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**PRELIMINARY DESIGN OF A TUNE KICKER
FOR THE PIMMS SYNCHROTRON**

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Abstract

The design of a fast kicker for tune measurements and to scan the aperture of the PIMMS synchrotron is described. Two independent kickers, with a similar design, are foreseen for the horizontal and the vertical planes, respectively. The characteristics of the power circuit are also presented.

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1. INTRODUCTION

The design of a fast kicker for tune measurements and to scan the aperture of the PIMMS synchrotron is described. Two independent kickers, with a similar design presented in Section 3, are foreseen for the horizontal and the vertical planes, respectively. The possibilities to use, for both planes, a single kicker rotating around the beam axis, or a skew kicker are not addressed in the present paper, but could be considered to save longitudinal space in the machine. In Section 4 the characteristics of the power circuit are presented.

2. DESIGN REQUIREMENTS

In order to use the same kicker design to kick the beam both horizontally and vertically, the kicker aperture has to be a square. The side is determined by the requirements in terms of good-field region in the PIMMS synchrotron [1]. In Fig. 1 the dimensions of half the good-field region outside the main dipoles (thick line) are compared with the inner size of the kicker chamber (dashed line) and the inner size of the normal synchrotron chamber (thin line). The inner radius of the kicker chamber is equal to 65 mm.

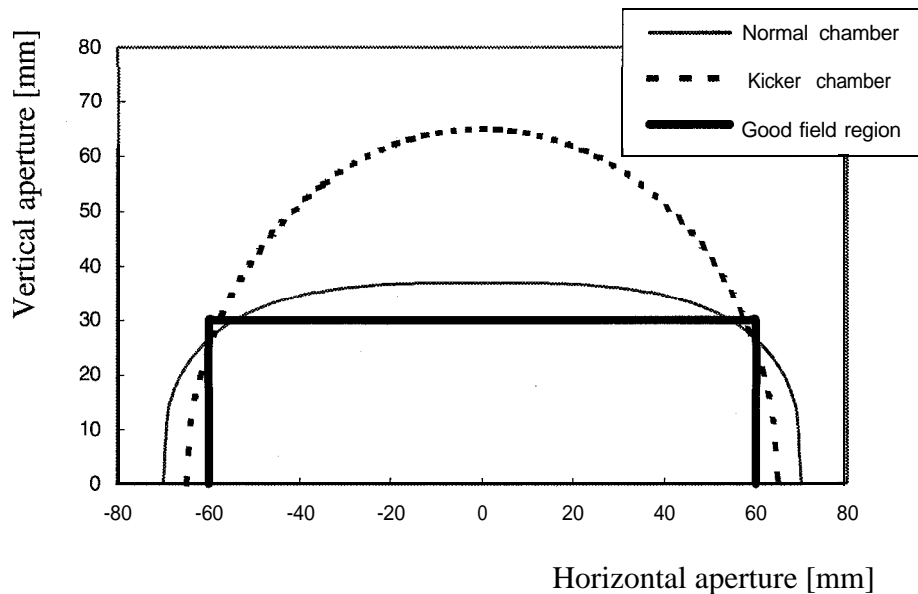


Figure 1: Rationale for kicker chamber aperture.

The time duration of the kicker pulse has to be shorter than the revolution period. At maximum extraction energy, i.e. 400 MeV/u for the carbon beam, the revolution time is: $T_{\text{rev}} \cong 350$ ns. The maximum deflection of 0.81 mrad, corresponding to a maximum kicker strength of 5.1×10^{11} Tm, is required to scan the whole aperture of the vacuum chamber with the beam and verify the dynamic aperture of the synchrotron [2].

The longitudinal space available in the synchrotron to allocate both the horizontal and the vertical kickers is about 800 mm. Taking into account about 50 mm of free space on each side of the magnet, the overall maximum length of the kicker should not exceed 300 mm.

The two kicker magnets could be positioned in sequence on the same girder and with a common chamber. In Table 1 the design requirements for the tune kicker magnet are summarised.

