MPS/Int. BR/73-8
19.11.1973

A 50 MeV BEAM DISTRIBUTOR AND CHOPPER FOR THE PSB INJECTION LINE *

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*) PS project No. 0018 discussed at the MAC meeting No. 16 (MPS/DL Mi/73-29) and authorized by C.J. Zilverschoon on November 22, 1973.

INTRODUCTION

In designing the injection line for the PSB it had been assumed that the beam could be interrupted at will by appropriate choppers at 500 keV.

Experience has shown that while this can be done on an MD basis, the changes in beam loading induce transients in tank levels and phases which affect beam quality.

It was therefore decided to investigate the possibilities of chopping at 50 MeV.

GENERAL CONSIDERATIONS

Originally two forms of chopping had been foreseen.

1. 3 MHz chopper

This was to be used mainly for adjusting injection. For the orbit measurement equipment to function correctly, the gaps in the beam must be at least 100 ns long.

2. Slow chopper

This device was intended to :

i) Remove the low quality front end of the beam.

ii) Create gaps covering the switching time of the vertical distributor.

iii) Cut off the unwanted tail end of the beam.

We begin by examining the requirements for a 50 MeV, 3 MHz chopper, consisting of a 3 MHz deflector followed by an aperture plate situated at a waist in the beam.

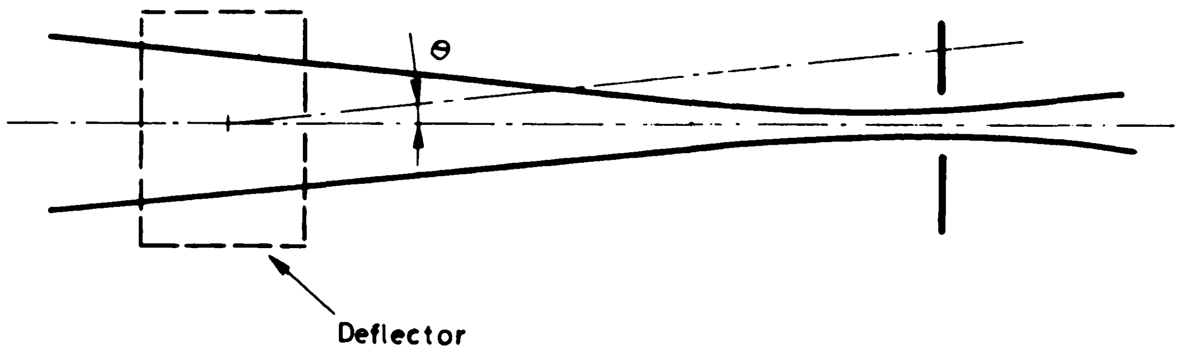


Fig.1

We call :

θ_1 the deflection for which the beam begins to graze the aperture plate,

θ_2 the deflection just sufficient to cut off the beam.

In Fig. 2 we show the effect of an idealized trapezoidal deflection as seen on the Σ and Δ electrodes after injection.

For a rise from zero to θ_2 of 50 ns (already probably quite hard to achieve) one obtains a portion of undisturbed beam that would be adequate for orbit measurements, provided the observation amplifiers do not distort the signal appreciably.

However, a substantial part of the beam is injected with a wrong angle and forms a disturbing halo. In order to reduce this to say 10% of the beam, one would require a rise time of the order of 15 ns.

Such a device would not be easy to construct and would require careful development work using the largest tubes available.

Another way to proceed would be to accept a relatively slow deflection, perhaps even produced by a resonant device and then place two further deflectors after the aperture plate,to "straighten out" the beam.

While this is quite straightforward in principle, it would require very careful control of amplitudes and phases, and occupy a lot of space.

As it has been found that by using $\sim \frac{1}{2}$ turn injection, acceptable injection conditions can be achieved, it seems reasonable to examine this alternative, using the equivalent of the slow chopper to interrupt the beam.

As a half turn lasts $\sim$ 800 ns, rise and fall times of the order of 50-100 ns become acceptable, with the additional advantage that we need only one shot per machine cycle, so that the usual kicker system using thyratrons can be used.

An evaluation[1)] of the magnets needed to create gaps in the beam indicated that the three magnets required would be very comparable to the present vertical distributor. As in addition we need new fast head chopper and tail clipper, this brings to light the following alternative:

a) keep the original vertical distributor and build

3 hole choppers
1 head chopper
1 tail chopper;

