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M. Fascetti, A. Massarotti, P. Papitto, M. Puglisi and F. Tazzioli : THE INJECTION SYSTEM OF ADONE. -

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THE INJECTION SYSTEM OF ADONE. -

1. - INTRODUCTION. -

The present injection system in the storage ring Adone consists of two closed deflectors and a bumper coil that perturbs temporarily the closed orbit. It has been adopted in the Frascati ring on proposal by R. Littauer(1) who also tested a prototype system.

This paper is a description of a complete injection system based on Littauer's project, which has substituted the provisional one.

The adoption of the actual system was stimulated by several drawbacks evidenced by the previous deflectors that were of open construction(2).

Some drawbacks were of optical nature as the large amplitude of betatron oscillations of the injected particles, the reduction of the vertical acceptance due to the deflector structure and the perturbation on the stored beam caused by the stray field of the deflector.

Another source of trouble was the high voltage in the pulse forming network that determined frequent breakdown of some components.

The injection technique based on closed deflector and orbit perturbation had been already proposed by L. Mango(3) but the type of orbit perturbation considered was too difficult to implement.

We summarize briefly the principle of operation of the actual injection system sending for a better description to ref. (1). A single pulsed coil placed in a straight section produces outwards displacements in the diametrically opposite section and in other points spaced about one betatron wavelength λ along the circumference. This is illustrated in Fig. 1, where half the rectified circumference is shown.

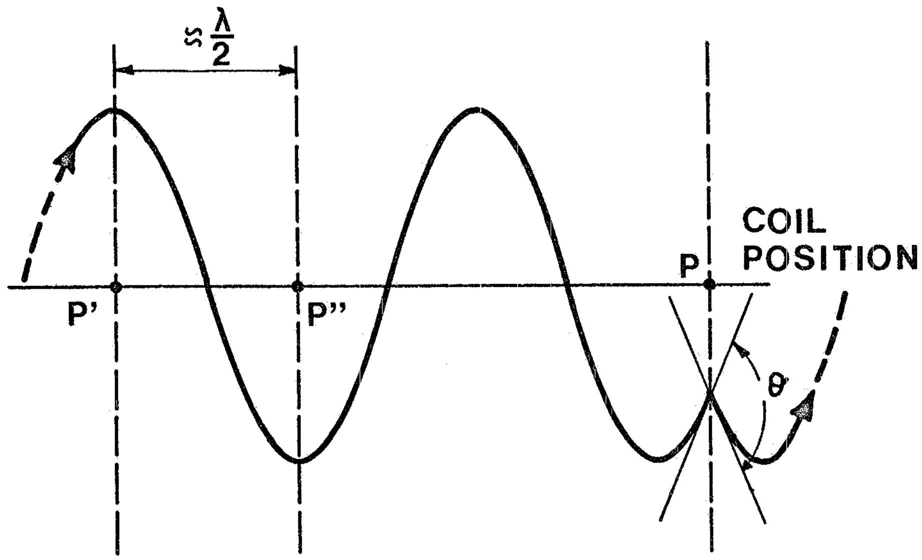


FIG. 1

One of the inflectors is situated at point p', while the other one is placed in p", about half a betatron wavelength apart. Thus the second inflector may be served by the same coil by changing the polarity of the applied field.

If B is the field and L the length of the coil, particles of energy E are deflected through an angle

$$\theta\,(\text{mrad}) = 30\,\frac{BL}{E}\quad\frac{\text{Gauss x m}}{\text{MeV}} \quad . \tag{1}$$

If we call $\Delta\nu$ the betatron wave number shift per turn, the maximum displacement, at point p', will be

$$a = \frac{\theta}{2}\,\frac{\lambda}{\pi}\,\frac{1}{\sin(\pi\Delta\nu)} \quad . \tag{2}$$

The waveform chosen for the perturbation is half a sinusoid. Injection of particles is started when θ is maximum and such that the displaced closed orbit passes through the deflector. The duration of the pulse is determined by two opposite exigences. The perturbation must decay slowly enough so that the change of the closed orbit itself does not induce large betatron oscillations.

On the other hand some of the particles will be injected with an initial displacement with respect to the instantaneous orbit. A peak displacement towards the deflector will occur after $1/\Delta\nu$ turns. By that time the closed orbit must have changed so that the injected particles do not hit the deflector's septum.

In Adone $\Delta\nu \approx 0.1$, the injection pulse lasts about 2 μsec (about 6 turns) and a good compromise for the perturbation has turned out to be a half sine of about 10 μsec duration.

2. - THE BUMPER COIL. -

For a displacement $a \approx 100$ mm, with a betatron wavelength $\lambda \approx 30$ m and $\Delta\nu \approx 0.1$, from equation (2) we need a deflection angle $\theta \approx 7$ mrad.

From equation (1) we need a product

$$B \times l \; (\text{Gauss} \times \text{m}) \approx 0.23 \; E \; (\text{MeV}) \, .$$

At 450 MeV injection energy and choosing $l = 2$ m, the field needed B is ≈ 50 G. A section of the coil is shown in Fig. 2.

