

The capacitor C is charged to a voltage V_0, then the thyratron switch S is fired and the anode voltage falls from V_0 to its low arc voltage. The recovery path is of the resistive type, with a relatively high impedance with respect that of the magnet+capacitor circuit, in order to have a well shaped half sine wave current. At the zero crossing of the load current pulse the thyratron, if of the unidirectional type, interrupts the discharge of the capacitor into the magnet. Consequently, the anode jumps to the almost full reverse voltage. The tube manufacturer usually recommends not to overcome a specified negative voltage value within the first 10-20 μs after the zero crossing of the current. This event can cause the thyratron, which is still highly ionized, arc back and, if the current or voltage values are close to the limit of the thyratron, cause circuit ringing (Figure 2 and Figure 3). The reverse arcing results in an evaporation of the emissive coating and cause severe damage to the electrodes surface [3], thus shortening the lifetime of the device.

The use of the circuit configuration of Figure 1 is possible when the correct compromise between voltage, current and pulse duration can be found.
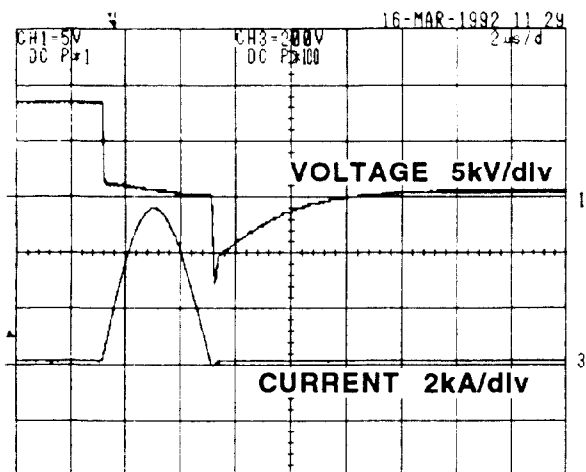
Figure 2. Current and Voltage waveforms obtained with the EEV CX1154 deuterium filled thyratron: the compromise peak current-voltage is still affordable for the thyratron, thank to a correct set of grid and reservoir parameters, even with a current well above the nominal peak value of the device. The recovery resistance value is 3.5 Ω
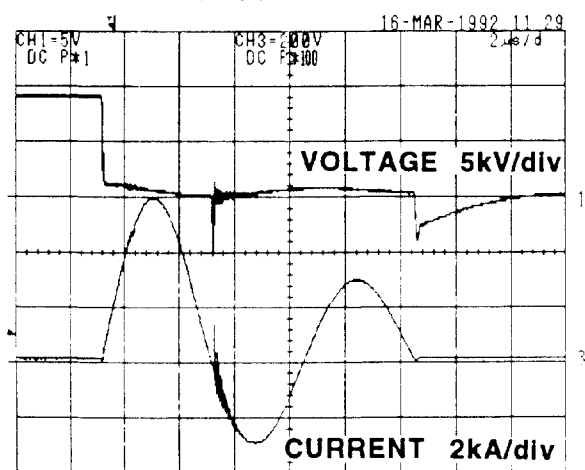

Figure 3. The increase of the current-voltage values causes the CX1154 ringing due to the combination of high reverse voltage and high forward ionization.

The use of an inductive recovery path, with an inductance value comparable to that of the magnet load, can considerably reduce the reverse voltage, and from the beam optics point of view it is still affordable even if it results in a deformation of the sinusoidal pulse shape. Nevertheless this solution was rejected because the rapid appearing of a positive voltage at the anode electrode of the thyratron would cause the unwanted forward refiring of the device.

Therefore the use of the circuit shown in Figure 1 with a high resistance value of the recovery resistor can be possible with a safe operation only with high power thyratrons as the EEV CX1549, which represents a good but expensive solution for our application.

In order to experiment the use of a smaller thyratron for driving the ELETTRA kickers, thyratron friendly circuit

conditions are to be found. Lower recovery resistance values can be experimented. The lower the recovery resistance, the lower the reverse voltage at the anode, but at the same time the current pulse modifies its shape and in particular the duration can increase over any acceptable limit. Moreover there is a lower limit of the resistance fixed by the need of total dissipation of the energy stored in the capacitor. In Figure 4 the current flowing in the thyratron and the anode to cathode voltage waveforms are shown with a recovery resistance value of 2.0 Ω. The recovery circuit was made with a parallel connections of the series of power resistors and high voltage diodes. This solution allows us to have the main power dissipations in the resistors and not in the diodes.