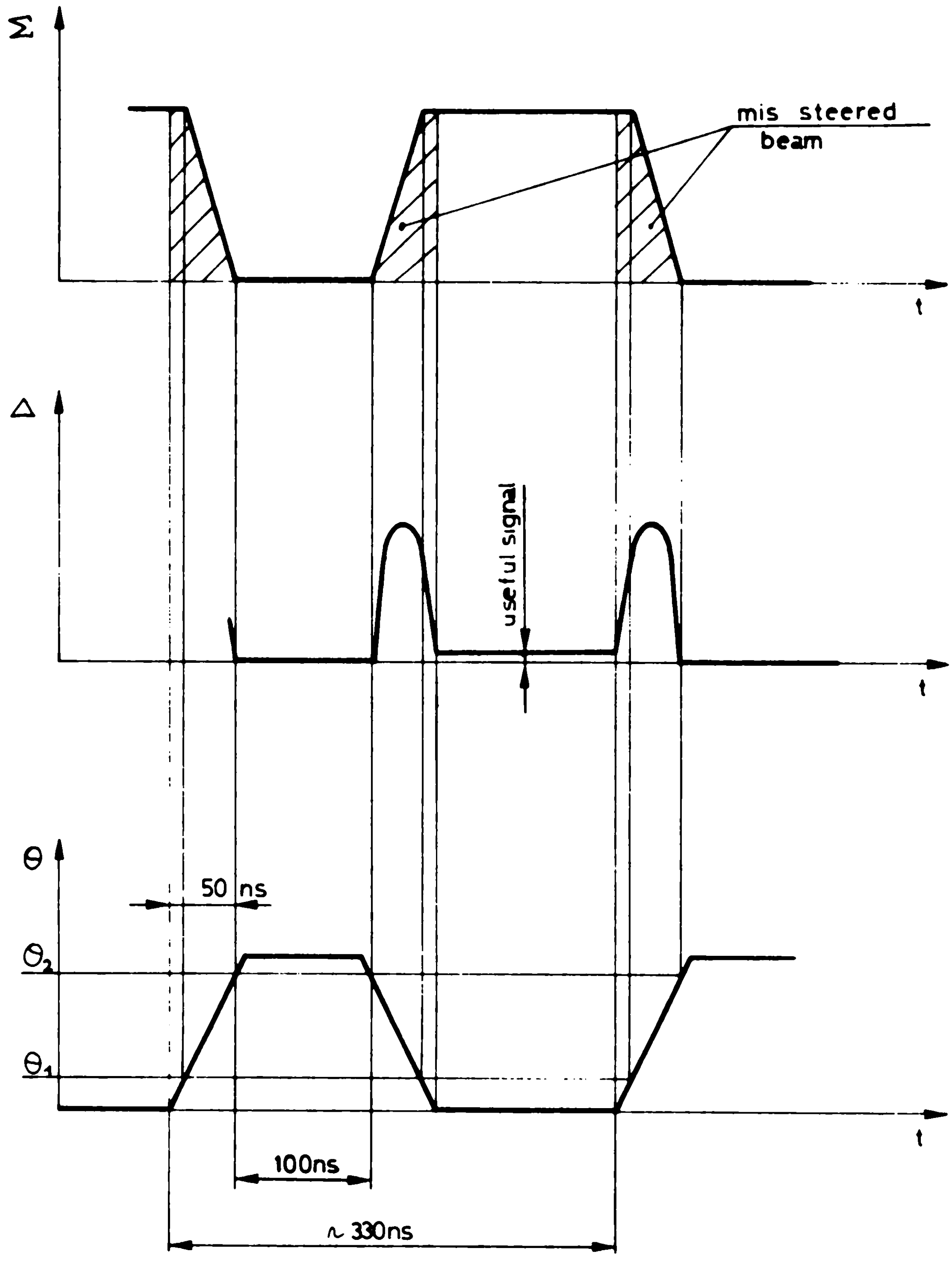
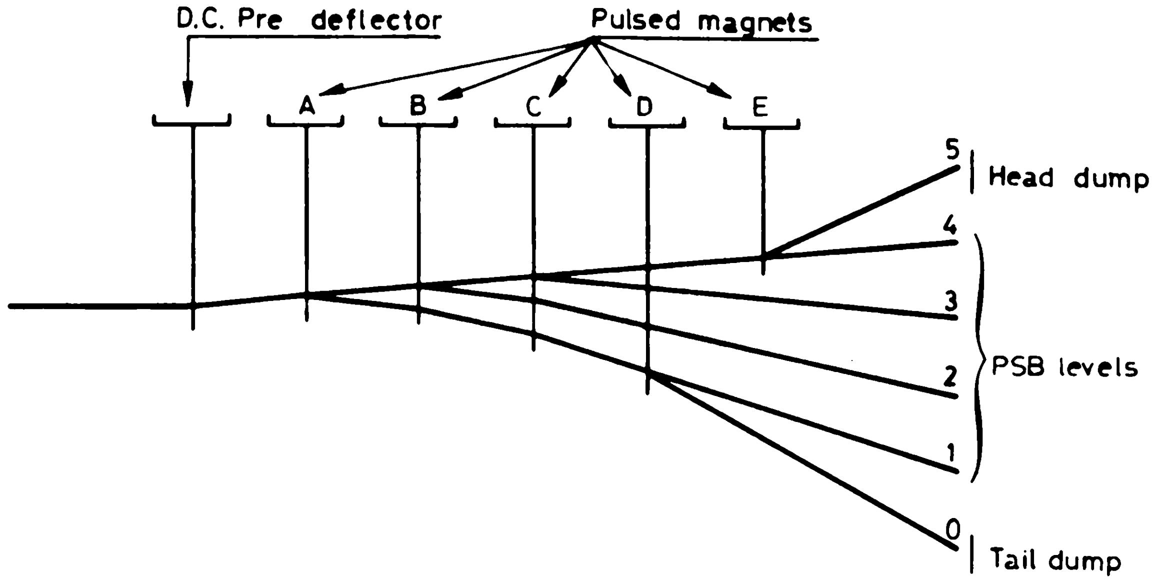

