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DESIGN PROPOSAL FOR A KICKER FOR THE FAST EXTRACTION OF ANTIPROTONS FROM SS 26

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1. SUMMARY

This proposal describes the design and performance of a lumped inductance kicker magnet for installation in ss 28, the main purpose of which would be the fast extraction of antiprotons from ss 26 for LEAR. The design is based on the short circuited magnet principle as used for the staircase magnet of the Continuous Transfer; the pulse generator can incorporate numerous Continuous Transfer surplus spares with consequent cost reduction.

2. INTRODUCTION

Various possibilities for the fast extraction of antiprotons from ss 26 have been studied and described in a technical note by M. Bouthéon(1). The most favoured solution is that of a dedicated fast extraction kicker located in ss 28 and the present design proposal describes such a kicker. The performance specification which has been respected is that which would also permit kicker 28 to be used for purposes other than the extraction of antiprotons (e.g. kicker 28 could take over the tasks at present performed by the single and multi-turn kickers in ss 30).

This proposal is based wherever possible on the re-utilisation of high voltage pulse equipment which has been liberated consequent upon the reduction to six steps of the staircase generator of the Continuous Transfer. This has imposed certain constraints on the choice of some parameters but not to the point of unbalancing the design proposal.

In the interests of economy in the civil engineering field the proposal assumes that the pulse generator would be housed in that part of B362 which could be freed by the removal of the now defunct original TIK 45 injection kicker (2) pulse generator. The resulting transmission cable run to ss 28 is about 150 metres,which from an attenuation standpoint is judged acceptable but which nevertheless may cause difficulties in one of the pulse generator thyratron switches for one of the foreseen modes of operation. A standby technical solution is available, if needed, at slightly increased cost for the pulse generator.

3. DESIGN PROPOSAL

The schematic diagram for the magnet and its pulse generator is shown in Figure 1. The principle employed is that of total reflection of the incident pulse by a short-circuited magnet. Pulse length control and pulse energy absorption is effected by a bi-directional "dump" switch and terminator at the remote end of the pulse forming network. This principle is similar to that used successfully on the staircase magnet of the fast bumper for Continuous Transfer, although in the latter case the dump switch was not bi-directional as pulse length control was not needed.

The major elements of the system are described below.

3.1. Magnet

The magnet is a lumped inductance single turn device using a ferrite window-frame magnetic circuit, the bottom block of which is interrupted at the vertical median plane to reduce the inductive coupling between beam and magnet. The magnet is installed in machine vacuum and in view of its simplicity and anticipated reliability it is proposed that its tank should be a circular vessel with axial access via one end flange; this arrangement precludes access to the magnet with the tank installed on the beam line but is a much cheaper and more desirable solution, from the vacuum viewpoint, than the previously used half-shell tanks of the fast bumper magnets. Connection between the magnet and the transmission cables is made via parallel strip lines within the vacuum tank and coaxial ceramic feed-through at the tank wall. An apiezon oil-filled chamber, externally mounted on the vacuum tank, contains standardized LEMO sockets for receiving the transmission cables and also a response-time improving capacitor calculated for optimum magnet performance without inducing overswing of the magnetic field.

The magnet, tank, support frame and pumps would form a single assembly which would require the full axial length available in ss 28.

3.2. Pulse Forming Network (PFN)

The desired magnetic field flat top durations are respectively 400 ns for antiproton extraction and 2,8 or 6,7 μs for injection studies. Taking into account the field rise time of about 300 ns the minimum PFN two-way travelling times must be 0.7, 3.1 and 7 μs for the production of such magnetic flat tops.

Technically it would be possible to obtain all three magnet excitation waveforms from one single, long PFN by appropriate triggering of the dump switch. The drawbacks of such a system lie in poor fall time, due to excessive cable tail, and possibly reduced dump thyratron lifetime, due to the unnecessarily long dump current pulses which the thyratron has to handle in the main operating mode, namely as an antiproton ejection kicker.

In consequence it is proposed to provide drums of PFN cable which may be series connected by standardised LEMO connectors so as to permit PFN length appropriate to the magnetic flat top which is desired. Four cable drums are needed; the first contains 2 x 110 m of cable, the second, third and fourth 2 x 220 m cable each. The 400 ns flat top can be obtained from the first cable, the 2800 ns flat top from the first and second cables and the 6700 ns flat top from the series connection of all cables.

