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MULTISHOT AND MULTICHANNEL FAST EJECTION

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(Operation "Straight Flush")

Summary

A new fast beam extraction facility has been installed in the CERN proton synchrotron. The system provides, during the same machine cycle, up to three partial fast ejections to the same or different experimental areas at minimum intervals of 150 to 200 ms. The number of proton bunches at each ejection may be varied continuously, and furthermore the system may be programmed to perform different ejection schedules from machine cycle to machine cycle.

1. INTRODUCTION

The original layout of the fast ejection system has been described in detail earlier [1]. In 1963 a mobile small aperture kicker magnet in straight section 97 together with a mobile septum magnet $\lambda/4$ downstream in straight section 1 provided fast ejection into the south hall. Later, the fast ejection system was improved and extended for new experimental areas[2]: one stationary septum magnet was installed in straight section 74 for the neutrino experiment and another in straight section 58 for the 2m hydrogen bubble chamber situated in the east hall.

As only 1 to 3 bunches were usually required for the bubble chamber experiments, further partial ejections of the internal beam during the same cycle became an interesting proposition. In order to satisfy the increased cycling rate of the 2m hydrogen bubble chamber, multiple fast ejection was necessary. Moreover, a new fast ejection channel for the storage rings will be installed with a septum magnet in straight section 16. To share the beam amongst the different experimental areas, the fast ejection system was modified for multiple ejection into septum magnets in straight sections 58, 74, 16. At present in CPS, the old septum magnet in straight section 1 has been removed, but will probably be replaced by a septum magnet in straight section 2.

The septum magnets are placed 60 mm outwards of the centre of the machine aperture. A bump of 50 mm amplitude, i.e. a local adiabatic closed orbit deformation places the beam in front of the septum, see fig. 1. A fast pulse in the kicker magnet then induces a betatronic oscillation of 27 mm amplitude around the closed orbit. The kicked bunches are swept into the aperture of the septum magnet and are ejected into the experimental area. The local bump of the closed orbit is generated by the backleg windings on main magnet units found up and downstream of the septum magnet. In the ejection scheme, a fine adjustment of the bump provided by the backleg windings is derived from the beam steering RF perturbation. This adjustment is employed only directly before the kicker magnet is excited, and in this way beam losses at the septum are minimized. For an excitation pulse of 2500 A in the kicker magnet, the radial displacement of the beam by the betatronic oscillation amounts to 18 mm at 19,2 GeV/c in the region of the septum magnets. For a nominal beam diameter of 12 mm and a septum of thickness 3 mm, this allows a margin of 3 mm in positioning the beam at the septum.

To synchronize all the septum magnets, bumps and beam steering RF-perturbations with the kicker magnet in multishot and multichannel operation, a new control system was built. With these controls, all main ejection parameters can be selected separately for three partial ejections. These parameters are : energy of ejected beam, first ejected bunch, number of ejected bunches and amplitude and polarity of the magnetic pulse in the kicker magnet. The sequence of partial ejections can be programmed so as to share the beam among the different fast ejection channels.

2. KICKER MAGNET

The central part of the fast ejection system is a mobile small aperture kicker magnet of 20×22 mm^2 useful beam aperture[3]. To enable the kicker magnet to be moved in and out of the beam, the vacuum tube in straight section 97 is enlarged to a vacuum tank.

The required magnetic field pulse of rise time 0,1 μs and flat top 2,1 μs, is achieved by building the kicker magnet as a delay line which forms part of a matched transmission line. The ferrite rings of the kicker magnet are distributed between air condensers and form together a coaxial delay line of 85 ns delay time and 10 ohms characteristic impedance. The aperture for the beam is cut out of the ferrite rings and capacitor plates, see fig. 2. There are two magnet units fixed to a central support, and each of the magnet units is energized separately. The nominal excitation current for each kicker magnet unit is 3000 A, corresponding to a high voltage pulse of 30 kV. For short pulses of 0,1 to 0,3 μs duration the kicker magnet may be pulsed by 3500 A, corresponding to a high voltage pulse of 35 kV.