Σ
mis steered
beam
t
Δ
useful signal
t
Θ
50 ns
Θ_2
Θ_1
t
100ns
~ 330ns

Fig. 2

a) Schematic Layout



b) Deflections

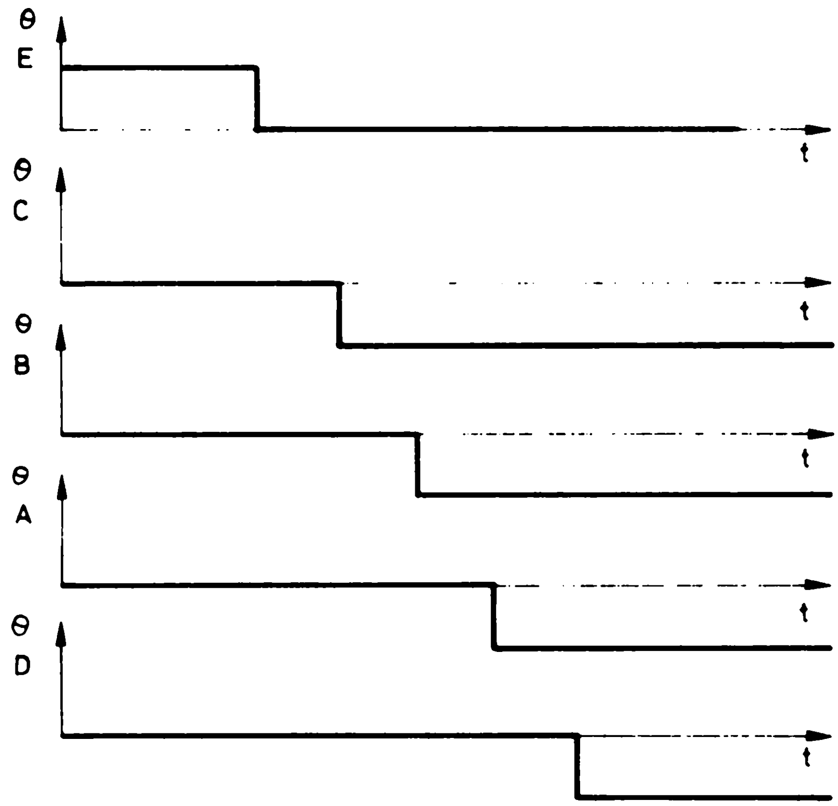


Fig.3

b) build a new 5 level distributor which incorporates all functions.

The second solution has a number of advantages:

i) uses less elements - five instead of eight as there are three separator power supplies for the existing distributor;

ii) uses less space in the injection line;

iii) all active elements are situated in an equipment room, accessible during running;

iv) less elements to programme for pulse to pulse variations of beam intensity[6].

As far as costs are concerned we have in either case to build five magnets or roughly equivalent characteristics. The power supplies for b) are somewhat more expensive, which has to be weighed against operational advantages and probable economics in running costs that are not readily quantifiable.

The view taken by the Injection Line Hardware Working Group was that on the balance b) was the more desirable long term solution and a design study was therefore carried out, based on the scheme shown in Fig. 3.

3. Specifications for a new vertical distributor

3.1 Rise time

In order to arrive at a specification for the rise time we consider the situation at the entrance to the septum, when a beam of ∿ 25 mm height is deflected by ∿ 35 mm.

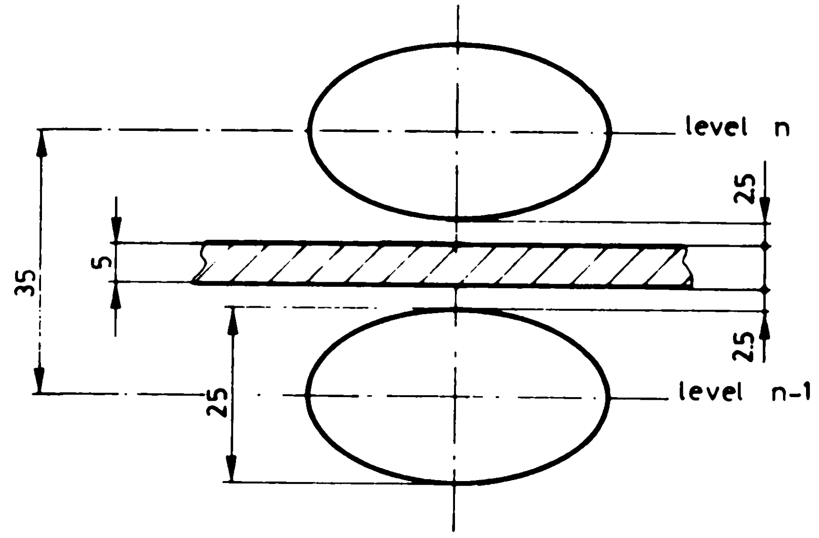


Fig.4

We consider the sequence (Fig. 4) :

Beam position	Displacement mm	% of max
Beam grazes septum	2.5	7
" appears in level n-1	7.5	21
" disappears from level n	27.5	79
" stops grazing septum	32.5	93

In addition we need to define what constitutes perceptible mis-steering. If we take this to mean a displacement such as would correspond to a 10% emittance growth, this corresponds to 5% of beam height, in this case 1.25 mm, or ∿ 3% of the deflection from one level to the next.