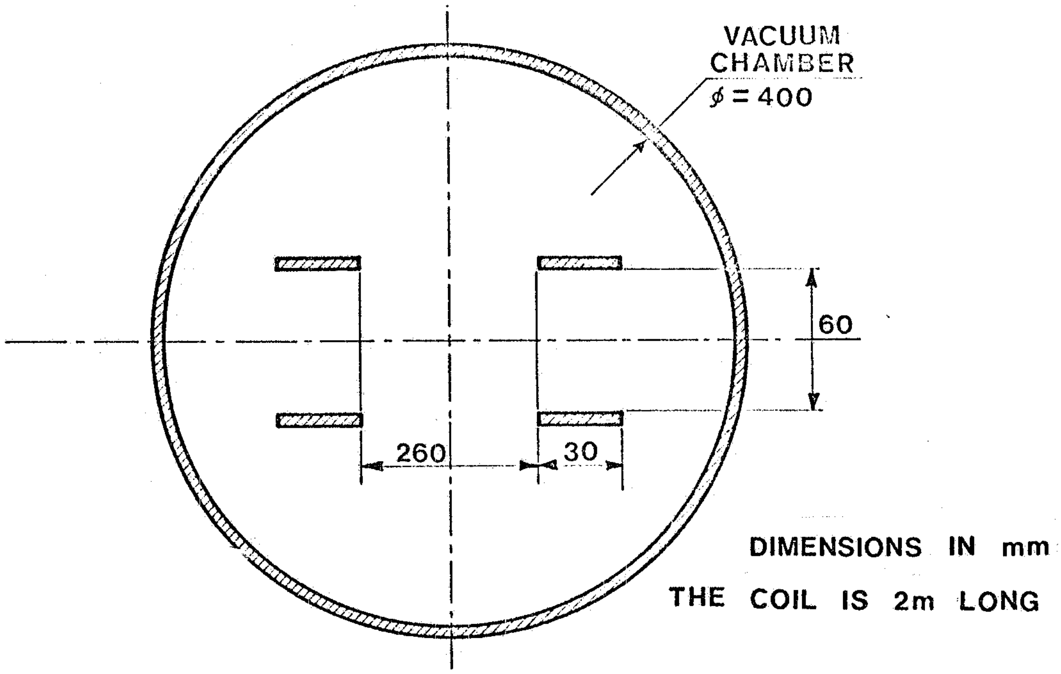


FIG. 2

The upper and lower loops are in series. Due to the steep decay of the field pulse the coil must be placed inside the vacuum chamber. With the shown dimensions the ratio between field and current is :

$$\frac{B}{I} \approx 30 \frac{G}{KA} \, ,$$

so, to obtain 50 G one needs about 1.7 KA. The inductance of the coil plus the connections to the outside terminals is 6 μH at 36 KHz.

3. - THE DEFLECTOR STRUCTURE. -

A section of the deflector is shown in Fig. 3.

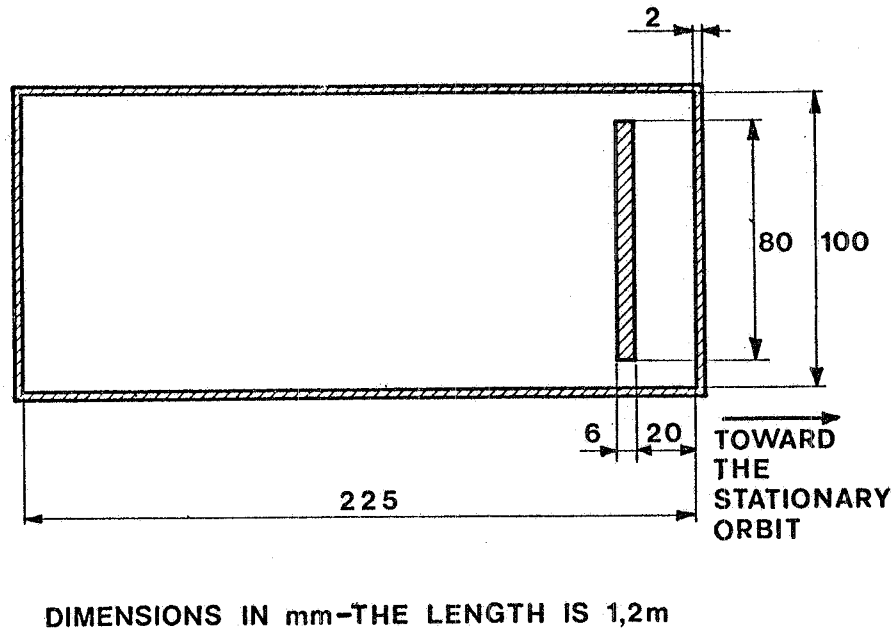


FIG. 3

The deflector is enclosed in a copper shield which also serves as current return for the internal electrode that is a flat sheet. In the gap the field is roughly uniform, decreasing from the inside electrode to the shield with a small gradient of about 10^{-3} for every 3 mm. The shield has been chosen 2 mm thick from skin depth considerations. The current required to create the field is about 13 A/Gauss. Taking a length of 1.2 m and for a deflection angle of 130 mrad, the field needed to inject at 450 MeV is 1600 Gauss and the corresponding current is about 21000 A.

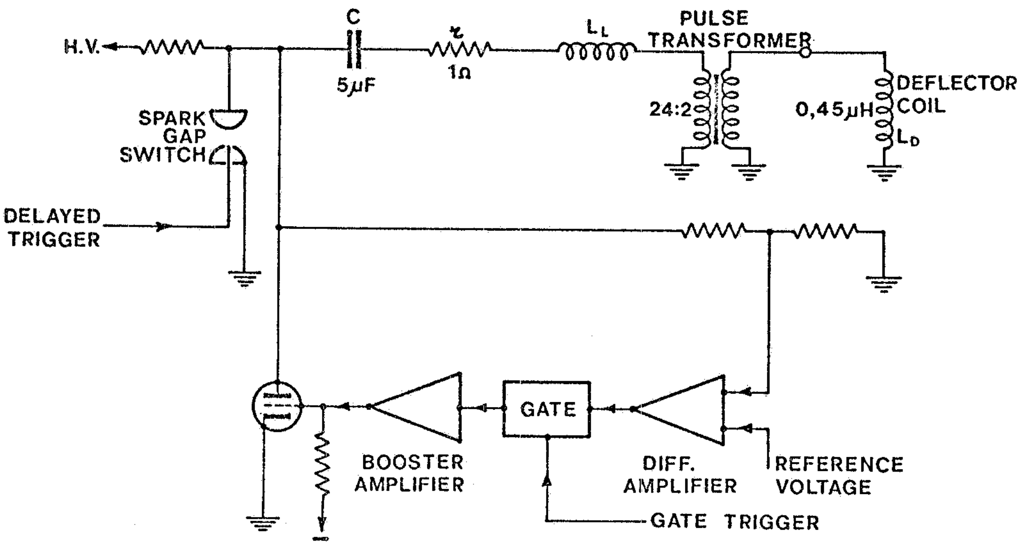
The current waveform in the deflector is no more critical as it was in the open one and we have chosen a damped sinusoid for ease of generation.