Irrespective of length the PFN is formed from two RG 220/U 50 ohm cables in parallel to obtain the desired pulse generator impedance of 25 ohms.

3.3. Thyratron Switches

Two thyratron switches are needed; the first is that which discharges the PFN into the transmission cable leading to the magnet, known as the main switch and the second which serves the dual purpose of controlling the magnet pulse length and connecting the termination resistor for absorption of the pulse, and known as the dump switch.

The main switch passes only unidirectional current if the transmission cable is terminated in a perfect short circuit. When terminated with a short-circuited lumped inductance magnet the initial behaviour of the termination is that of an open circuit with consequent reverse current. In applications where the pulse generator pulse length exceeds the two-way travelling time of the transmission cable this is without particular importance as the reflected reverse current results in a decrease of main switch current but not a reversal.
The need for a magnetic flat top of 400 ns, coupled with a transmission cable length of about 150 m dictated by available buildings, unfortunately results in reverse current at the main thyratron (Figure 2) in this application.

A spare main switch tank incorporating two CX1159 thyratrons and a pulsed resonant charging power supply is available from the Continuous Transfer system. It is proposed to use this tank with little modification and to connect its two thyratrons in series by a short external coaxial cable jumper. Satisfactory voltage division across the thyratrons can be obtained by connecting an appropriate bleed resistor between the two anodes. The use of two series tubes is desirable because it will allow operation at the maximum pulse generator design voltage of 35 kV without the need to specially select thyratrons for single tube working at this level - the thyratron maximum forward voltage rating is 33 kV but certain tubes exceed this figure. Further, 2 series tubes may help the reverse current problem, if one exists. It is not known from CERN experience or that of the tube manufacturer if the CX1159 can pass the reverse current of Figure 2 without destructive internal arcing. The anode/grid tube recovery time is short, about 0,2 µs, and it is therefore possible that 2 series tubes would be able to hold off the inverse voltage of about 8 kV which could be expected to appear across the main switch if reverse current is refused. If this happens then low level multiple reflections will occur between the short-circuited magnet and the open circuited main switch, as in the case of the Continuous Transfer fast bumper; such reflections are acceptable as they occur only in the absence of beam and their level is low enough not to solicit in any way the transmission cable and magnet insulation.

Some reduction in the prospective reverse current of the main thyratron is possible by fitting an R-C filter at the thyratron cathode at the expense of a small (approx. 8 ns) deterioration in the field rise time. If such a filter is needed adequate space can be found in the existing tank.

If it should be found that reverse current problems still remain after adopting the foregoing measures then an ultimate and certain remedy would be to strip the switch tank of its CX1159 thyratrons and drives and replacement by a single bi-directional CX1154 B thyratron, which is specially designed for forward and reverse current handling. Such a change would involve new (double) tube drives but it is felt that with careful attention to detail adequate space could be found in the tank for one CX1154B thyratron. Heat losses from this tube would not be so much higher as to need modification of the existing tank cooling system. The maximum voltage rating of the CX1154 B is 35 kV.

The second thyratron switch (dump switch) has to have bi-directional current capability because of its dual role of pulse length controller and terminator switch. The degree of reverse current to be handled is such as to render the CX1154 B thyratron obligatory. No existing equipment is available and therefore a coaxial thyratron plus terminator assembly has to be designed.

3.4. Power Supply

The spare power supply available from the Continuous Transfer system is of the pulsed resonant type and was originally designed for charging about 1000 metres of RG 220/U cable to 50 kV. Calculations show that it can equally well charge the maximum cable length of the PFN (1500 metres) to 35 kV. Some change of the primary capacitance will be necessary when changing from a magnetic flat top of 400 ns to the longer ones of 2800 or 6700 ns.

3.5. Transmission Cable

The distance between the pulse generator in B362 and the magnet in ss 28 approaches 150 metres. It is proposed to run 2 RG 220/U cables in parallel for the pulse transmission/reflection between the two points. Easy passage between B362 and the Ring already exists for such cables and the cable run within the Ring tunnel presents no untoward difficulty.