From Fig. 5 which schematically depicts the sequence of events, we see that the disappearing beam is mis-steered during the time the distributor rises from 3% to 79% and the appearing beam is mis-steered during the rise from 21% to 97%.

Taking account of the fact that the mis-steered beam will have an average intensity of roughly half, we conclude that if we do not want to have more than 10% of the beam in the mis-steered halo (for a half turn injected), then the sum of the appearance time (from 21% to 97% of pulse level) and the disappearance time (3% to 79%) should not exceed ∿ 160 ns.

3.2 <u>Stability and flatness of pulse</u>

As discussed above, a steering error corresponding to a 1 mm displacement at the septum is appreciable.

The current pulses to the kickers must be sufficiently steady and flat so that the sum of the errors for the largest deflection (∿ 3 x 35 mm = 105 mm) does not exceed this limit, which indicates ∿ 1% of pulse height as a minimum requirement for pulse to pulse stability and flatness.

In addition, as the fast rise time is intended for adjusting injection by using ∿ ½ turn injection, those transients that exceed 1% should not last longer than ∿ 300 ns and the initial overshoot must not exceed 3%.

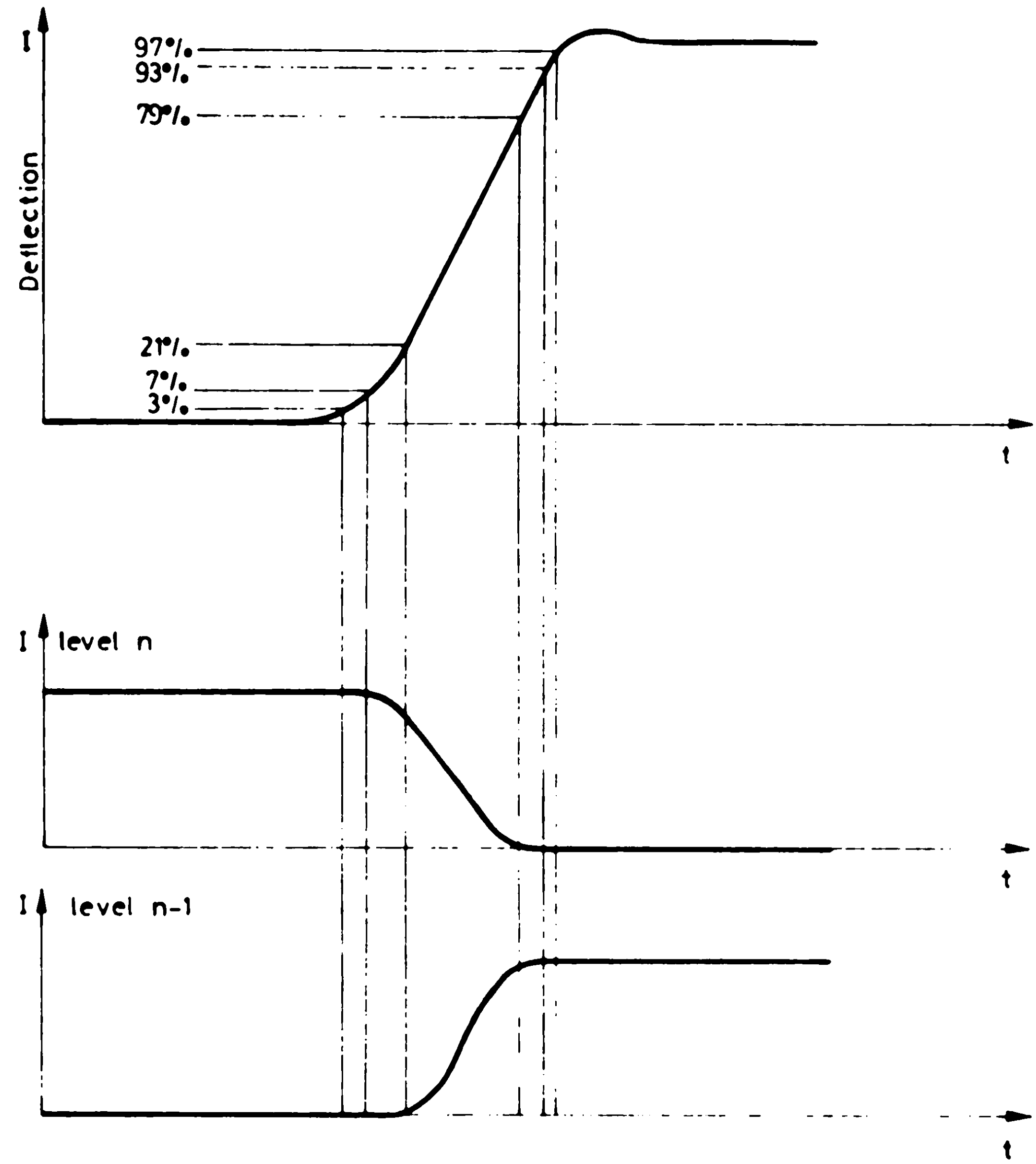


Fig.5

3.3 Deflections

There are imposed by the geometry and work out as follows :

E(5 - 4)	3.73 mr
C(4 - 3)	3.73 mr
B(3 - 2)	3.56 mr
A(2 - 1)	3.76 mr
D(1 - 0)	3.99 mr

Detailed calculations are given in Appendix A.