If the current is to vary by no more than 2×10^{-3} for 1 μsec on either side of the peak, the period of the sinusoid must be about 150 μsec.

The inductance of the deflector plus the connection leads has resulted about 0.45 μH at 7 KHz.

4. - THE PULSE FORMING NETWORK FOR THE DEFLECTOR. -

A schematic diagram of the pulse forming network for the deflector is shown in Fig. 4. The deflector is represented by its equivalent inductance L_D. Its very low impedance is raised by means of a



DEFLECTOR PULSE FORMING NETWORK SCHEMATIC

FIG. 4

pulse transformer. The latter has a laminated iron core. The windings are made of copper sheet insulated with mylar layers. L_L represents the leakage inductance of the transformer plus that of the connections to the capacitor C. The resistor represents all the losses in the components and connections plus an additional Nickel wire resistor added intentionally to obtain the desired damping of the waveform. The current waveform in the deflector is given by the following expression :

$$i(t) = \frac{n V_o \omega_o C}{\sqrt{1 - \frac{\alpha^2}{\omega_o^2}}} e^{-\alpha t} \sin \left(\omega_o \sqrt{1 - \frac{\alpha^2}{\omega_o^2}} \right) t \qquad (3)$$

where :

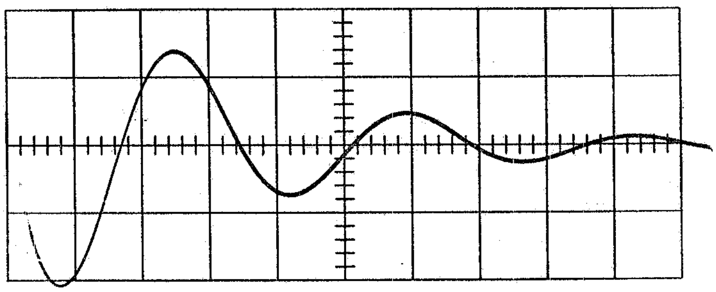
n = transformer step ratio,
V_o = capacitor charging voltage,
ω_o = undamped oscillation angular frequency,
α = damping factor.

A compromise must be reached between keeping primary current and charging voltage within reasonable limits. The chosen data of the circuit are :

$n = 12 = 24/2$; $\alpha/\omega_o = 0.15$; $C = 5\,\mu F$; $2\pi/\omega_o \approx 170\ \mu sec$.

The resulting ratio $V_o/B = 9.7$ V/Gauss, so, to obtain 1600 Gauss one needs $V_o \approx 16$ KV.

The waveform of the deflector current is shown in Fig. 5.



Deflector current waveform 50 μsec/cm.

FIG. 5

The capacitor charging voltage is stabilized by a shunt regulating system. The regulation is effective only in a short time interval around the trigger instant, so as to avoid excessive power dissipation in the charging resistor and in the shunt regulating tube. The waveform of the regulated charging voltage is shown in Fig. 6 (upper trace),

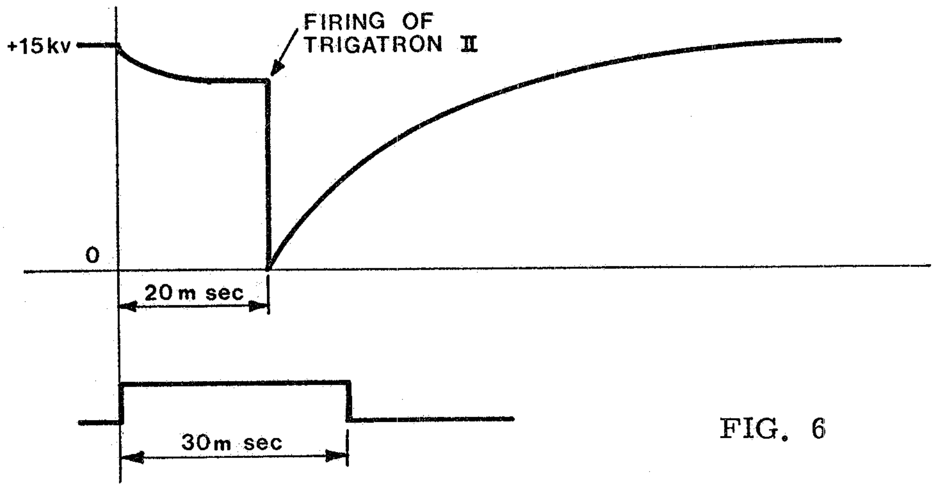


FIG. 6

together with that of the gate voltage (lower trace) that sets the regulating system into operation. The repetition rate is limited to 3 pps by power dissipation in the components. Stabilization of the deflector's current against line variations of ± 10% is better, than 1%.

As the frequency of the deflector's waveform is rather low, the overall inductance in series with C can be made high and the current generator can be placed far away from the deflector itself. This has been done to save space in the proximity of the vacuum chamber.

Only the pulse transformer is situated on the deflector's vacuum vessel and is connected to the generator, situated about 120 m away, by a high current cable. A shunt matching network is placed across the transformer primary so as to avoid small reflections on the leading edge of the pulse. A photo of the deflector and annexed transformer is shown in Fig. 7.