Table 1: Design requirements for the tune kicker for PIMMS.

Inner radius of the kicker chamber [rut-n]	65
Maximum pulse duration [ns]	350
Maximum deflection angle (θ) [mrad]	0.81
Maximum kicker strength [Tm]	5.1×10^3
Maximum kicker overall length [mm]	300

3. THE KICKER DESIGN

In Fig. 2 a schematic drawing of the kicker cross-section is presented.

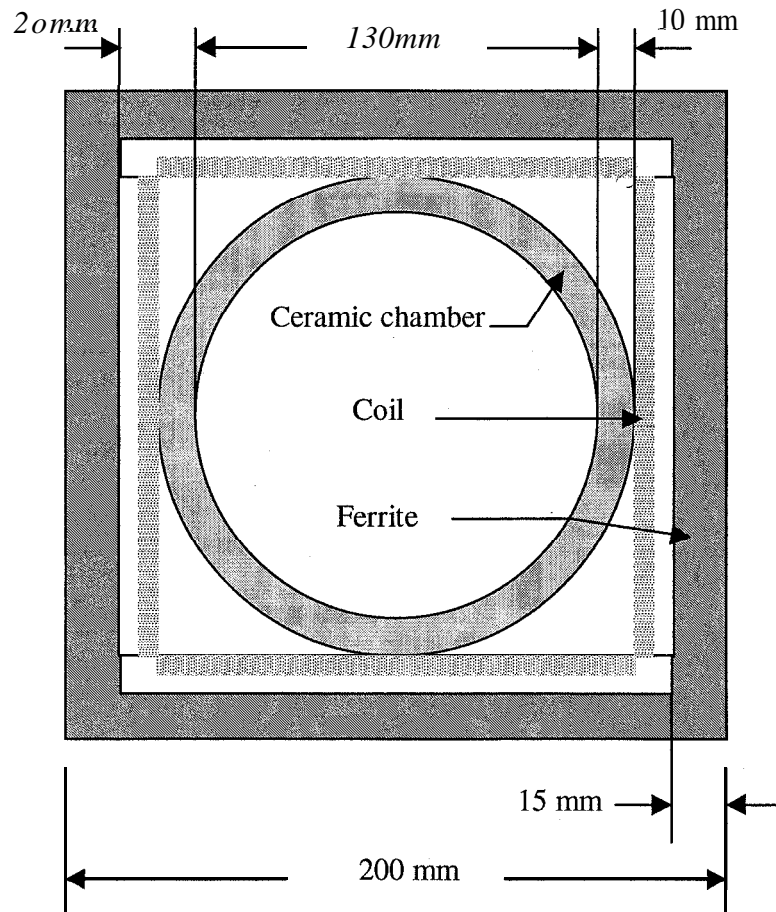


Figure 2: Cross section of the kicker aperture.

The possibility to put the kicker magnet inside the synchrotron vacuum has been ruled out by considerations of ease of construction and costs. As discussed in the previous Section, the chamber is round. This is a first approximation, in fact the chamber design could be similar to the super elliptic profile of the normal chamber in order to reduce the cross-

section variations seen by the beam. Nevertheless the kicker design is not going to change, being fixed by the necessity to produce the same field pattern in the two orthogonal planes. The chamber material is ceramic, since it is necessary to allow the fast penetration of the magnetic field in the region occupied by the beam. The ceramic chamber thickness has been considered equal to 10 mm, any reduction of this value, compatible with the mechanical stability and the vacuum tightness, has a positive impact on the kicker aperture (i.e. 150 mm, considered as the space between the coil walls).

The position of the coil can be seen outside the ceramic chamber; only two opposite conductors are present at a time in a kicker: e.g. the vertical (horizontal) ones to produce the horizontal (vertical) kick. The conductor thickness is a few millimetres and the remaining space is needed for the insulation and the spacers to hold the coils in place. The choice of a single turn coil reduces the magnet inductance and limits the value of the maximum voltage and simplifies the power circuit described in the following Section.