3.4 Apertures

For the line as it stands, an aperture of 50 mm (horiz.) x 100 mm (vert.) as in the present distributor would be quite satisfactory, even allowing for the fact that the new distributor is longer (extra stages for head and tail clipping).

To allow some margin for future developments (Linac beam emittance up to 40π) it is proposed to widen the two downstream modules to 55 mm.

See Appendix B for further details.

3.5 Pulse length

At present, the maximum pulse length specified for the Linac beam is 100 μs and it is proposed to design the pulse forming networks for this figure. However, in view of the fact that the new Linac will be capable of producing a 200 μs beam pulse, it seems reasonable to take the following steps:

i) design the pulse forming networks in such a manner that they can be extended to produce longer pulses;

ii) design their charging units with adequate power to charge the extended PFNs;

iii) the beam dump will be designed with adequate power dissipation capabilities.

The resulting supplementary expenditure is small compared to the total cost.

4. Design and cost estimates

4.1 Pulse generator

The pulse generator for a fast IDIS module mainly consists of a PFN, its charging supply, thyratron switches, the pulse transmission line and the matching resistors.

A diagram of the system is shown in Fig. 6. Its main components and mode of operation are as follows: a 40 mF energy storage capacitor, charged to 300 V by an auxiliary charging unit, is connected by a SCR to the primary winding of an HV step-up transformer. The resulting oscillation between transformer stray inductance and equivalent circuit capacitance charges the PFN to 25 kV within 5 ms.

The PFN consists of 22 LC sections, a booster capacitor C_o, a head cell C_T, R_T and a speed up capacitor C_t. The inductances, mounted on top of the capacitors, as well as the head cell resistor R_T are adjustable to correct the pulse shape.

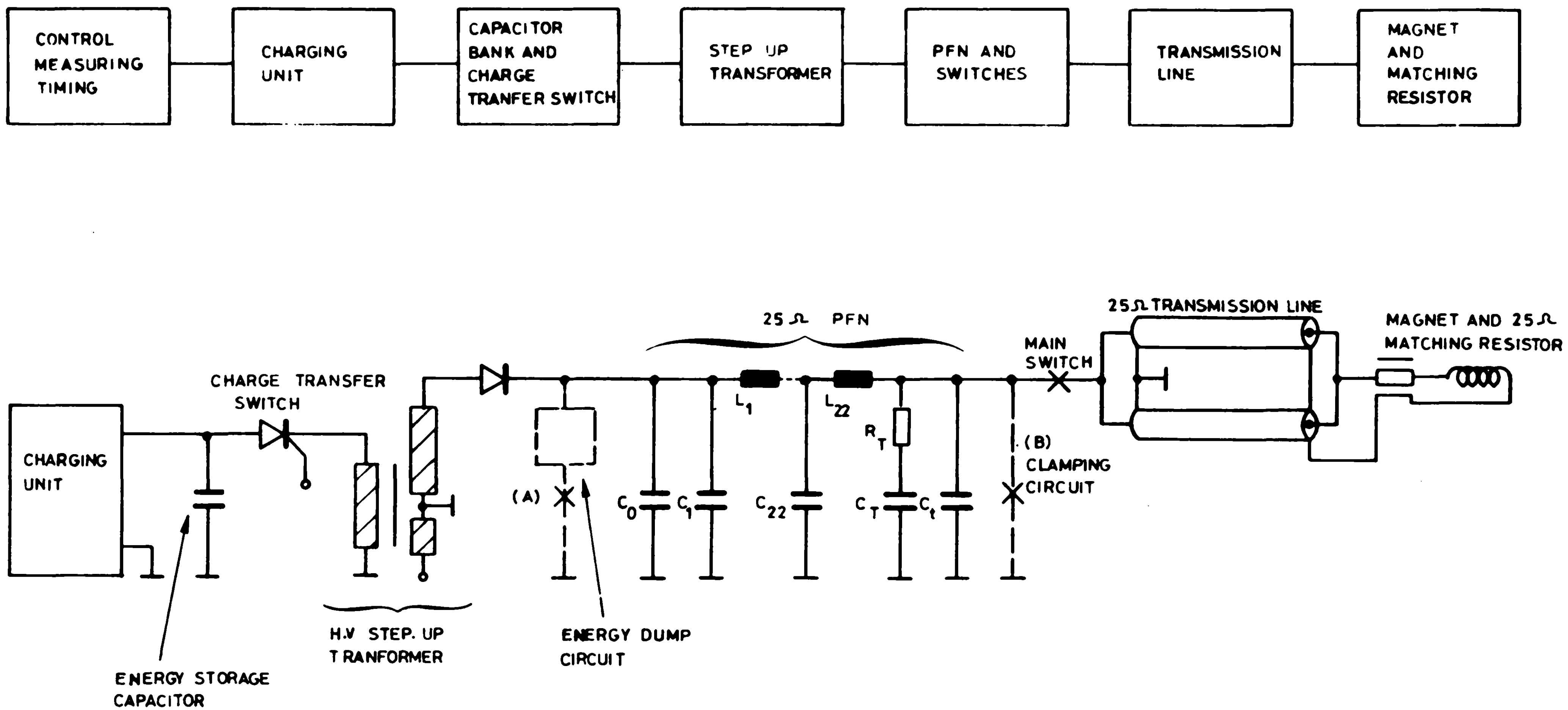
The PFN characteristic impedance is 25 ohm. A thyratron switch connects the PFN, charged at 25 kV, to the pulse transmission line. Two additional switches provide fast fall time and PFN energy dumping for the circuit pulse of the head dump module. The layout of the prototype PFN is shown in Fig. 7. The PFN is designed for operation in air but, if required, the tank may be filled with oil or preferably with SF_6. The pulse transmission line consists of two parallel connected, 25 m long, RG 221 U cables; it is connected to the 25 ohm matching resistor, which is built of carbon charged ceramic disks assembled in a coaxial structure. The resistor is oil filled and indirectly water cooled : it is mounted beneath the magnet support. The electrical connection to the magnet is obtained via a coaxial vacuum feedthrough. The other end of the magnet coil is connected to the tank.