To deflect the beam inwards and outwards, field inverters are employed to reverse the current direction in the kicker magnet. This method avoids flashover difficulties encountered with reversal of voltage polarity.

3. HIGH VOLTAGE PULSE GENERATOR

The excitation pulse for the kicker magnet is generated by discharging a lumped element delay line of 10 ohms characteristic impedance into the kicker magnet unit. There are two separate storage lines, each energizing a kicker magnet unit, and they can be operated together or separately, see fig. 3. The pulse voltage is half the line voltage usually between 30 to 70 kV. The storage line is connected at both ends to a matched transmission line by means of sparkgaps. By varying the instants of triggering the front and tail gap the pulse can arbitrarily be divided between the kicker magnet and the tail resistor. The pulse length at the magnet can then be varied between 0,1 and 2,1 μs. In order to obtain a fast rise of the field in the kicker magnet, the pulse voltage is sharpened by a RC section before the front gap. In order to obtain a corresponding fall time of the magnetic field, the clipping gap short circuits the line at the relevant moment.

The sparkgaps are based on the principle of the three electrode, swinging-cascade gap [4]. To reduce the influence of erosion, the electrodes are of annular construction. The sparkgaps are triggered by 30 kV pulses derived from Marx pulse generators driven by hydrogen thyratrons. The total jitter of the trigger generators and sparkgaps is typically 12 ns.

The storage lines are charged by a power supply providing 30 to 70 kV within 150 to 200 ms. The high voltage is stabilized to 1 $^{o}/o$ by a servoloop in which a voltage derived from a HV divider acts on phase cutting ignitrons in the primary circuit.

4. CONTROLS

The new fast ejection facilities are controlled by a comprehensive electronic system. Its main features derived from operational experience are :

- automatic control where possible
- simple and fool-proof operation
- adequate displays.

The kicker magnet is moved by an electrohydraulic servosystem which is remote controlled. Any movement within 250 mm stroke and 10 g acceleration can be programmed. The magnet and the vacuum tank are protected against mechanical overstresses by hydraulic interlocks and accelerometers.

The programming and timing part receives the control signals for the beam sharing, and transmits the preselected ejection parameters to the kicker magnet and its pulse generator. The program sequencer (fig. 4) repeats and distributes the program of the main control room for five ejection areas. If the accelerator does not run, the program sequencer can generate an autonomous program for high voltage tests. Three kick and bunch selector chassis (fig. 5) control each a fast ejection. The trigger pulses for septum magnet, bump, beam steering RF perturbation, RF separators, monitoring, etc. are locked to the ejection moment by special preset timing counters. If the ejection moment is changed, the pre and post pulses follow automatically maintaining the preset time interval before or after ejection.

An interlock system protects ejection channels, kicker magnet and pulse generator in case of failures. There are general interlocks and area interlocks. The general interlocks switch off the power supply of the high voltage pulse generator in conditions of alarm from vacuum, temperature, pressure overvoltage and overcurrent detectors in the kicker magnet or pulse generator. The area interlocks inhibit the firing of the pulse generator at ejection channels, in which ejection is forbidden by personal protection. There are other area interlocks in case of improper ejection into an area: if the pulses of the two kicker magnets are not equal (pulse balance), if the sparkgap pressure does not correspond to the high voltage (pressure - HV balance) or if the field inverters are not in the correct position.

The monitoring of all relevant signals in the kicker magnet and pulse generator enables a quick fault diagnosis. All fast high voltage signals and some low level signals as for example the magnetic kick, can be selected on an oscilloscope by a remote coaxial signal selector. The observation pulses are in most cases time differentiated by electrostatic pickups and reintegrated by passive integrators.

5. BEAM SHARING SCHEMES

The new ejection facilities offer a variety of beam sharing schemes composed of three basic features :

- total or partial ejection of any number of bunches between 1 and 20;
- single, double or triple ejection in intervals of 150 to 200 ms into the same or different experimental areas;
- sequencing of ejection programs for each machine cycle.