In Fig. 2 there are no indications on the voltage connections and the mechanical supports of the various parts, but a similar arrangement could be found in the design of the LEAR bump magnets described in ref. [3].

In the LEAR design the physical total length is 225 mm and the effective magnetic length 190 mm. In the present calculation a kicker length of 290 mm and an effective magnetic length of 250 mm have been considered.

The choice of a single turn coil allows minimisation of the magnet inductance at the expense of a bigger value of the maximum current: 2.45 kA. Considering a scaling factor for the stray inductance (equal to 55% [3]), the total value of the magnet inductance is 0.57 μH .

The maximum value of the magnetic field inside the kicker aperture is equal to 0.02 T. A ferrite frame (type Philips 8C1 1), necessarily used to allow the penetration of the field lines with fast rise time (of the order of 100 ns), surrounds the kicker aperture to contain the field. The ferrite thickness is determined by the maximum usable field value avoiding saturation, we choose 0.2 T. In Table 2 the characteristics of the kicker are summarised.

The tune measurement is performed with a bunched beam that is adiabatically shrinking with increasing energy and the measurement is done by monitoring the centre of gravity of the kicked beam, so that the field uniformity is not of primary importance. Nevertheless, this effect has to be studied and measurements have to be performed since the absolute position of the centre of gravity of the beam is influenced by the field uniformity.

Table 2: Characteristics of the tune kicker for PIMMS.

Kicker aperture [mm ²]	150 x 150
Overall magnet length [mm]	290
Magnetic length (l) [mm]	250
Number of turns	1
Magnet inductance (L) [μH]	0.57
Maximum value of the magnetic field in the gap [T]	0.02
Maximum current (I) [kA]	2.45

4. THE POWER CIRCUIT CHARACTERISTICS

In order to simplify the construction and reduce the costs with respect to a PFN (Pulse Forming Network) circuit, a discharge-like power circuit has been considered (similar circuits are reported in ref. [4] and in Appendix A, a simple, basic power discharge circuit is treated analytically). In the present case, the pulse length is fixed by the circuit elements and has been chosen according to the minimum revolution time of the beam in the synchrotron. For measurements performed at lower beam energy, the pulse duration may be shorter than the beam length so only part of the beam is kicked. Nevertheless, the pick-up sensitivity seems to be adequate to measure the orbit displacement and thus the tune of the synchrotron with an accuracy of the order of 10^{-4} [2].