A pulse transformer is included in the resistor assembly and permits isolated display of the magnet current. The prototype matching resistor is shown in Fig. 8. The design parameters of the prototype PFN are given in Table 4.1.

TABLE 4.1

Performance specification and parameters of prototype PFN

- Charging voltage	25 kV
- Pulse current	500 A
- PFN impedance	25 Ω
- Duration of flat top	75 μs
- Rise time of current	70 ns
- Overshoot	3 %
- Duration of transient (overshoot to flat top)	0,3 μs
- Current variation during flat top	± 1 %
- Pulse repetition rate	2 pps
- Isolating and cooling medium	air
- Mode of charging	resonant within 5 ms



- A) AND B) ARE TO BE ADDED FOR THE HEAD DUMP CIRCUIT ONLY

'G. 6 BLOCK- AND CIRCUIT-DIAGRAMS OF CURRENT PULSE GENERATOR FOR FAST IDIS MODULE

4.2 Magnet (see Fig. 9)

Compared with the existing I-DIS, the cross-section of the magnets (aperture , ferrite and coil dimensions) is about the same, but the length, the coil end configuration and the current connections are different, in order to obtain compact, low inductance modules having negligeable fringe field near the magnet ends. This allows one to pack the five modules closely together, without loss of longitudinal space and without problems of interaction by magnetic coupling.

The magnets are of the window-frame type, with the coil end-conductors imbedded into the last ferrite at each end. The current connections are located in the centre, as close as possible to the coil and directly matched to the coaxial feed-through leading to the terminating resistor on the outside of the tank. The coil itself is made of welded stainless steel strips, and the core of high-speed nickel zinc ferrites, e.g. Philips 4H1, 8C1 or Indiana H2 as used for the existing I-DIS.

The five modules are aligned by means of supporting blocks on a horizontal base plate, having a removable vacuum cover of half cylindrical shape on the upper side, and the terminating resistors orientated vertically below. A prototype assembly of one module with its test tank is being designed in the MPS/ML drawing office.

Main Magnet Parameters

Per module :

	Distributor	Clippers	
Gap (horiz. x vert.)	50x98	55x98	(mm^2)
Physical length	0.40	0.44	(m)
Equivalent length	0.34	0.38	(m)
Inductance	0.88	0.88	(μH)
Weight (ferrites/total)	9.4/18	10.6/20	(Kg)
$\int Bdl$	42	43	(G.m)
θ at 50 MeV	4.0	4.1	(mrad)
B_{gap}	125	114	(G)
$B_{max\ core}$	480	440	(G)

4.3 Budget

List of material and cost estimates.

a) Five pulse generators systems, terminating resistors and cables :

		SFr.
-	Control, measuring, timing equipment (CERN)	10'000
-	Low voltage charging unit (Sorensen)	27'000
-	Energy storage capacitor (Leclanche)	5'000
-	HV pulse transformer (Moser Glaser)	60'000
-	Charge transfer switch (BAC)	2'500
-	HV rectifier (Doorbell)	5'000
-	PFN (LCC)	75'000
-	Thyratron switches (English Electric)	7'500
-	Transmission line and connectors (Suhner & Lemo)	10'000
-	Matching resistors (Morganite)	5'000
-	Mechanical parts (CERN)	2'000
-	Auxiliaries, cabinets	15'000
-	Manufacturing of mechanical parts	20'000
	TOTAL	244'000

b) Magnet assembly :

-	Ferrites ($\sim$ 50 Kg), machined	8'000
-	Coils, including tooling	15'000
-	Frames + ancillary parts	15'000
-	Assembly work	5'000
-	Feed-throughs	10'000
-	Vacuum tank, support	25'000
-	Re-arrangement of line	5'000
-	Additional ion pump	13'000
-	Pump supply, cabling	3'000
	TOTAL	99'000

c) Total cost : $\sim$ 350'000

ACKNOWLEDGEMENTS

We wish to thank D. Fiander for several constructive discussions and K.H. Reich for his interest and support. We also wish to acknowledge with thanks the cooperation of all those colleagues who helped with the design and construction of the prototype.