Some examples serve to illustrate the flexibility of the fast ejection system :

For the external target of the 2 m hydrogen bubble chamber, two shots each with 2 bunches have been ejected within 200 ms. The energy of ejection was varied within 19,2 and 24 GeV/c. At 19,2 GeV/c the ejection efficiency for the first shot was 90 °/o and for the second shot 80 °/o. The lower efficiency for the second shot was caused by an unstable flat top of the main magnets.

With the new power supply of the main magnets it is possible to stay with the accelerated beam at an intermediate energy and then to accelerate again to higher energy. With this arrangement two shots of two bunches have been ejected within 140 ms at 15 GeV/c for the bubble chamber, and then with further acceleration of the internal beam one shot of five bunches has been ejected at 19,2 GeV/c into the neutrino channel. Figs. 6, 7 and 8 illustrate a similar program with three partial ejections in intervals of 200 ms all at 19.2 GeV/c.

An example of sequencing was to eject three bunches for the external target of the bubble chamber during four subsequent machine cycles, and then for each fifth cycle to eject the whole beam into the neutrino channel.

The beam control after ejection can be maintained for 5 or more bunches remaining in the accelerator. For a single fast ejection of a few bunches an ejection efficiency better than 95 °/o can be obtained.

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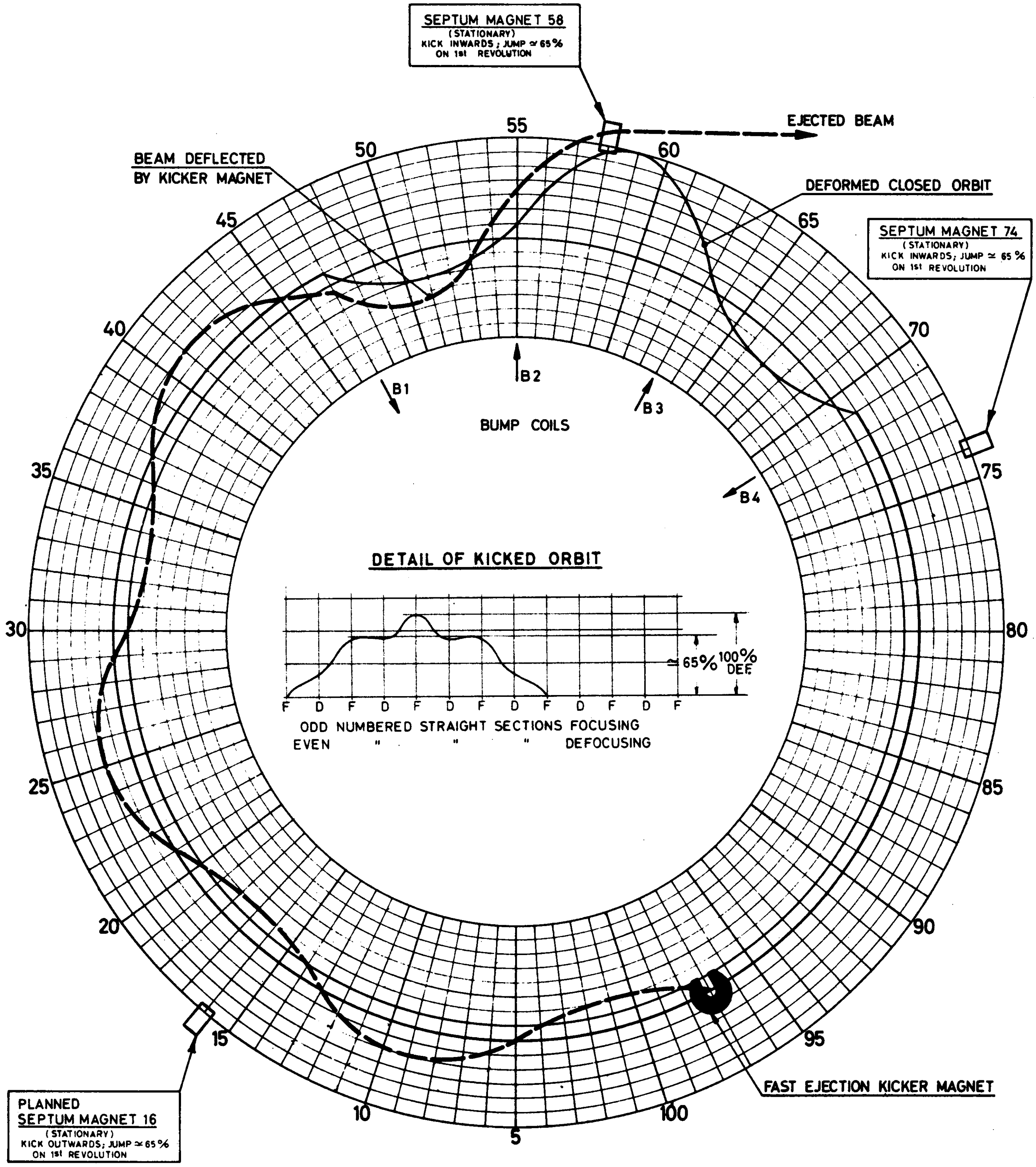