The choice of a short-circuited magnet imposes a more onerous duty on the transmission cables as these have to support not just the pulse voltage as in the case of a terminated magnet but the full swing of a substantial proportion of the pulse voltage; calculations indicate that for a PFN voltage of 35 kV the transmission cable voltage swing will be about 44 kV. It is considered that the cables, recovered from the Continuous Transfer system, can adequately handle this swing.

3.6. Controls

The pulse generator design is closely similar to that of other pulse generators used on the PS machine. It therefore has many common control and protection chassis.

It is proposed that remote computer control should be effected, at least initially,by the CT computer using a quad transceiver in B359 and a digital single transceiver in B362. The equipment interface would be similar to that to be used on the LEAR injection kicker. Local manual controls are foreseen in B362.

A monitoring system for power supply and fast pulse signals would be provided in B362, with display of certain selectable signals in the MCR.

4. PERFORMANCE

The parameter list for the system is given in Table 1. The field rise and fall times have been computed on the basis of thyratron current rise times (10 - 90)% of 40 ns and include the effects of cable attenuation both in the PFN and transmission cables. The optimum rise/fall time magnet compensation capacitor has been found to be 1500 pF and the performance figures relate to the circuit containing this capacitor.

Field rise/fall times, defined between the 5% - 95% levels, are well within the specified 300 ns for the application of antiproton extraction. Considerable deterioration of the field fall time occurs for the longest magnetic flat top, due to the attenuation of the PFN cable. In practice it may be possible to considerably improve this fall time by pre-distortion of the dump switch generated wave by the inclusion of appropriate circuit elements at the dump switch.

The rise time performance has been calculated without a cathode/ground R-C filter at the main switch and also with a 25 ohm/680 pF filter. The inclusion of the filter does not seriously extend the rise time but reduces by 22% the main thyratron reverse current. Even more powerful filtering could be anticipated if rise time can be sacrificed.

The nominally desired kick strength of 196 gauss-metres is obtained with a PFN charging voltage of 30,4 kV. As the maximum charging voltage is 35 kV there is a 15% reserve of kicking power.

A field program has been used to predict the field distribution within the aperture. The magnet cross-section, together with the field distribution within the aperture is shown in Figure 3a. The uniform field region is well in excess of the specified ± 35 mm horizontally, ± 20 mm vertically. The field distribution along the transverse horizontal centre line of the aperture is shown in Figure 3b.

5. COST

After taking account of equipment which may be recovered from other projects, or otherwise available free of charge, the estimated material budget necessary for the realisation of this project according to the parameters of Table 1 is given in Table 2.

The time between project authorization and completion would be 15 - 18 months.

6. REFERENCES

1. "Propositions pour l'éjection rapide d'antiprotons en section droite 26", M. Bouthéon, PS/OP/Note 80-12.

2. Private communication, B. Nicolai.

Distribution :

D. Bloess
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TABLE 1

Design Parameters for $\bar{p}$ ejection kicker for PS

General	Magnet location		ss 28		
	Pulse generator location		B362		
	Effective transmission cable length		≤ 150 m		
Magnet	Number of modules		1		
	Type		Lumped inductance		
	Termination		Short circuit		
	Compensating capacitor		1500 pF		
	Physical aperture, width		159 ± 0,5 mm		
	height		70 ± 0,5 mm		
	Useful field region +1%, -0%, width		± 62 mm		
	height		± 27 mm		
	Ferrite length		900 mm		
	Effective length		925 mm		
	Nominal kick strength for V_{PFN} = 30,4 kV		196 g.m.		
	Corresponding air gap flux density		212 gauss		
	mean ferrite flux density		1225 gauss		
	remanent $\int B d\ell$		0,34 gauss-meter		
	Ferrite type		8C11 (Philips)		
	Ferrite weight		44 kg		
			Without filter	With filter	
	Field rise time	10 - 90%	192 ns	197 ns	
		5 - 95%	247 ns	254 ns	
		2 - 98%	307 ns	315 ns	
	Field fall time	Flat top	400	2800	6700 ns
		98 - 2%	376	855	– "
		95 - 5%	273	338	734 "
		90 - 10%	206	234	326 "
	Magnet + stray inductance		2,88 μH		
Pulse Generator	PFN and transmission cable type		RG 220/u		
	PFN impedance		25 ohms		
	Nominal operating voltage		30,4 kV		
	Max. operating voltage		35 kV		
	Pulse length		100 ns - 7700 ns		
	Main switch thyratron type		2 series CX1159*		
	Dump switch thyratron type		CX1154B		
	Dump terminating resistor		25 ohms		
	Typical thyratron current rise 10 - 90%		40 ns		
	Main switch reverse current (400 ns field flat top)	with filter	187A	half height duration $\underline{\Omega}$ 50 ns	
		without filter	238A		
	PFN recharging time		2,1 - 5,3 ms (according to PFN length)		
	Transmission cable voltage swing		± 0,65 V_{PFN}		
	Permissible repetition rate		1 pulse per 1,2 s		