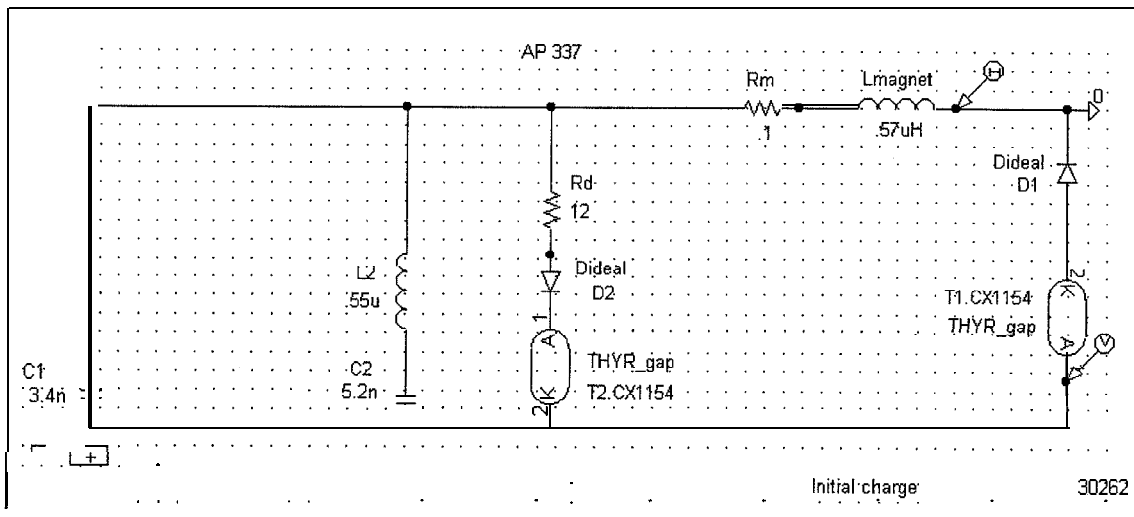


Figure 3: Capacitor discharge circuit.

The equivalent circuit used to power the tune kicker is shown in Fig. 3. The branch with $C2$ and $L2$ is added in parallel to the basic configuration (Appendix A) formed by Rd , $C1$ and the kicker inductance $Lmagnet$. The current waveform is the result of a superposition of a sine wave with frequency $1/(\text{pulse duration})$ and another sine wave with a frequency about three times higher. The relative amplitudes of these waves are adjusted by the choice of the circuit elements, to flatten the maximum of the current (Fig. 4), but keeping the pulse duration within the limits. The situation could be further improved by adding other branches to the circuit of Fig. 3 and at the limit of infinite branches the current pulse would be similar to a rectangular shape.

At $t = 0$ the two capacitors, $C1$ and $C2$ are charged and the thyatron switches are open, holding a voltage difference of 30.3 kV. The thyatron $T1$ is closed at $t_0 = 100$ ns, different from zero to evidence the voltage on the capacitor before the kicker discharge. The current flowing in the kicker is shown in Fig. 4 (see Appendix A for more details on the time evolution of the current).

The maximum value of the current is determined by the kick strength and is equal to 2.45 kA. The flatness of the central region has a uniformity within 1% in a time interval of about 100 ns around the maximum value. The pulse duration, calculated at 1% of the maximum value, is 3 15 ns.