Figure 1 : Fast ejection from straight section 58 into the east experimental area

Average closed orbit position is displaced between 10 and 20 mm outward. A local closed orbit distortion, centered around straight section 59, is created by a double pair of bump coils BIB2B3B4. This places the beam in front of the septum of the ejection magnet. The kicker magnet deflects the beam inwards, creating a betatron oscillation of enough amplitude to jump the septum.

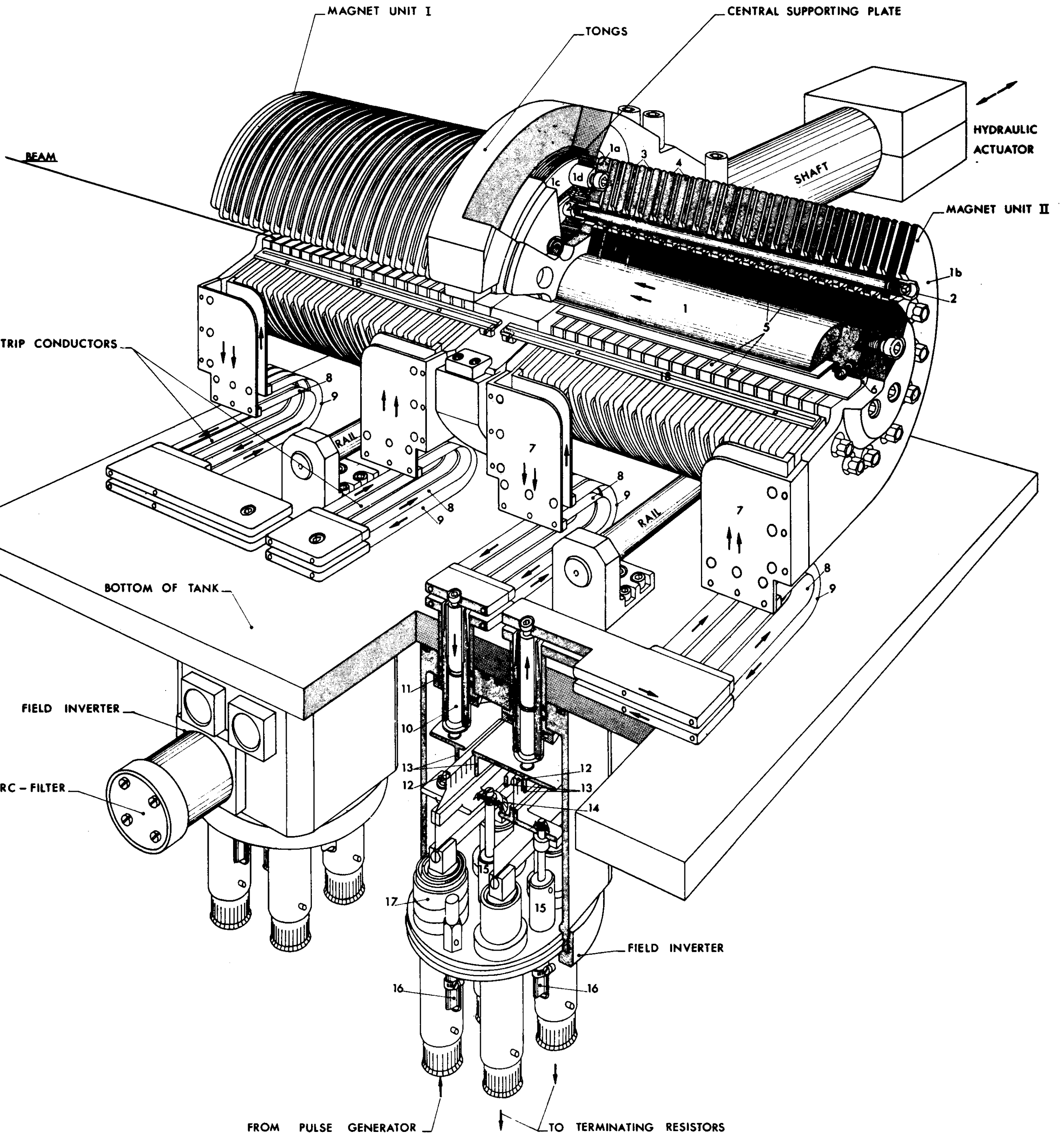

Fig.2 **Perspective view and partial cut of the kicker magnet:**

(1) inner conductor with (1 a) inner flange and (1 b) outer flange; (2) outer conductors, (1 c), (2 c) rings cast into central supporting plates; (1 d), (2 d) stubs welded onto rings; (3) large, thin capacitor plates of inner conductor; (4) small, thick capacitor plates of outer conductor; (5) ferrite rings, bprne by inner conductor; (6) profile aligning ferrite rings; (7) plates supporting flexible strip conductors; (8) flexible strip conductors connected to inner conductor; (9) flexible strip conductors connected to outer conductor; (10) inner conductor of coaxial traversal connected to inner conductor of magnet unit; (11) earthed outer conductor connected to outer conductor of magnet; (12) moving contacts of field inverter; (13) fixed contacts of field inverter; (14) moving bypass contact; (15) pneumatic cylinders actuating field inverter; (16) pressurized air connections to cylinders; (17) electrostatic pickup ring for observation of incoming pulse; (18) long pickup loops for observing time depehdence of magnetic kick.