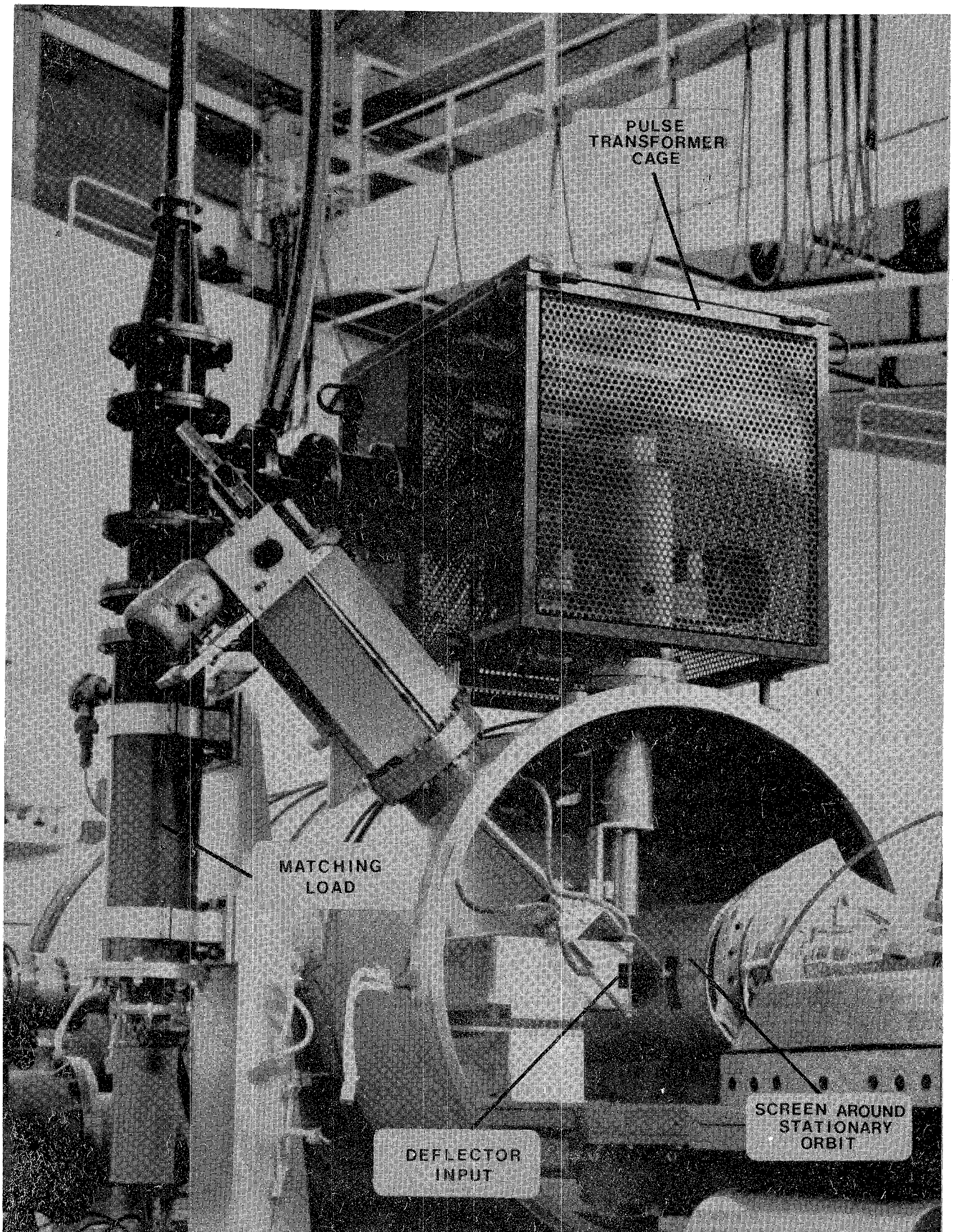
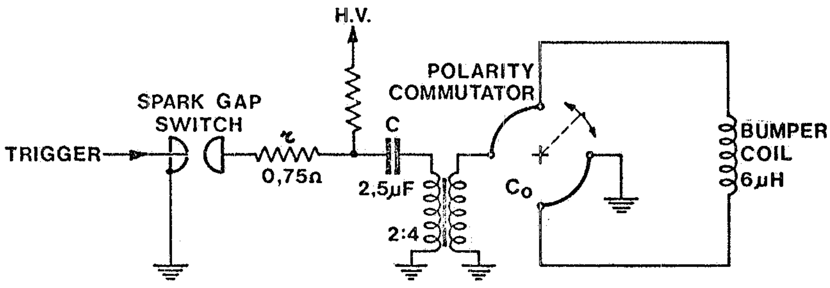


FIG. 7 - Deflector and anexed transformer photo.

5. - THE p. f. n. FOR THE BUMPER. -

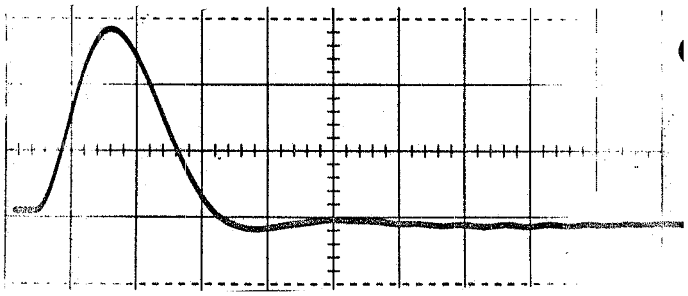
The p. f. n. for the bumper coil is based on the same principle as that for the deflector. A schematic circuit is shown in Fig. 8. In this case however the impedence level of the coil is much higher and



BUMPER PULSE FORMING NETWORK SCHEMATIC

FIG. 8

the current requirement much lower, so it has been judged preferable to reduce the voltage level by means of a pulse transformer of ratio 2. The damping factor of the waveform is also much greater than in the case of the deflector. A photo of the bumper current waveform is showed in Fig. 9.



Bumper current waveform 5 μsec/cm.

