Test results of the 8.35 kA, 15 kV, 10 pps pulser for the Elettra Kickers

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Abstract

With reference to the Conceptual Design of ELETTRA [1], the kicker magnets to be used for the injection into the 2 GeV storage ring Elettra require to be supplied by a high peak pulsed current whose characteristics must be strictly controlled over a long period of operation. A thyratron friendly circuit configuration, based on a capacitor discharge type power pulser with a resistive recovery, has been designed and tested at 8800 A peak current, 10 pps, showing the ability to operate for more than 2 million pulses without any fault firing and with no significant degradation of the thyratron.

I. INTRODUCTION

After a long and accurate analysis of the problem the following parameters for each Kicker have been defined, as it is shown in table 1.

Table 1. Kicker Magnet main parameters.

Electron beam energy	2 GeV
Deflection angle	22 mrad
Magnetic core length	600 mm
Free aperture	90 H x 48 V mm
Peak magnetic field	0.22 T
Magnet inductance	1.5 μH
Total inductance	2 μH
Peak current	8350 A
Charging voltage	15 kV
Pulse duration	5 μs
Pulse repetition rate	10 pps

It should be pointed out that the mandatory characteristics are:

1 - the intensity and the shape of each pulse;
2 - the perfect synchronism between the four Kickers;
3 - the absolute identity of the pulses even during long periods of time.

The power pulser is based on a capacitor discharge circuit: a capacitor is charged up to the full voltage, then it is discharged by means of a thyratron switch, which is triggered when the pulse is required.

Because of the intensity of the current pulse the use of thyratrons connected in parallel could be adopted as well, but the required compact design of the injection section, the problem of sharing the current in a correct way without increasing the jitter and moreover the needed reliability of the whole system forced us to investigate the possibility of using a single thyratron solution.

The configuration of a circuit able to operate in safe conditions even for such high peak currents is presented and the results of the most relevant tests at 8800 A peak current, at 10 pps repetition rate are reported and discussed.

II. THE POWER PULSE CIRCUIT

A. General considerations

The capacitor discharge power circuit with the magnet inductance **L** and the resistive recovery path (diode **D** and resistor **R**) is shown in fig. 1.

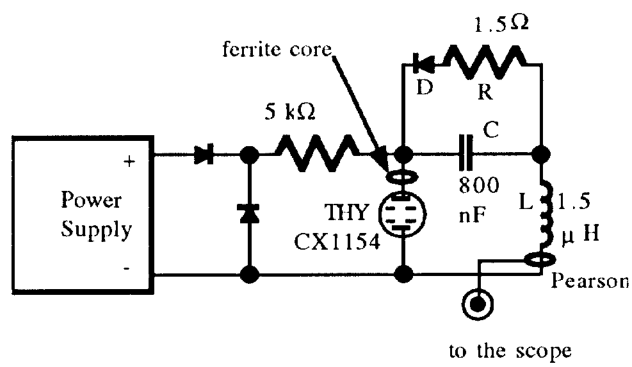

fig. 1 Simplified scheme of the power pulse circuit.

The capacitor **C** is charged up to the full voltage, then when the thyratron **THY** is fired the anode voltage falls down to its conduction value. If the time constant of the recovery path is high compared to the pulse duration, at the moment when the anode current reaches the zero crossing point, i. e. when the thyratron switches off, the anode rapidly jumps to a reverse voltage which is comparable to the full voltage.

The tube manufacturer usually recommends to stay within a specified negative voltage value (10 kV) within the first 25 μs after the zero crossing; if this prescription is violated then the thyratron, which is still highly ionized, could arc back and, if the current or voltage values exceed the thyratron maximum ratings, could cause the circuit to oscillate.

Moreover the reverse arcing causes an evaporation of the cathode emissive coating and a severe damage to the electrodes surface [2], thus shortening the lifetime of the tube.

The reverse conduction also produces a short negative current pulse, which is strongly dependent from the characteristics of the thyratron; these ones cannot be exactly the same for the four Kickers of the injection section, thus lowering the efficiency of the injection process.

In order to obtain a safe long term operation with such a high current, friendly circuit conditions for the thyratron are to be found.