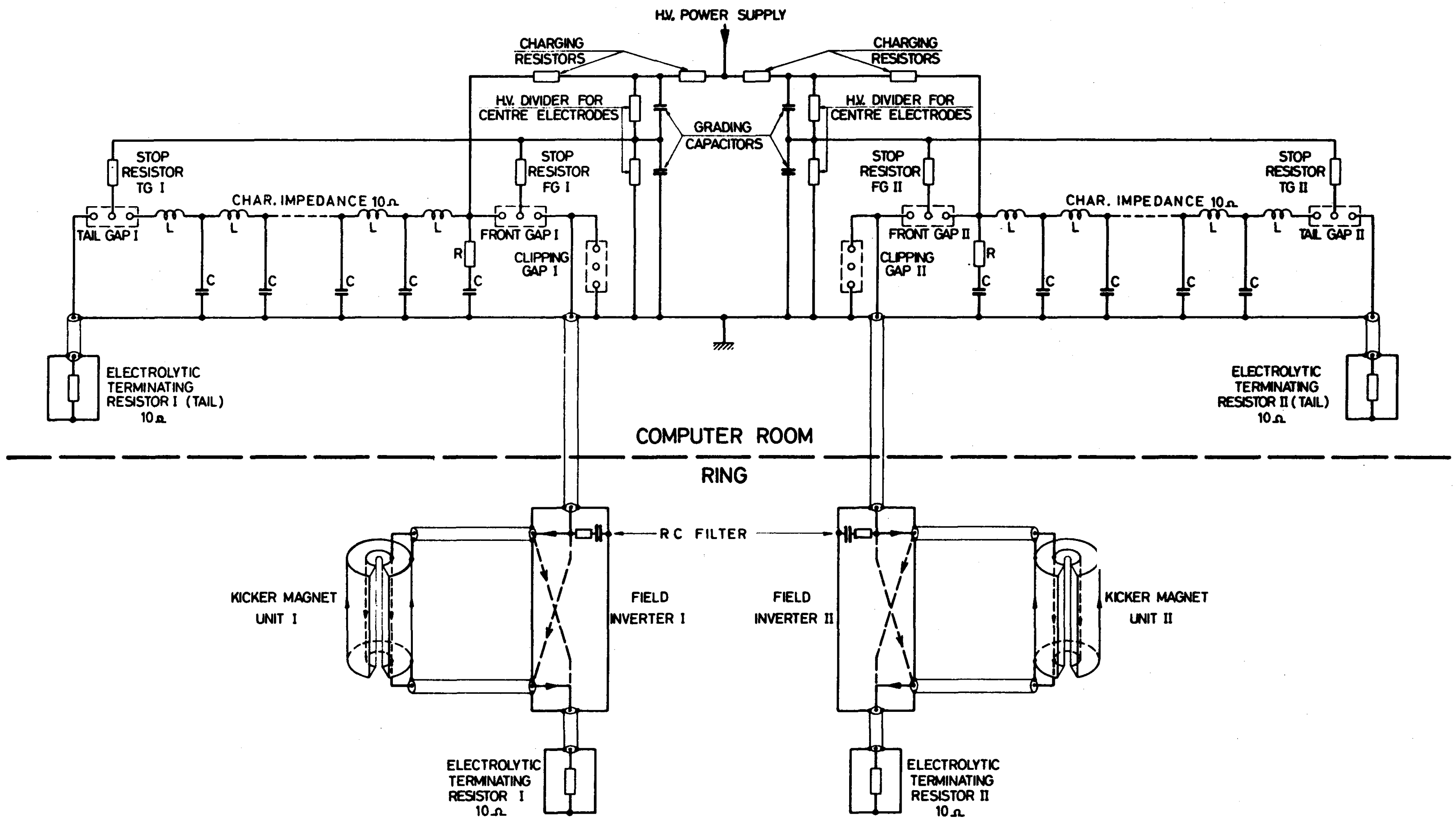

Figure 3 : Simplified diagram of the H.V. pulse circuits

The kicker magnet consists of two units, each with a mechanical field inverter, permitting inversion of the current. Each unit is excited by its own line type pulser. The pulse duration can be adjusted by relative timing of front gap, tailgap and clipping gap.