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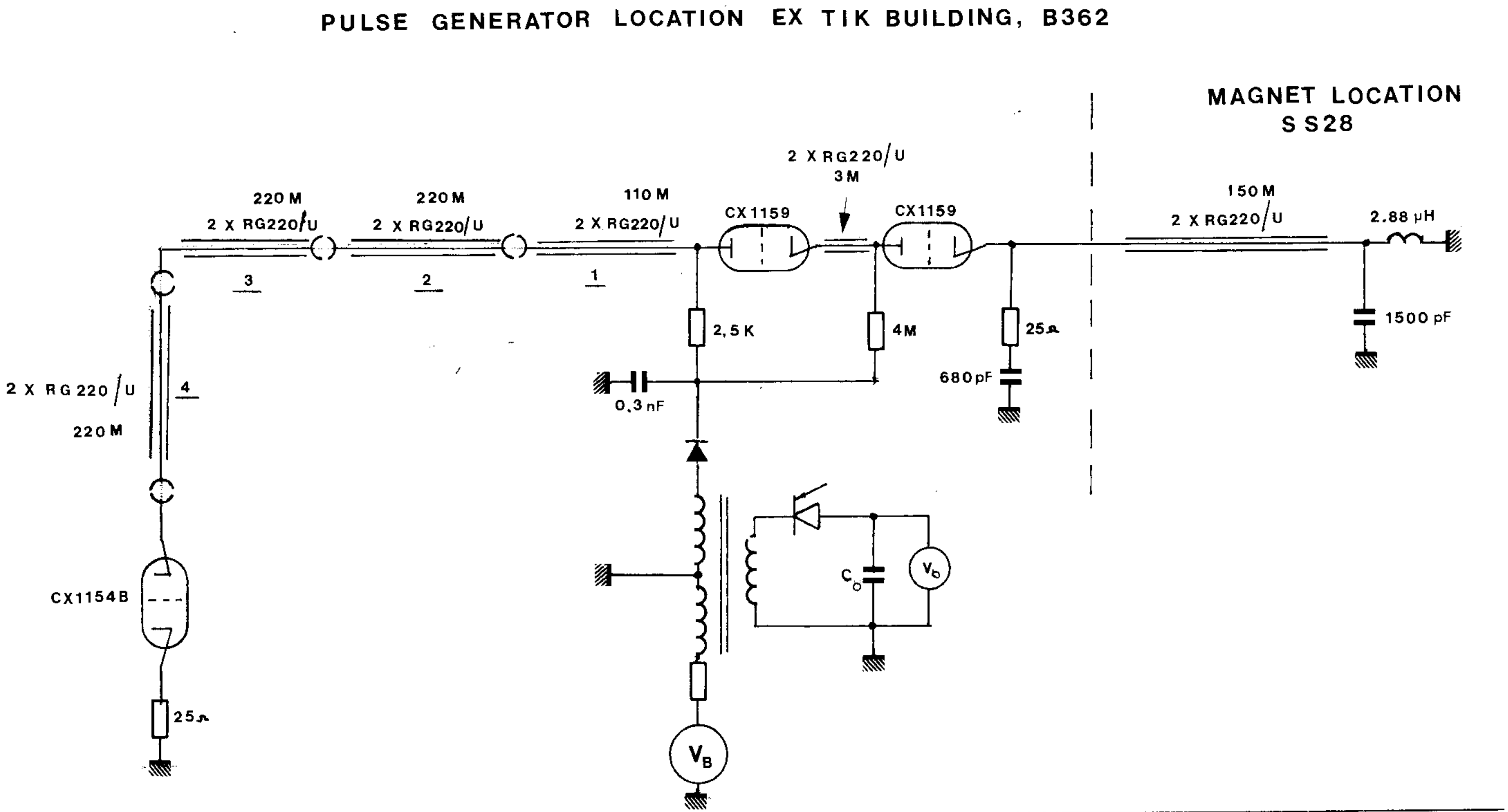
* It may be necessary to use a CX1154B tube for reasons of reverse current.