An effective solution has been reached lowering the recovery stray inductance to a minimum practical value, then trimming the recovery resistance to an optimum value (in the range of 1.5 Ω) and adding a saturable inductance in series with the thyratron's anode. It is possible to show that, in these conditions the anode current reaches the zero value with low derivative, thus reducing the negative anode voltage to a safe value (below 1kV).

B. The thyratron

The thyratron used in this application is a **EEV CX1154**, a deuterium filled tetrode ceramic thyratron with separate reservoir; the absolute maximum ratings are summarized in table 2.

Table 2. CX1154 maximum ratings.

Anode:		
peak forward voltage		35 kV
peak inverse voltage		35 kV
peak forward current (high prr)		3 kA
peak forward current (prr < 60 pps)		4 kA
peak forward current (prr < 0.1 pps)		15 kA
average current		3 A
current rise rate	(high prr)	5 kA/μs
current rise rate	(low prr)	100 kA/μs

Even if the 8350 A peak current of the Kickers is high with respect to the nominal current ratings, the following consideration suggested us to investigate the possibility of using a EEV CX1154 in this application:

- the maximum anode peak current capability rapidly increases as the pulse repetition rate is reduced, starting from 3 kA at high prr, to 15 kA in single shot-crowbar operation, provided that the pulse has a i · t less than 0.1 A · s and a prr less than 0.1 pps; similarly the anode current rise rate increases from 5 kA/μs at high repetition rate to 100 kA/μs in single shot-crowbar operation;
- the average current of the system is about 0.3 A which is a factor 10 smaller than the 3 A maximum rating;
- the operating voltage is less than a half of the tube maximum rating, so there is a wide range of possibility in adjusting the reservoir voltage to obtain a good compromise among voltage hold-off, recovery time and current rise rate during the tube life;
- a suitable rechoke network allows to control the anode inverse voltage keeping it within a small amount, which is useful to quickly turn off the thyratron; in this way the accidental refiring of the tube can be avoided even at such high current levels.
- the heathers, grid bias and drive requirements, as the relative cooling and mechanics, remain for this tube quite contained with respect to what is needed for bigger devices, allowing efficient and relatively simple circuitry and compact overall size of the system with increased reliability.

C. The bias circuit

Taking into account the required tube performances, special care has been taken in the design of the thyratron bias circuit. The chosen configuration is characterized by the grid1 DC primed and by the grid2 pulsed.

The cathode and reservoir filaments have been independently supplied stabilizing the AC mains and then using shielded adjustable step-down transformers, with a NTC protection against inrush currents and with local decoupling capacitors. This allows to minimize the intrinsic jitter of the tube.

The grid1 and grid2 bias circuit has been connected to the same stabilized AC mains; after a rectification and a smoothing, the grid1 has been primed with 140 V open circuit, 130 mA DC, while grid2 has been biased with -130 V DC voltage. This circuit include also the grid2 fast pulse driver that converts a logic level trigger signal into a positive slope pulse with a peak voltage of about 800 V, a rise time of 20 ns and a duration of 2.5 μs.

In this way the requirements for a correct tube operation are fully satisfied.

III. TEST RESULTS

The power pulse circuit is characterized by the following components:

- Kicker Magnet (inductance 1.5 μH)
- Thyratron EEV CX1154
- Low inductance oil filled capacitor 800 nF, 25 kV, made by NWL
- Ferrite core Thomson T22
- Resistive recovery system made up by a parallel of 5 connections, each connection made by a high voltage diode SEMIKRON HSK E 100000/4500-1,2 and a home made low inductance power resistor.

The anode voltage has been monitored with a high voltage probe TEKTRONIX P6015, the current with a pulse current transformer PEARSON 110A (0.1 V/A) and the trigger signal has been sent directly to a digital oscilloscope. Typical waveforms of the anode voltage and of the current pulse are shown in fig. 2.

The digital oscilloscope has been connected to a PC computer by means of a GPIB board in order to monitor the three signals; the status of the thyratron, i.e. filaments, grids voltage and current, has been monitored as well by means of a I/O board.