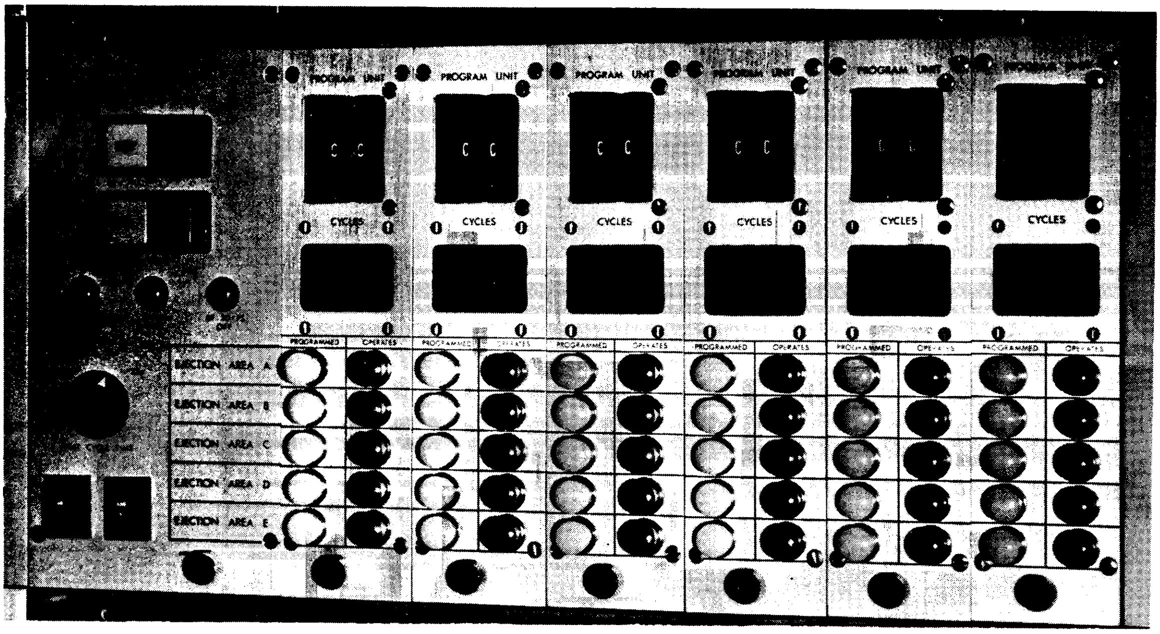

Figure 4 : Program sequencer

The programs are repeated for a preselected number of acceleration cycles, with Nixies displaying the counted cycles. In each program unit the ejection areas are switched on with the left-hand knob, and the right hand light flashes when the high voltage pulse generator is triggered. After completion of the preselected cycles, the next program unit is started; the last program unit restarts the first unit. For tests during stopages of the PS accelerator, the test unit simulates the M-train, RF and RF/20 signals. The test cycle time can be varied between 0,5 and 3,3 sec.

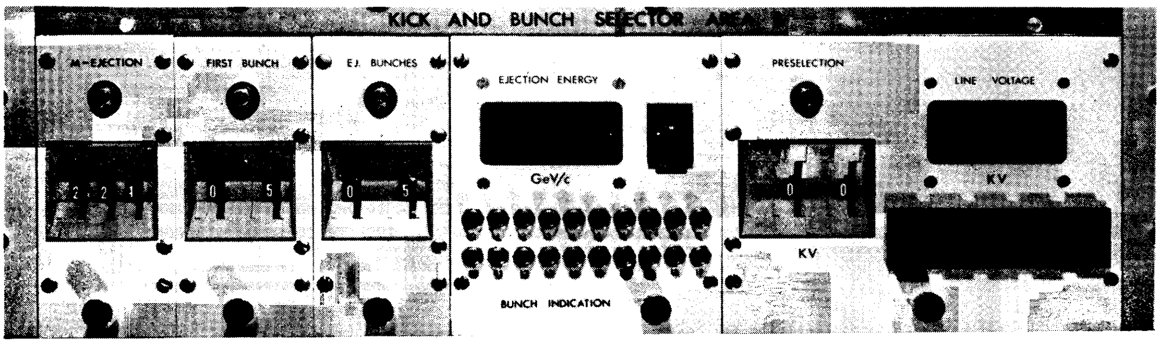

Figure 5 : Kick and Bunch selector

The M-ejection unit counts the M-pulse train and provides a selection of the ejection energy. The first bunch unit selects the first bunch to be ejected, and the ejected bunches unit selects the total number of bunches to be ejected. The ejection energy is calculated from the main magnetic field, and is displayed by Nixies. The line voltage is preselected, sampled immediately before ejection and displayed. Pushbuttons under the line voltage display select the lines to be pulsed and the polarity of the magnetic kick.