TABLE 2

Estimated costs	KF
Vacuum tank and pumps	32
Magnet, dummy load	35
Pulse generator	43
Controls and monitoring	27
Installation	20
Civil engineering	25
Temporary labour	18
Essential spares	10
	210 KF



MAX PFN VOLTAGE = 35 KV
400 nS FLAT TOP PFN 1
2800 nS " " PFN 1 + 2
6700 nS " " PFN 1 + 2 + 3 + 4
C_O = 10 mF FOR 400 nS FLAT TOP
C_O = 20 mF FOR 2800 nS, 6700 nS

FIG 1

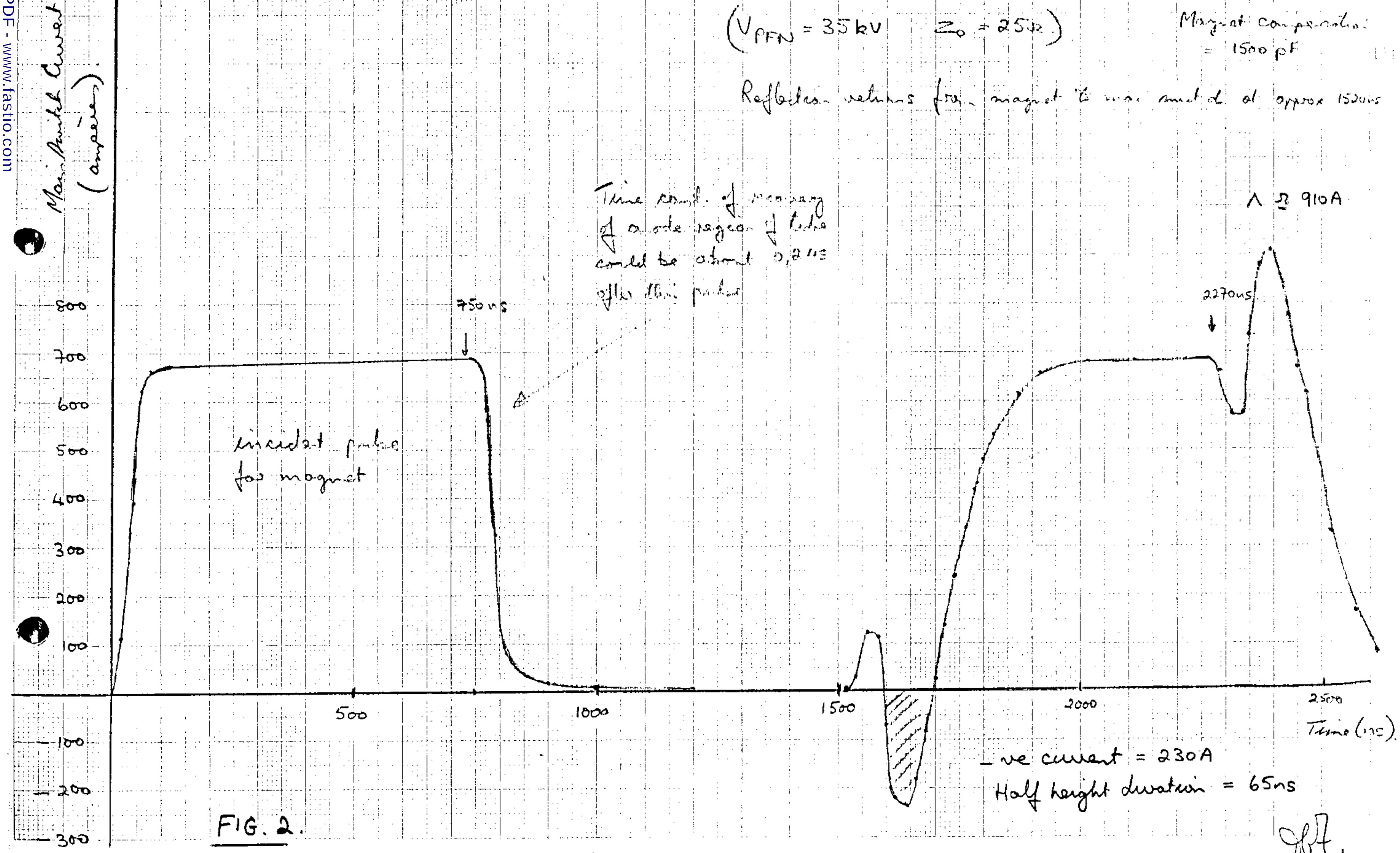
PROPOSED SCHEME FOR KICKER 28

SS28 Kicker Main Switch Current for 0,4 µs flat-top + 150 m transmission cable

(V_{PFN} = 35 kV Z_0 = 25 Ω)

Magnet capacitance = 1500 pF

Reflection returns from magnet to main switch at approx 1500 ns



Time const. of recovery of anode region of tube could be about 0,2 µs after the pulse

– ve current = 230A
Half height duration = 65 ns

FIG. 2.