FIG. 9

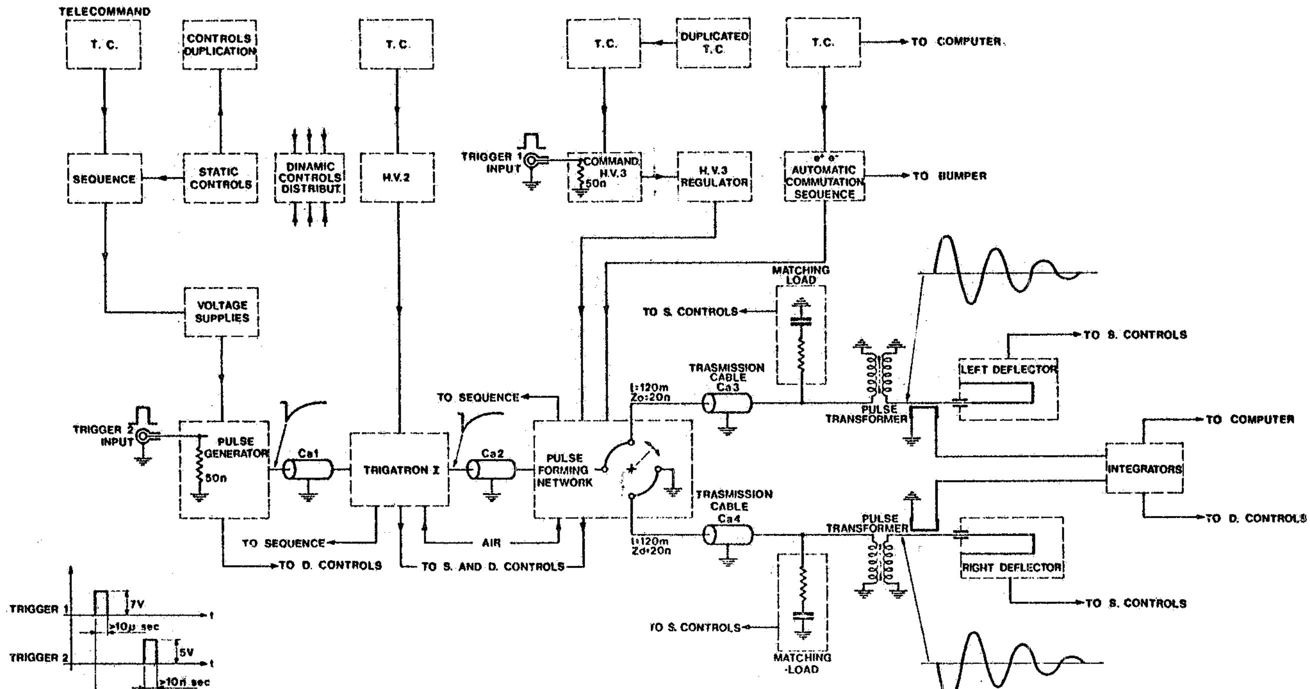
The chosen values of the parameters are : C = 2.5 μF ; $\alpha = 9.35 \times 10^4$ sec^{-1} ; $T = 2\pi/\omega_0 = 20$ μsec . For a useful bumper current of 1.7 KA the required capacitor charging voltage is 6.4 KV.

As the pulse duration is short one cannot tolerate the increment in inductance due to long connection leads, so one is obliged to place the p. f. n. close to the vacuum chamber. A photo of the p. f. n. in place is shown in Fig. 10.

6. - THE SYSTEM OF THE PULSED DEFLECTORS. -

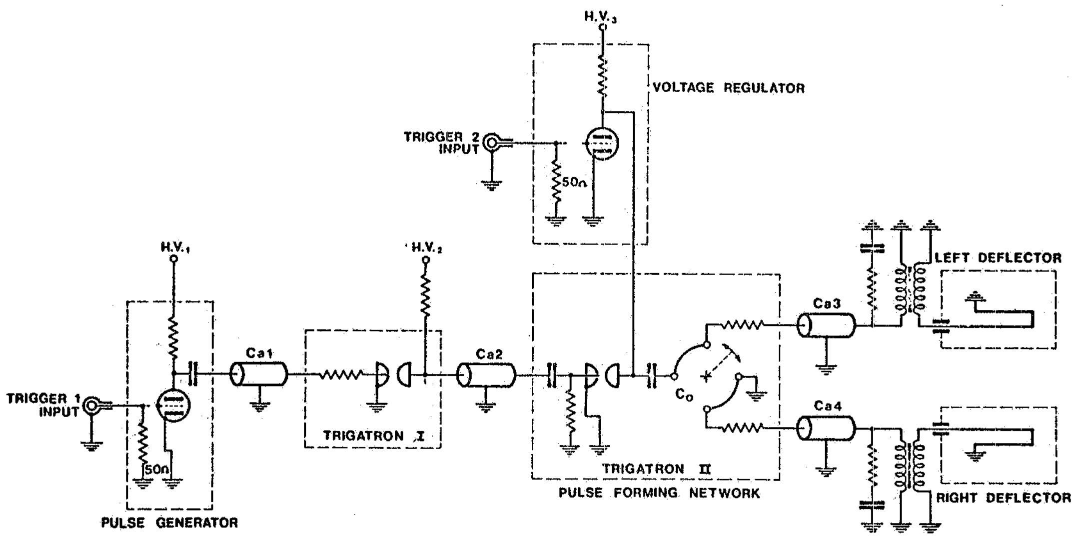
The block diagram of the main parts of the deflector system is shown in Fig. 11 a)(x). Two trigger pulses are needed, 20 msec apart.

(x) - A more detailed circuit is drawn in Fig. 11 b).