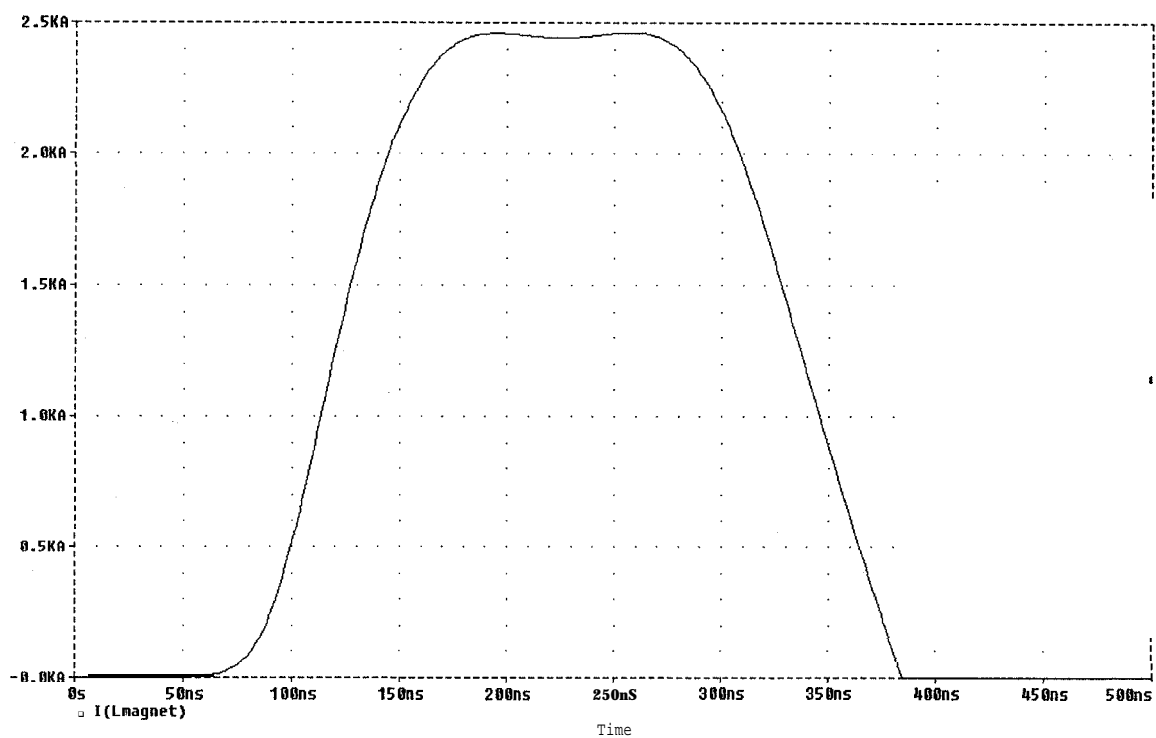


Figure 4: **Current** flowing in the kicker magnet.

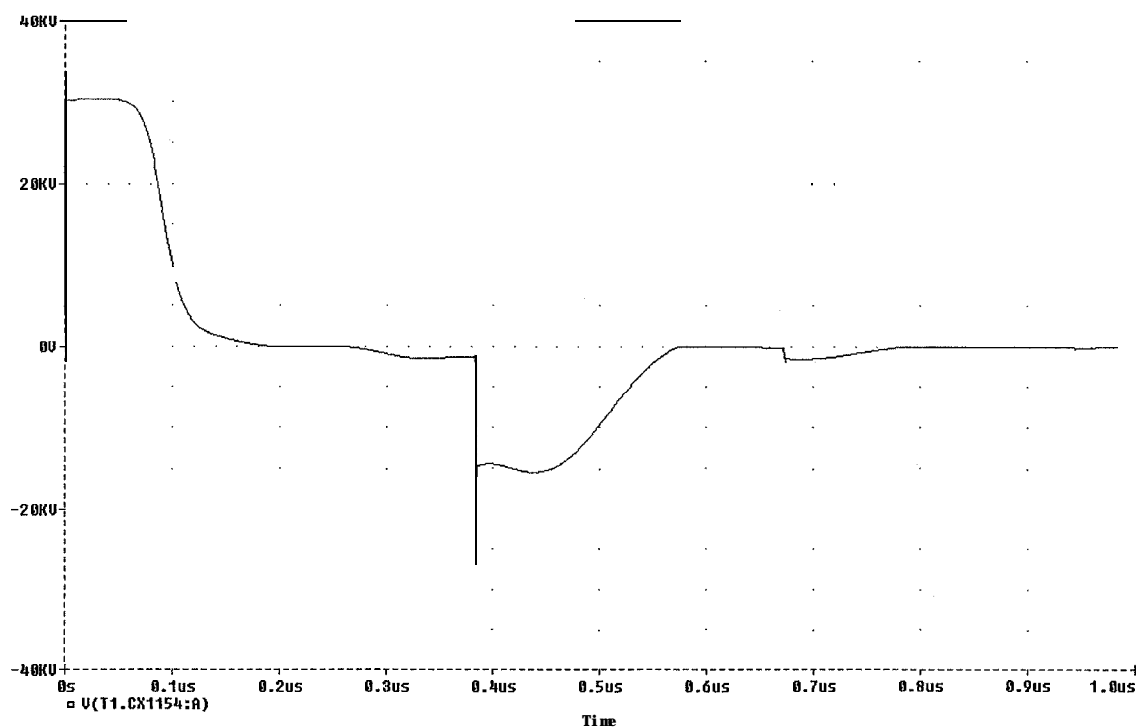


Figure 5: **Voltage** variation across the thyatron switches.

The voltage to which the two capacitances, $C1$ and $C2$, are charged is 30.3 kV and the voltage across the thyratrons is shown in Fig. 5. In this case ceramic thyratrons of the type CX 1154 should be used to keep a security margin (specified maximum voltage: 40 kV). The maximum reversed voltage is about 26.7 kV.