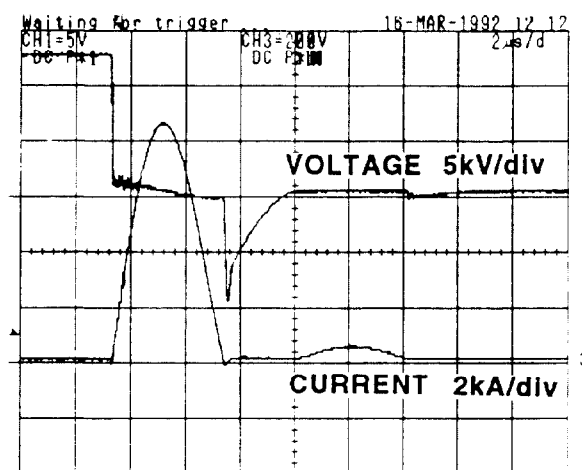The voltages are monitored with a 1000:1 probe, the currents with fast transformers

Figure 4. Current flowing in the thyratron CX1154 and anode-cathode voltage waveforms with 2.0 Ω recovery resistor.

In Figure 4 the reduction of the reverse voltage value on the thyratron is remarkable. The current flowing in the thyratron without ringing is higher than in the case of Figure 2 and close to the specified nominal current for the ELETTRA kicker pulsers. However, the low recovery resistance value makes the thyratron refiring after the pulse, as shown in the same Figure 4. Furthermore, some occasional ringing was observed at a current value of 10 kA. Then a good compromise for the recovery resistance value was found with a total value of 2.5 Ω, for which the current voltage waveforms in Figure 5 were obtained. A refiring current is still appearing, even if not really very high. Moreover the reverse voltage at the thyratron anode seems to be still too high for a safe operation of the thyratron.

Therefore, two ferrite cores, with a total cross sectional area of 5 cm^2, were added directly in series to the magnet. The ferrites act as saturable inductances, thus delaying and reducing the negative voltage across the thyratron. The use of saturable reactances also introduces a delay in the main current pulse, depending on the supply voltage, the cross sectional area of the cores and the magnetic saturation value of the material. A jitter is also introduced, which can be considered roughly less

than one order of magnitude of the delay time, thus still affordable for the beam optics, if the temperature of the ferrite core is maintained to reasonable values. The effect of the two ferrite cores is shown in Figure 6. The negative voltage across the thyratron remains below 10 kV with a peak current value exceeding 10 kA. Moreover the refiring current does not appear
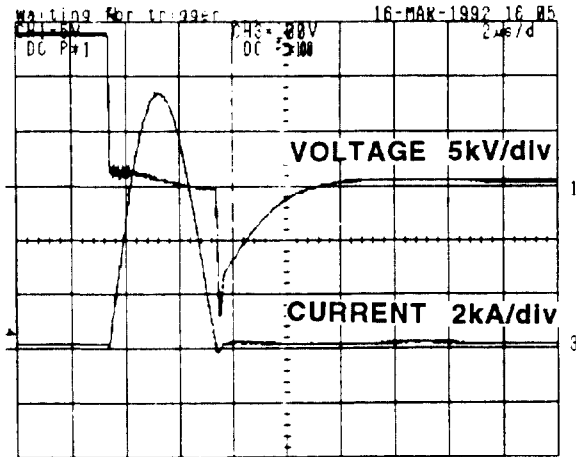

Figure 5. Current flowing in the thyratron CX1154 and anode-cathode voltage waveforms with 2.5 Ω recovery resistor.
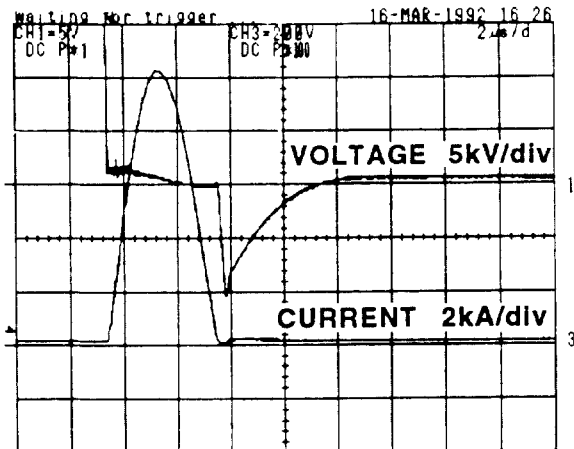

Figure 6. Current flowing in the thyratron CX1154 and anode-cathode voltage waveforms with 2.5 Ω recovery resistors and two ferrite cores in series with the magnet.

This last solution seems to be quit affordable for the EEV CX1154 tetrode thyratron, and an experimental set up able to verify the number of eventual fault fires as well as the jitter is being completing to start the long term tests.

3. CONCLUSIONS

The long term tests with two different thyratrons, the EEV CX1154 and the EEV CX1549 will start within April. The decision for the final circuit configuration will be taken before the end of June and the routine tests on the final pulsers

which will be installed in the machine will start in October. The installation of the kicker system is foreseen in March 1993.

6. REFERENCES

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