BLOCK DIAGRAM OF DEFLECTOR SYSTEM

a)



P.F.N. and TRIGGER CHAIN for the DEFLECTORS

b)

FIG. 11

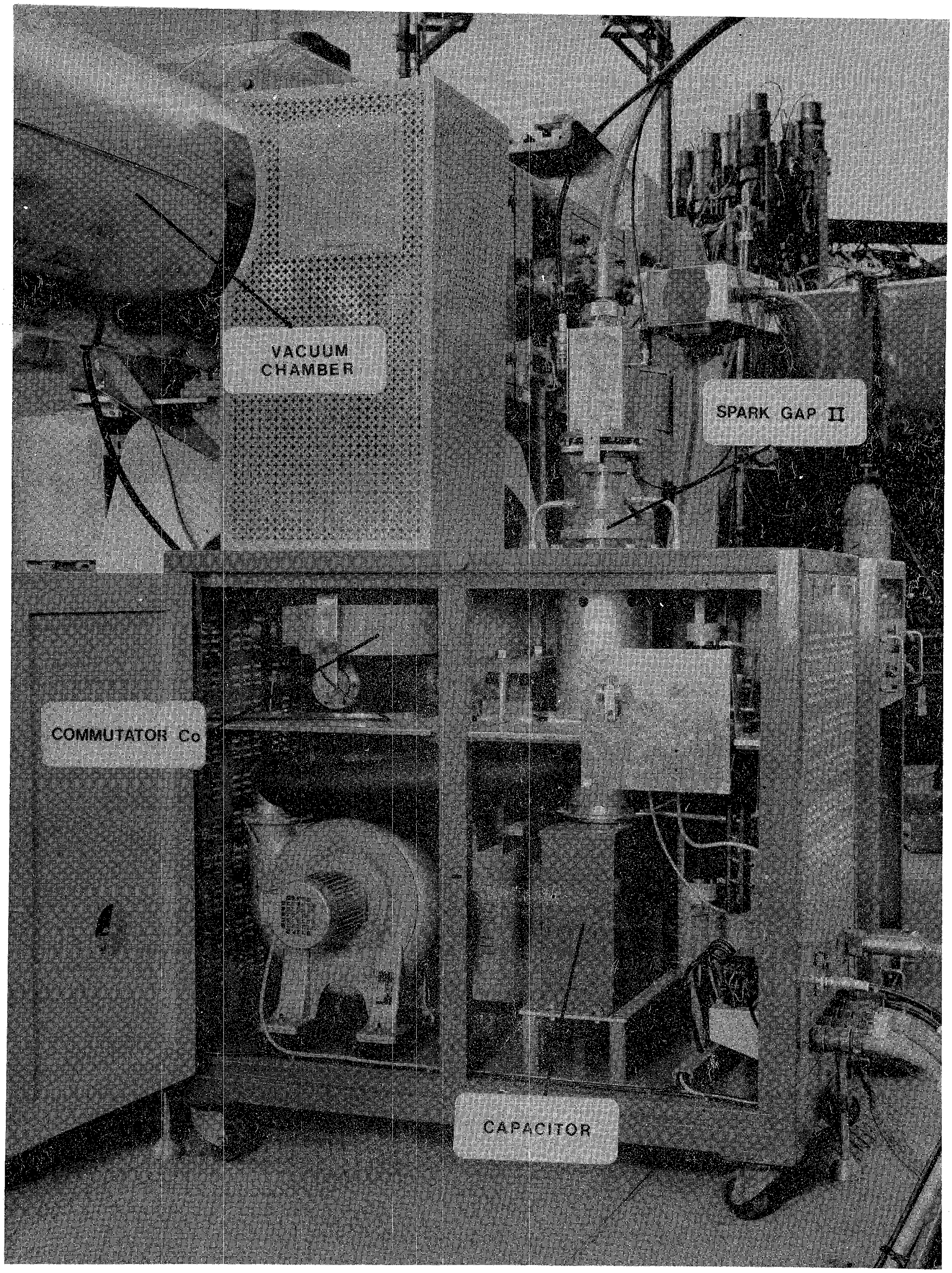


FIG. 10 - Bumper pulse forming network photo.