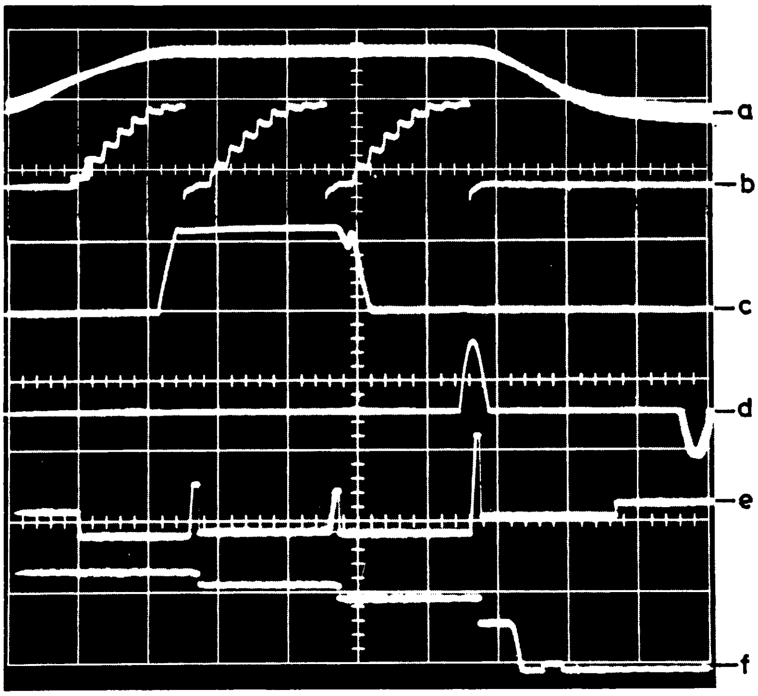

Figure 6 Triple fast ejection

Two shots are ejected into the bubble chamber channel and then one shot into the neutrino channel, all in intervals of 200 ms at 19.2 GeV/c. The oscillogrammes (100 ms/div) show

a) kicker movement

b) line voltage

c) bump current during ejection into bubble chamber channel

d) bump current during ejection into the neutrino channel

e) RF-perturbations

f) internal beam current trafo

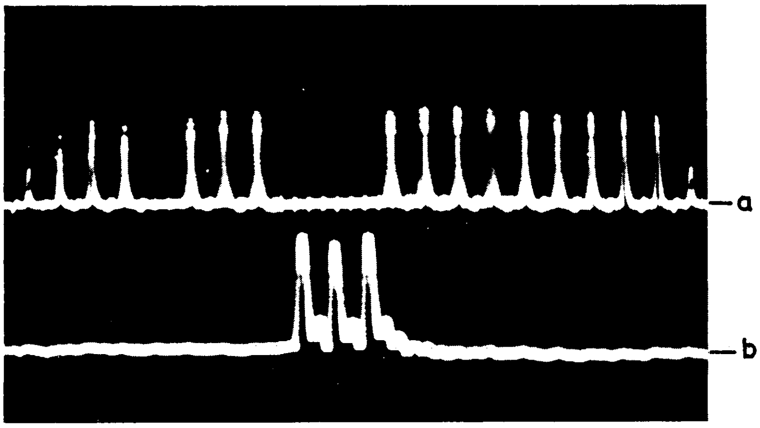

Figure 7 Second shot of triple fast ejection

The oscillogramme a) shows the bunch structure with 105 ns from bunch to bunch of the internal beam just after the second shot, 1 bunch having been ejected by the first shot and 3 bunches by the second shot. The oscillogramme b) shows the three ejected bunches of the second shot passing the bubble chamber channel.

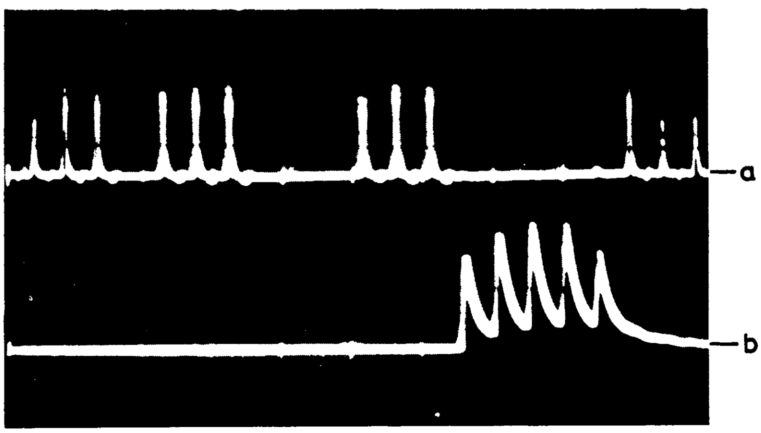

Figure 8 Third shot of triple fast ejection

The oscillogramme a) shows the bunch structure with 105 ns from bunch to bunch of the internal beam just after the third shot, 1 bunch having been ejected by the first shot, 3 bunches by the second shot and 5 bunches by the third shot. The oscillogramme b) shows the 5 ejected bunches of the third shot in the neutrino channel.