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3. K. Schindl, Injection into th PSB, PSB/RI Working Note 73-4.

4. T.R. Sherwood, Memorandum 26.3.73.

5. M. Weiss,MPS/LIN/Note 72-1.

6. J.P. Potier, Possibilités de modulation d'intensité dans le PS, MPS/CO Note 73-67, and

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A P P E N D I X A

PSB Injection Line, distributor region : Layout, apertures, deflections

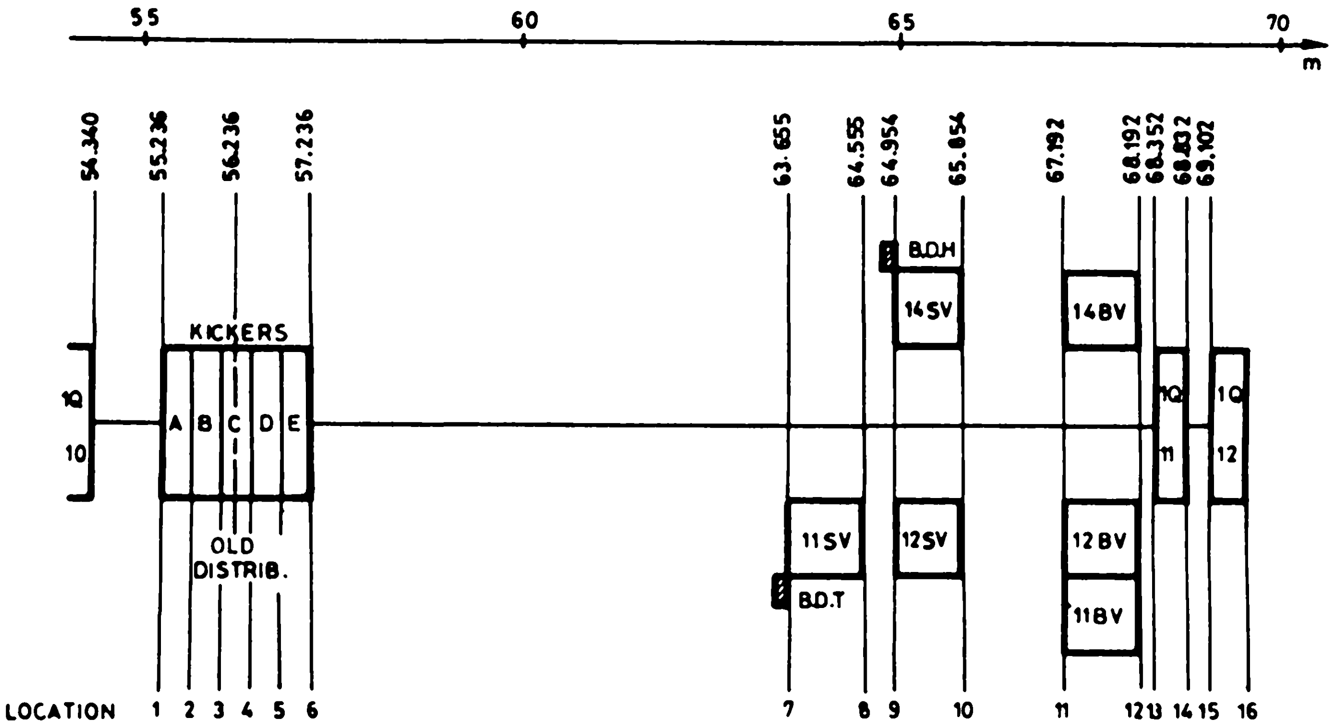

Fig.10

: Layout of PSB injection line, distributor region (BDH = Beam dump head; T = Tail).

A1) Apertures of critical elements

Element	Aperture (mm)		Remarks
	Horizontal	Vertical	
Kicker A-E	50/55	100	See appendix B
14SV	112	30	Scrapers 5 mm wide
"13SV"	112	25	between levels
12SV	112	30	
11SV	102	30	
14SV	116	77	
"13BV"	116	116	Vacuum chamber follows
12BV	120	77	nominal trajectory
11BV	120	77	
1-Q	140	140	Useful aperture (Ø 150 mm)

A2) <u>Deflections of kickers A-E</u>

A linac beam with $\varepsilon_v = 40\ \pi$ has the vertical beam diameters :

24 mm at 11SV entry (Beam dump tail)
20 mm at 14SV entry (Beam dump head)

Kick	Kicker	ΔZ (mm)		Δs Deflection (mrad)			Remarks
		Min	Nom	m	Min	Nom	
5-4	E	25	29.5	7.918	3.16	3.73	Half aperture 14SV = 15 mm Half beam size = 10 mm
4-3	C	-	32.5	8.718	-	3.73	
3-2	B	-	32.5	9.118	-	3.56	
2-1	A	-	30.7	8.219	-	3.73	Centre distance level : 3 to 1 = 58.5 mm Centre distance level : 3 to 2 is 27.8 mm in location 11SV Therefore 2-1 = 30.7 mm
1-0	D	27	28	7.019	3.85	3.99	Half aperture level 1 = 15 mm Half beam size = 12 mm