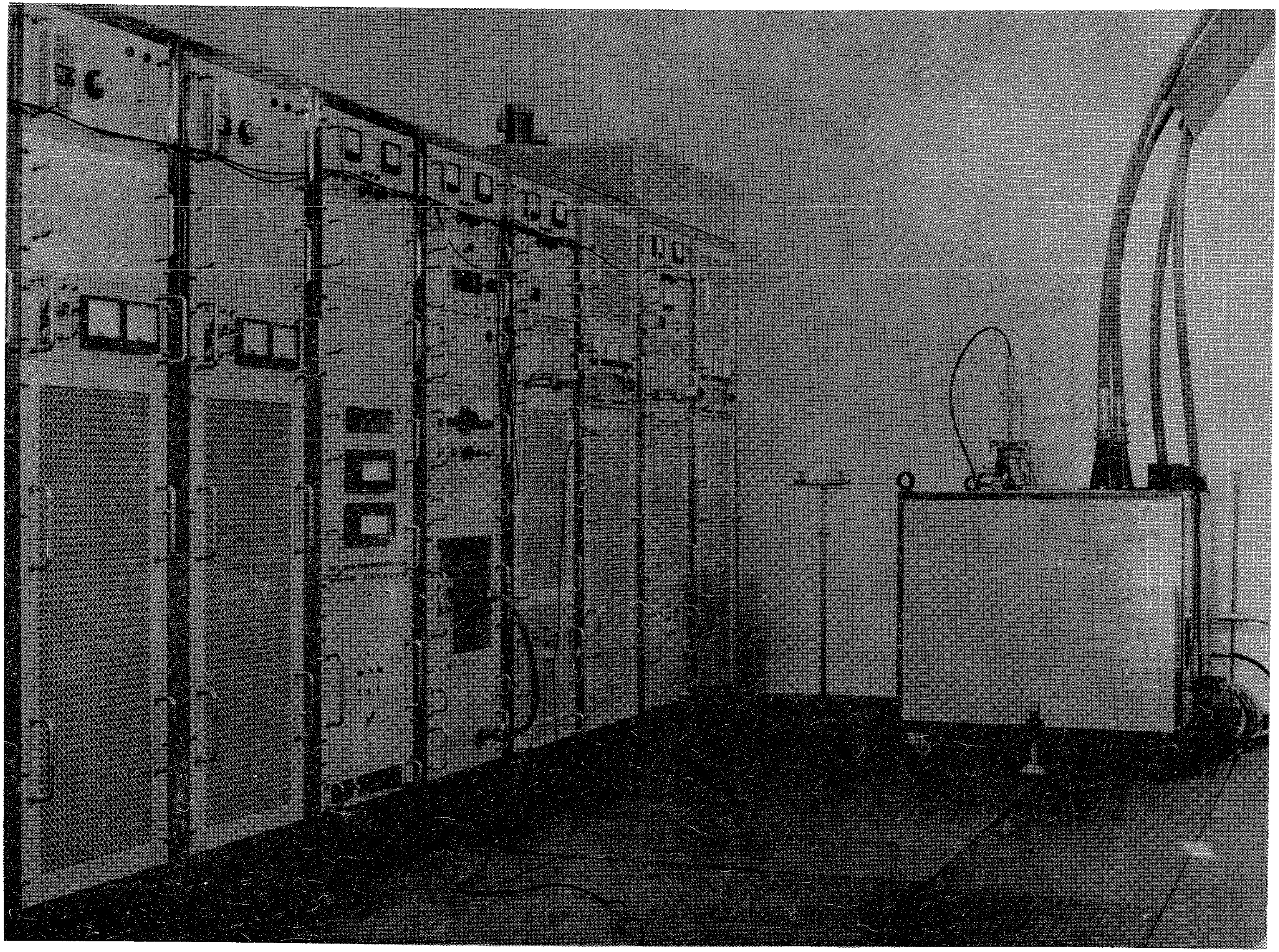


FIG. 11c - Part of the system racks and the deflector P. F. M.

The first one (duration > 10 μsec, 7 V on 50 Ω) triggers the gate that sets into operation the shunt regulating network. The second pulse (> 10 nsec, 5 V on 50 Ω) commands the trigger chain whose first stage is a pulse generator that gives a 5 KV peak pulse with a short rise time (about 10 nsec) and a delay of about 30 nsec. This generator is described elsewhere[4].

This first generator is connected by a very short length of coaxial cable Ca_1 to the control electrode of a trigatron spark gap. The latter grounds one terminal of coaxial cable Ca_2, about 0.10 m long, which is previously charged to about 15 KV.

The other end of Ca_2 is directly connected to the control electrode of a second trigatron spark gap II. This allows to obtain a voltage step that tends to twice the charging voltage of the cable before ignition of the trigger electrode discharge. The series of reflections that ensue on cable Ca_2 due to this unmatched situation die out in a time very short with respect to the duration of the current pulse in the deflector. The spark gap II is the main switch that figures in the pulse forming network.

In Fig. 11c) is a photo of part of the system racks and the deflector p. f. n.

7. - THE SYSTEM OF THE BUMPER. -

A block diagram of the main parts of the bumper system is shown in Fig. 12 a)[x]. It differs from the previous one in that no stabilization of the supply voltage is needed, as the pulse amplitude is not very critical. Only one trigger pulse is therefore necessary (> 10 nsec, 5 V on 50 Ω). There are a pulse generator and two trigatron spark gaps in cascade as in the deflector system.

Due to the short period of the formed pulse, much care has been taken in minimizing the transformer's leakage inductance and that of the connection leads from the transformer to the capacitor.

8. - COMMANDS AND CONTROLS. -

The system comprises many automatic steps in the sequence of starting operations and remote control of several parameters. The design has been made having in mind also the possibility of control by computer.

The push-button operations to set both systems on are made in suitable sequence and, together with the various controls, they are

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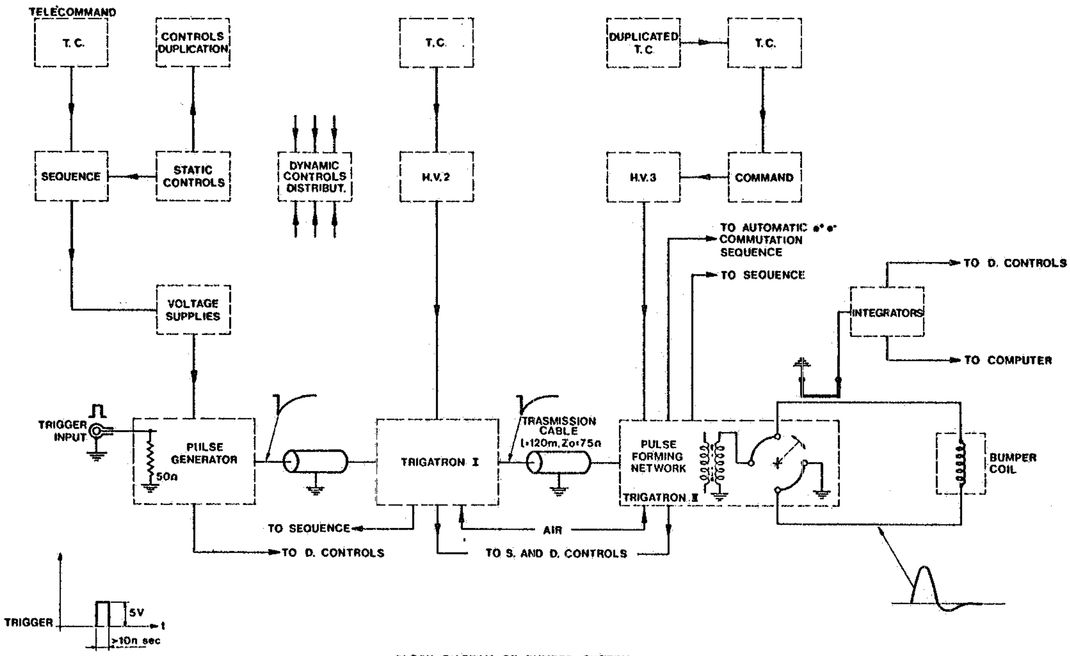
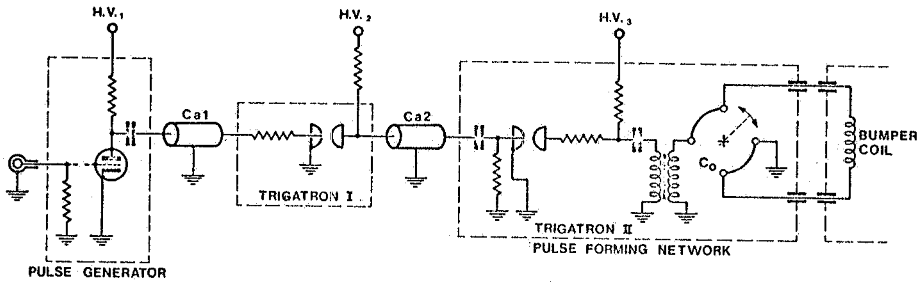
(x) - A more detailed circuit may be seen in Fig. 12 b).