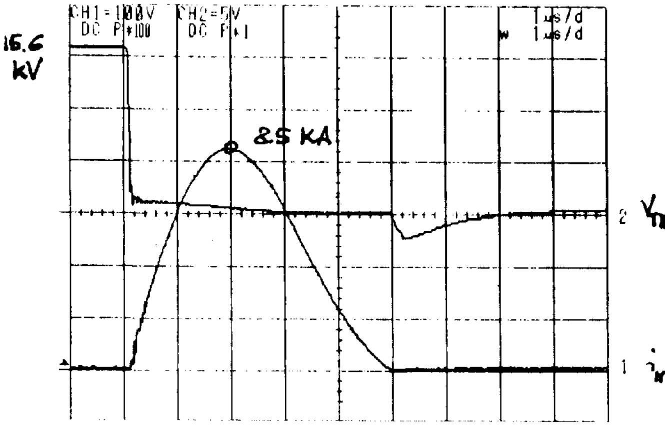

fig. 2 Anode voltage and current pulse waveforms.
chan. 2: anode voltage 5 kV/div
chan. 1: current pulse 2kA/div

The delay from the trigger pulse and 1/3 of the peak current value has been evaluated and the general status of the working system has been output on the computer display as it can be seen in fig 3.

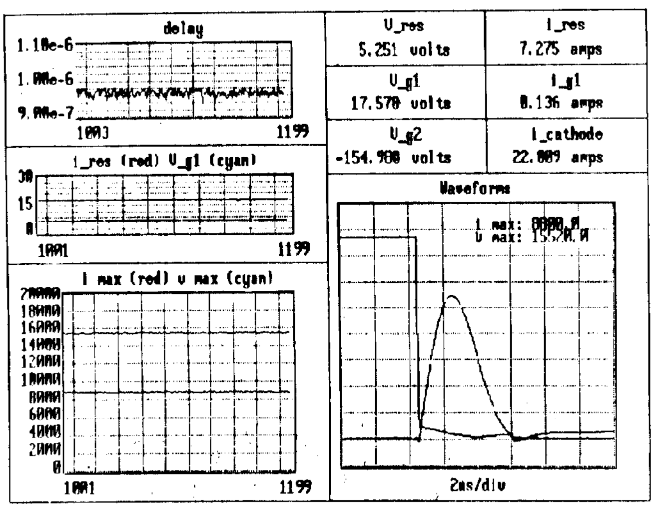

fig. 3 Waveforms and signals during the test.

More than 2 million pulses at the nominal repetition rate and at a current value 5% higher than the nominal one required at 2 GeV have been shot and some point can be remarked:

- keeping constant the charging voltage, the peak current value always remained the same within the PEARSON + oscilloscope accuracy;
- the delay between the trigger pulse and 1/3 of the current pulse peak value showed a total jitter which is less than the corresponding sampling interval of the oscilloscope;
- all the monitored parameters of the thyratron did not show significant variation during the test; in particular no drift toward dangerous values has been noticed suggesting a safe long term operation of the thyratron with respect to electrodes degradation;
- the number of power and trigger pulses have been monitored as well showing a total absence of fault fires, i.e. the number of trigger and power pulses have been exactly the same during the whole test; this is very important for the Kicker Magnets which are installed directly in the storage ring, because an unmatched kick would kill the whole electron beam.

IV. CONCLUSIONS

The test results achieved until now allow the following conclusions:

- the EEV CX1154 is an adequate device for this application even if the peak current levels are high; a correct biasing and triggering is essential to have optimum performances and a good reproducibility of the current pulse;
- the efforts to arrange the circuit in order to keep the inverse voltage drop across the thyratron have been one of the principal goals in designing this system because this parameter is directly connected with the thyratron ageing; the higher is the inverse voltage drop, the lower is the lifetime of the tube;
- no significant degradation in the parameters of the thyratron has been noticed showing the ability of the system to operate in safe conditions during a long period of time.

V. REFERENCES

[1] The ELETTRA conceptual design report", April 1989.
[2] G. Mc Duff, K. Rust, "Life extension of thyratrons in short pulse circuits with the use of saturable magnetic sharpeners", IEEE 19th Power Modulator Symposium, S. Diego, CA, June 26 - 28, 1990.