A3) <u>Vertical beam size increase in kickers A-E due to deflections</u>

Location	Beam size increase ΔZ (mm) due to					ΔZ Total
	Kicker A	B	C	D	E	
2	0.2x3.73					0.7
3	0.6x3.73	0.2x3.56				2.9
4	1.0x3.73	0.6x3.56	0.2x3.73			6.6
5	1.4x3.73	1.0x3.56	0.6x3.73	0.2x3.99		11.8
6	1.8x3.73	1.4x3.56	1.0x3.73	0.6x3.99	0.2x3.73	18.6

APPENDIX B

PSB Injection line : Computation of desirable apertures

B1) Criteria : The apertures of the injection line elements are determined by :

a) the beam optics and matching requirements for PSB injection [3]. Cases A-G stand for 7 representative injection settings [4].

b) the emittance of the Linac beam. At present, it is of the order of $20\pi \cdot 10^{-6}$ rad.m for ∿ 85 % of the beam in either plane (with a current of 50-60 mA). With higher intensities (being operational very soon), larger emittances are expected [5]. As a working hypothesis, $\varepsilon_H = \varepsilon_V = 40\pi \cdot 10^{-6}$ rad.m and 80 mA beam current have been assumed for the optics calculation including space-charge effects.

B2) Method : Beam sizes have been computed by means of "TRANSPORT" for the 7 cases, assuming standard Linac beam properties at "Hand-over" point (I-BH2).

B3) Results : are given in the following table, for cases A-G, and locations 1-16. As for the vertical beam sizes, the number given in A3) (beam size increase due to kicker) are taken into account. Critical sizes are surrounded by a rectangle. Note that computer injection studies using case E suggest that this case is not indispensable for the time being.

AM SIZES FOR $\varepsilon_H = \varepsilon_V = 40\,\pi \cdot 10^{-6}$ R m

HORIZONTAL

Location	Distributor - 5 kicker solution						I^1 SV		I^4 SV		I-8V		I-Q11		I-Q12	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Case A	38.0	40.7	41.9	43.9	46.1	48.2	86.7	92.5	95.4	101.3	110.3	117.0	118.0	104.9	88.7	72.6
Case B	35.2	36.7	38.3	40.0	41.8	43.6	77.8	83.1	85.7	91.2	99.4	105.6	106.6	94.8	80.2	65.7
Case C	41.8	44.2	46.6	49.2	[51.7]	[54.3]	98.4	[105.0]	108.3	[114.9]	[124.9]	[132.3]	133.5	118.6	100.3	81.9
Case D	38.0	39.9	41.9	44.0	46.1	48.3	86.7	92.6	95.5	101.4	110.4	117.1	118.1	105.0	88.8	72.6
Case E	48.7	[51.9]	[55.1]	[58.3]	[61.6]	[64.9]	[119.1]	[127.0]	[131.0]	[138.9]	[150.9]	[159.8]	[161.2]	[143.2]	121.0	98.8
Case F	29.3	29.7	30.2	30.8	31.6	32.6	58.8	63.5	65.9	70.8	78.3	83.9	84.8	75.8	64.4	53.3
Case G	28.7	28.8	29.1	29.6	30.2	31.0	56.5	61.2	63.6	68.4	76.1	81.8	82.7	74.0	62.9	52.2

VERTICAL

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Case A	87.6	84.0	80.6	77.2	73.7	70.2	22.3	19.3	18.7	20.1	26.6	33.3	34.5	43.2	51.2	57.1
Case B	80.8	77.4	74.1	70.7	67.4	64.1	20.8	19.4	19.8	22.5	29.8	36.6	37.7	46.8	55.3	61.4
Case C	81.0	77.6	74.3	71.0	67.6	64.3	20.7	19.3	19.7	22.4	29.7	36.5	37.7	46.8	55.3	61.4
Case D	80.9	77.5	74.2	70.8	67.5	64.3	20.8	19.4	19.7	22.4	29.8	36.5	37.7	46.7	55.3	61.3
Case E	81.2	77.9	74.5	71.2	67.9	64.6	20.7	19.2	19.6	22.2	29.6	36.4	37.6	46.7	55.2	61.3
Case F	80.7	77.4	74.0	70.7	67.4	64.1	20.9	19.5	19.9	22.5	29.8	36.5	37.6	46.6	55.1	61.1
Case G	87.5	84.0	80.5	77.0	73.6	70.2	22.5	19.4	18.9	20.2	26.6	33.2	34.4	43.0	51.0	56.8

VERTICAL INCLUDING KICKS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Case A		84.7	83.5	83.8	85.5	88.8										
Case B		78.1	77.0	77.3	79.2	72.7										
Case C		78.3	77.2	77.6	79.4	82.9										
Case D		78.2	77.1	77.4	79.3	82.9										
Case E		78.6	77.4	77.8	79.7	83.2										
Case F		78.1	76.9	77.3	79.2	82.7										
Case G		84.7	83.4	83.6	85.4	88.8										