BLOCK DIAGRAM OF BUMPER SYSTEM

a)



P.F.N. and TRIGGER CHAIN for the BUMPER

b)

FIG. 12

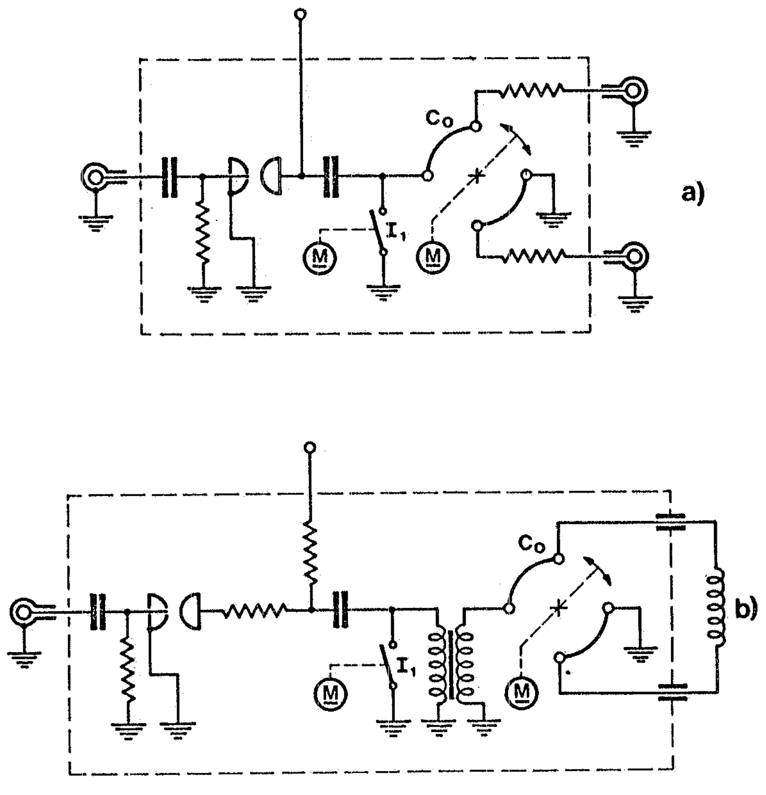
duplicated so that they can be effected both from the power plant room and from the control room.

The telecommands for regulation of the deflecting field values are duplicated and, together with the telecommand for switching from e^+ to e^- they are grouped on the central control panel of the accelerator.

The controls allow visualization of the state of various parameters of the plant. In case any of these go out of ratings, the fault is signalled and the sequence disabled from a suitable point onwards.

Magnetic pick-ups around the input leads to the bumper and deflector coils give, after integration, informations proportional to the current waveforms in those coils.

Presetting of the system as to polarity of the particles to be injected is effected by an automatic sequence. The first operation of this sequence is to inhibit the trigger to both systems. Then, by means of the motor-driven switches I_1(Fig. 13), the output of the p.f.n. is grounded so that an occasional firing of trigatron II can cause no flash over



Detail of a) DEFLECTOR and b) BUMPER POLARITY COMMUTATORS

FIG. 13

damage to the contacts of switch C_o during commutation. Consecutively C_o switches the p. f. n. from one deflector to the other one and a similar switch changes the sign of the bumper current.

Switch C_o is of the rotating type with spring brushes and commutating rotor.

After C_o has completed the commutation, switch I_1, opens again and thus enables again the system to be triggered.

As mentioned we foresee the control of the accelerator by on line computer. The values of some parameters and some state controls are therefore available for the computer. The computer may also execute some operations.

The controlled parameters are : high voltage on bumper p. f. n. capacitor and reference voltage for the supply of the deflector's p. f. n.

Possible operations are : a) reading of the state of the system and consequent order of polarity commutation ; b) setting of the values of the controlled parameters specified above . The latter is done by motor-potentiometer and analog to digital converter systems.

9. - OPERATION RESULTS. -

The system has given no relevant troubles during more than one year operation.

Lifetime of the main spark gaps is of the order of 5×10^5 shots. It has been remarkably lengthened with respect to a first model by making the electrode tips out of molybdenum rod and all the metallic parts within the spark chamber out of stainless steel. Moreover a well dried pressurized air flow is employed.

The actual injection system has allowed to attain a good injection velocity, about 25 mA/min positron current at 1. 5 p. p. s. and 350 MeV.

The authors should like to thank Mr. R. Palli for his contribution in the mechanical construction of the apparatus.

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