The choice of the resistance is determined on the one hand by the necessity to sharpen as much as possible the kicker pulse fall (large values of Rd), and on the other hand by the minimisation of the reverse voltage on the thyatron switches, $T1$ and $T2$ (small values of Rd). In the present case the resistance is equal to 12Ω . In Table 3 the characteristics of the circuit are summarised.

Table 3: Characteristics of the circuit represented in Fig. 3.

Capacitance $C1$ [nF]	3.9
Capacitance $C2$ [nF]	5.6
Magnet inductance (L_{magnet}) [μ H]	0.57
Inductance ($L2$) [μ H]	0.45
Resistance (Rd) [Ω]	12
Thyatron type ($T1$ and $T2$)	cx 1154
Power supply maximum voltage [kV]	35
Power supply maximum current [mA]	1
Pulse repetition rate [Hz]	1

The characteristics of the power supply are determined by the pulse repetition rate. For tune measurements it seems reasonable to perform a tune measurement per plane with a repetition rate of the order of 1 Hz. In this case the charge of the capacitors in the circuit shown in Fig. 3 can be easily accomplished with a commercially available high voltage power supply giving 35 kV and a current of 1 mA. In this case a single power supply could be used for both kickers.

5. CONCLUSIONS

A study for the PIMMS tune kicker has been presented. The proposed kicker design has already been realised for similar applications, the power circuit is quite simple and satisfies the requirements for tune measurements and dynamic chamber aperture scan. The proposed components are also commercially available.

6. ACKNOWLEDGMENTS

The authors have benefited from discussions with J. Bossler, P. Bryant (CERN) and L. Badano (TERA). We would also like to thank the PS Division for hosting this study.

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APPENDIX A

The typical power discharge circuit is shown in Fig. A1 [5]. The choice of the capacitor determines the pulse duration. In the present case $C = 11.29$ nF, thus giving a pulse duration of 305 ns taken at 1% of the maximum value. The capacitor is charged by the power supply to give the required kick to the beam.

When the switch $T1$ is fired (at $t = t_0$) the current flows in the kicker (represented by $(L_{\text{magnet}} - L)$) and along the external path of the circuit in Fig. A1.

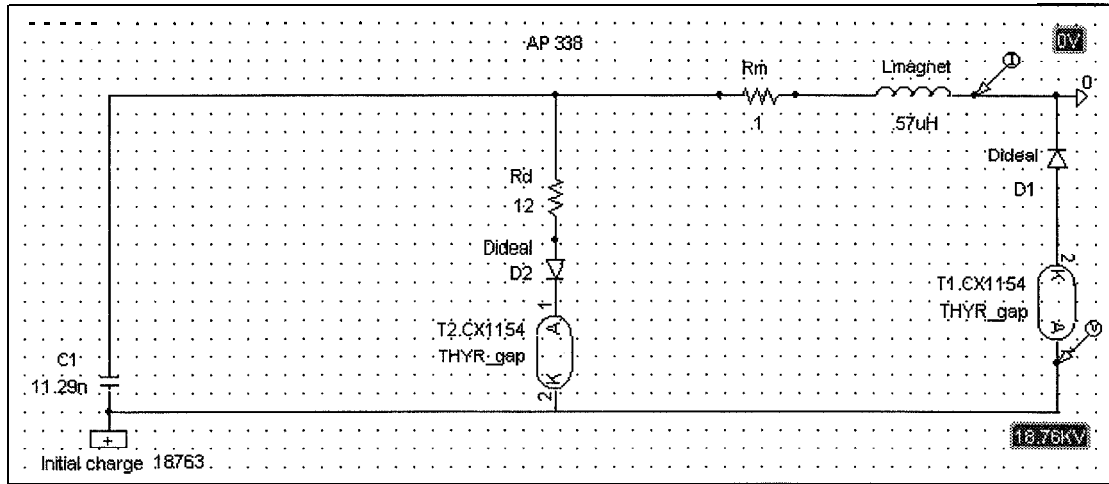


Figure A1: Basic capacitor discharge circuit.