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Fig. 3.a

Magnetic circuit cross-section of SS 28 ejection magnet M 1:1

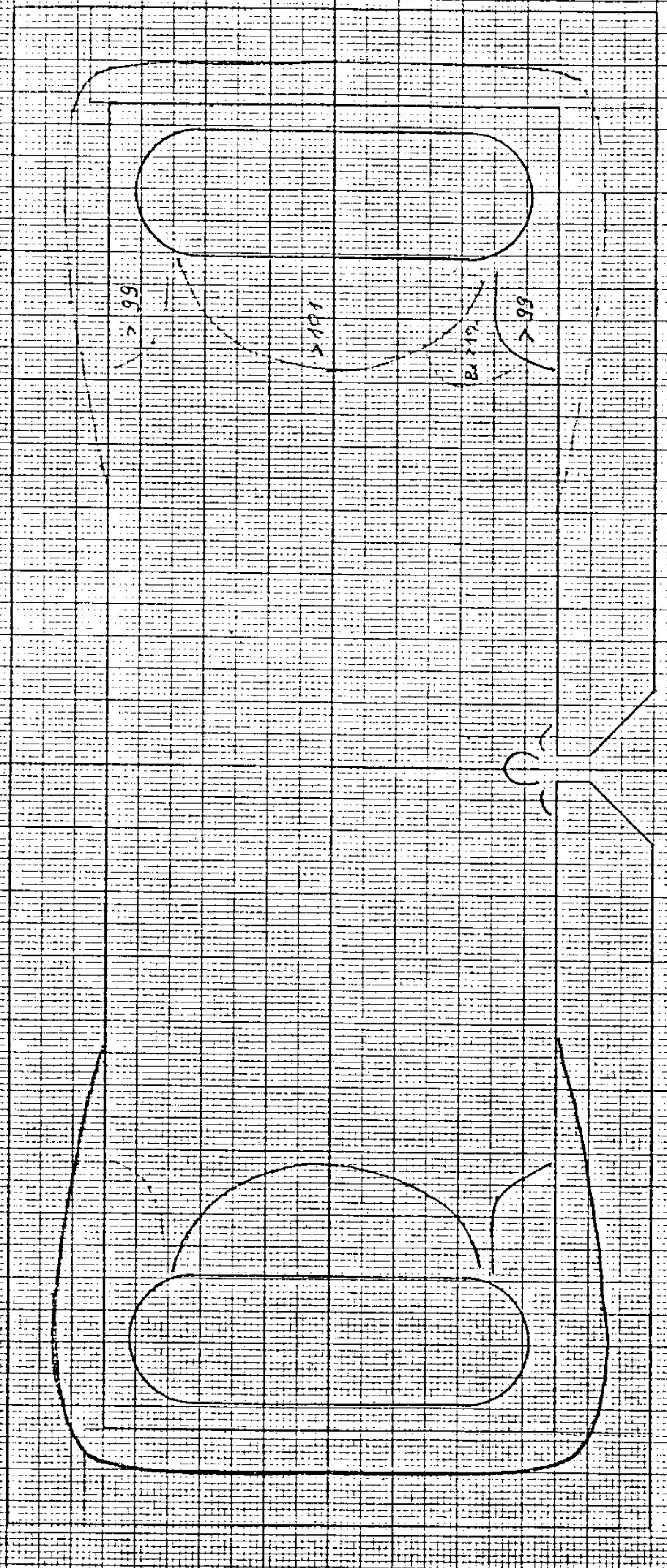