The form of the current pulse, for $t \in [t_0, t_0 + \pi/(2\omega_1)]$, is sinusoidal:

$$I_1^L = \frac{V}{\omega_1 L} \sin(\omega_1 t)$$

with V the voltage across C at $t \leq t_0$. The characteristic angular frequency, fixed by the kicker inductance (L) and power circuit capacitance (C), corresponding to a frequency of 2.0 MHz, is expressed by:

$$\omega_1 = \frac{1}{\sqrt{LC}}$$

During the capacitor discharge, the energy is flowing from C to L , the voltage across the capacitance is progressively reduced to zero and the thyatron T2 is not conducting. After a time $\pi/2\omega_1$ from the initial trigger, the voltage across C becomes zero, the current is maximum and T2 starts to conduct.

During this second time interval ($t \in [t_0 + \pi/(2\omega_1), t_0 + \text{atan}(2RC\omega_2)/\omega_2]$) the energy stored in L is discharged onto the parallel between R and C till the current becomes zero. The current behaviour is expressed by:

$$I_2^L = I_{\max} e^{-\frac{t}{2RC}} \cos(\omega_2 t) + \frac{I_{\max}}{2RC\omega_2} e^{-\frac{t}{2RC}} \sin(\omega_2 t)$$

with a characteristic angular frequency (frequency: 1.86 MHz), expressed by:

$$\omega_2 = \sqrt{\frac{1}{LC} - \frac{1}{4R^2C^2}}$$

In this basic configuration the voltage required to produce the maximum current in the kicker coil is determined by the inductance of the magnet and by the current rise time and is equal to 18.76 kV:

$$V = L \frac{dI}{dt}$$

The resistance is equal to 12 Ω and the reverse voltage across the thyatron *T1* after the kicker pulse is equal to 15.7 kV. The voltage behaviour is shown in Fig. A2 (thyatron switch type CX1154:A).

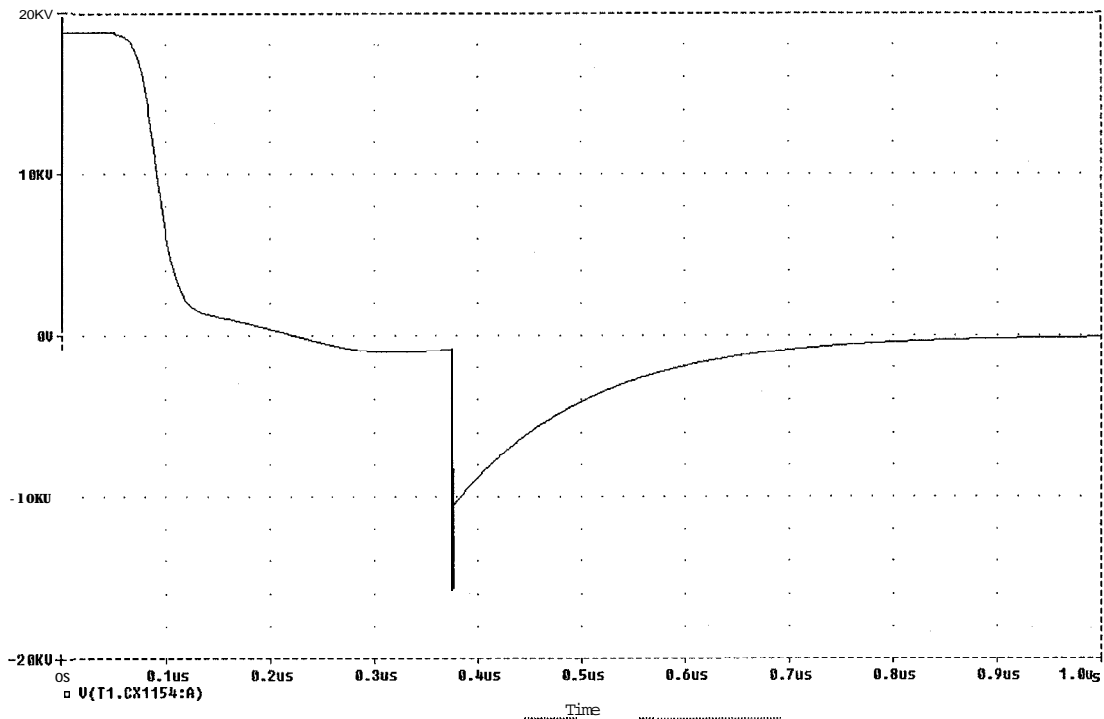


Figure A2: Voltage variation across the thyatron switch *T1*.

In Fig. A3 is represented the total current pulse in the kicker produced by the discharge circuit of Fig. A1. The current waveform is quite similar to a simple sinusoidal shape without a flat top at the maximum value of the current and with a fall determined by the choice of the resistance.

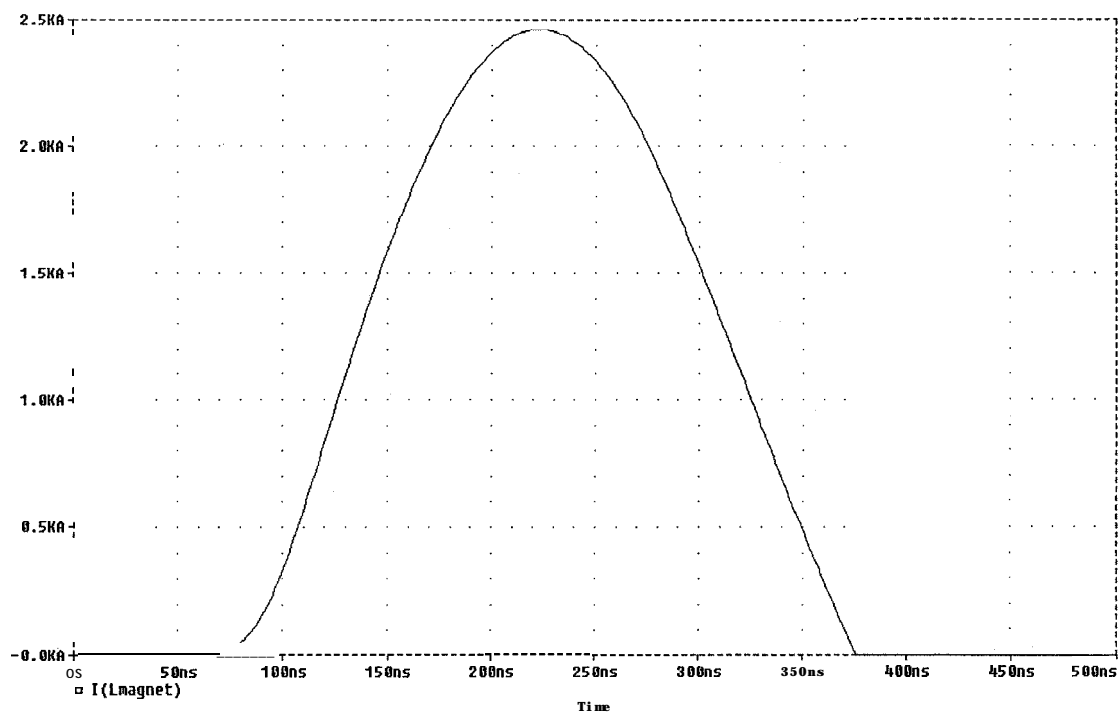


Figure A3: Current waveform in the kicker.

When the current in the kicker reaches zero, the thyatron TI opens and the remaining energy is dissipated in the loop between the capacitor and the resistance. This process lasts about 100 microsecond after which the capacitor is ready to be recharged for another pulse.