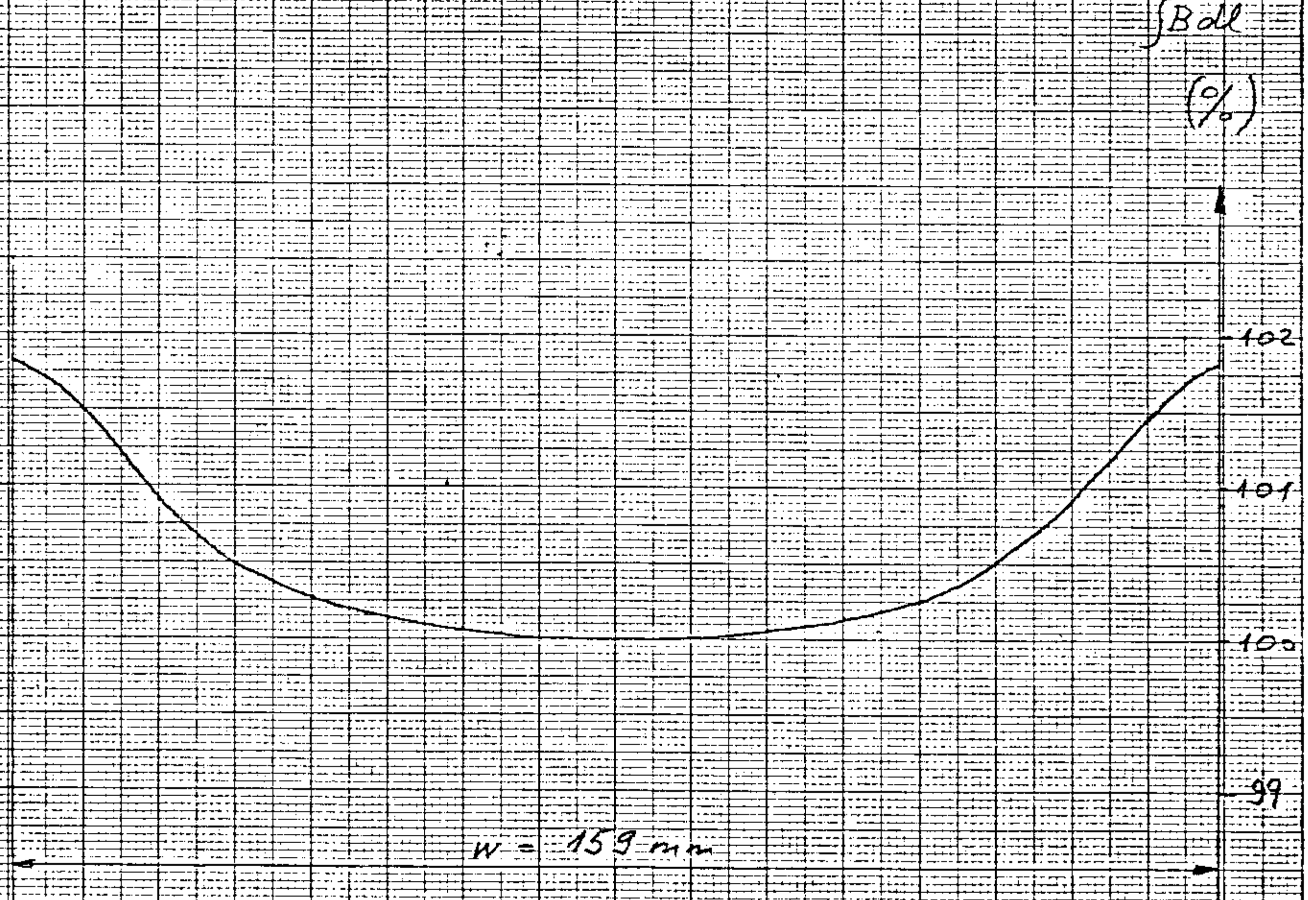


Fig. 3b

Field distribution on horizontal centre line



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