THE FAST EJECTION EQUIPMENT FOR THE SERPUKHOV 70 GeV PROTON SYNCHROTRON

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Abstract

A summary description of the equipment is given together with the performance up to the date of the conference.

General

The layout and general organization have been published in 1969[1]. The system provides up to 3 shots in one acceleration cycle into anyone or a combination of 3 fast ejection channels A, B, C. The extracted number of bunches, the ejection time and hence the energy can be chosen for each shot (table 1).

The design study was accepted in March 1969, prototyping covered the year 1969, design, construction, assembly and testing the year 1970 and nine months of 1971. At the time of the conference the system is 90 °/o assembled and life tested. Shipment to Serpukhov is due in October and first ejection early in 1972.

Kicker Magnet (KM16)

The magnet is divided into 10 modules of 30 cm magnetic length, each being part of a 5 Ω delay line pulser circuit, producing 40 kV/8 kA pulses of 0.17 - 5.1 μs duration. The modules (fig. 1) have ferrite magnetic circuits and 2 LC-sections, hence combining simple geometry to acceptable reflections[2]. The matching capacitors and terminating resistors are in an oil filled box under the vacuum tank (fig. 2). The field reaches 0.1 T with ± 1 °/o radial variation over ± 50 mm of the aperture. The 0 - 100 °/o risetime is 150 ns, the 100 - 10 °/o falltime is 160 ns, the top is flat to ± 3 °/o except for a reflection that may be phased between bunches by choosing the length of the transmission cables.

The pulse generators consist of charged delay-lines in an oil tank with a triggered sparkgap switch on either side in a screened cage (fig.3). By timing the switches the pulse length may be divided between the magnet and a dumping resistor. The frontgap (switching towards the magnet) contains a clipping gap which, by shorting the line cuts the tail and reduces the falltime of the current pulse. The frontgap with RC network (fig. 4) gives a risetime of 20 ns and a jitter of < 10 ns. All 10 frontgaps are triggered by a mastergap driven by a hydrogen thyratron; similarly the tailgaps and the clipping gaps. The pulses are transmitted 120 m to the KM through four 20 Ω coaxial cables in parallel per module.

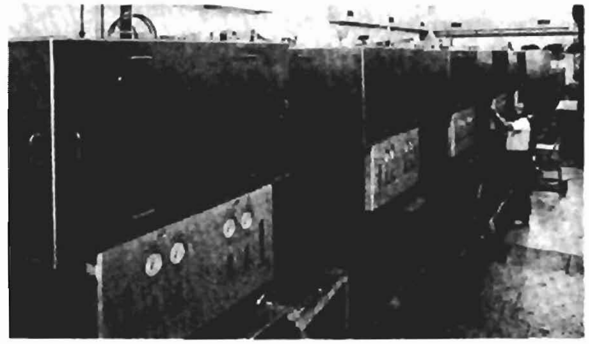

Fig. 3 Delay line pulsers are paired into 5 structures. One sees the screened cages.

The charging supplies (one per delay line) are 3-phase double wave transformer rectifiers with switching thyristors in the primary. Charging begins with a startpulse and ends when the set voltage of 80 kV is reached (± 1 °/o). Shot to shot kick strength regulation is obtained by charging the desired number of delay lines.

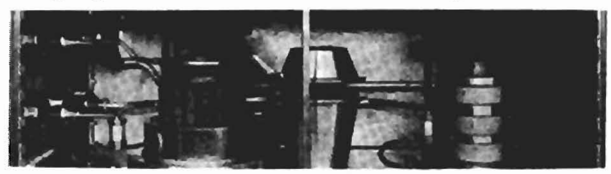

Fig. 4 Front gap (left) with pulse sharpening RC section (centre) and tail gap (right).

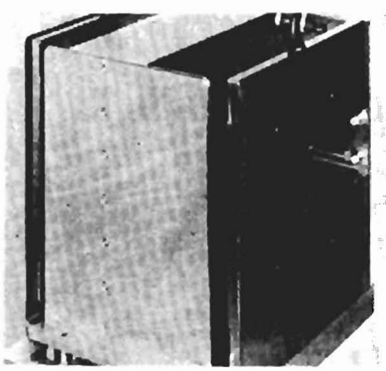

Fig. 1 A kicker magnet module, front plate is centre tap of two sections.

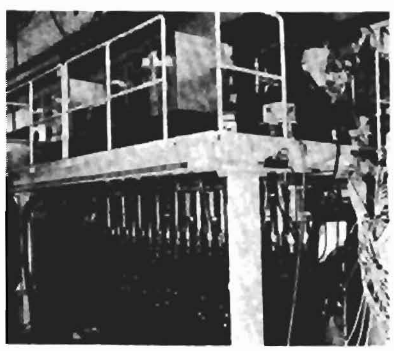

Fig. 2 Kicker magnet vacuum tank. Under it boxes with matching capacitors and terminating resistors.

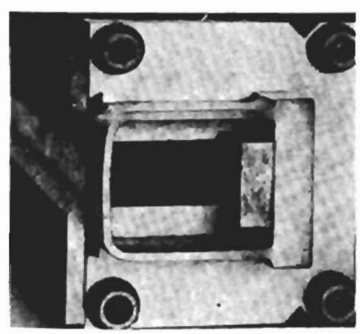

Fig. 5 Septum magnet SM26. At left 6 mm septum. In front current bridge between septum and return connector.

Table 1/specifications

Working range of the whole system 30-75 GeV

KM 16	
Aperture hxw	~100x140 mm^2
Kick strength	0.300 Tm
Beam jump at SM24 (75 GeV)	25 mm
Rise and fall time (3-97°/o)	150 ns
Max. spatial variation of kick	± 3°/o
Max. time variation of kick	± 3°/o
Residual kick after pulse	± 10°/o
Number of shots 1 accel. cycle	3
Interval between shots	250 ms
Pulse length for bunch number of	1-30
Time, number of bunches and excitation level to be discretely adjusted for each pulse	
SM 24	
Aperture hxw	~30x45 mm^2
Kick strength	1.0 Tm
Max. spatial variation of the kick	± 0.1°/o
Max. time variation of the kick	± 0.2°/o
Number of repeated shots	3
Interval between shots	250 ms
Timing + excitation level to be chosen for each shot	
SM 26	
Aperture hxw	30x60 mm^2
Kick strength	3.6 Tm
All other specifications like SM24	
Actuator	
Time for moving in or out	0.3 s
Precision in working position	± 0.5 mm
Number of movements per accel. cycle	3
Starting moment, shape of movement and stroke programmable	
Vacuum	
Max. end pressure in ejection tanks	10^{-5} mm Hg
Max. pumpdown time to 10^{-4} (after initial outgassing)	2 h
Electronics	
Ejection energy precision	± 0.15 °/o

Septum Magnets (SM24 and SM26)

The single conductor septums (3 mm SM 24 and 5 mm for SM26) are brazed together of oxygen free copper tubes of rectangular outer section with a round hole for cooling. The magnetic circuit is of 0.5 mm silicon steel laminations, epoxy bonded into a number of blocks, mounted on a steel profile and supported from outside the tank over a hollow shaft containing the coaxial current feedthroughs. The magnets (fig. 5) have been corrected to better than 0.1°/o radial kick variation in the aperture by shimming the current conductors along the magnet and the magnetic circuits at the ends. The leakage fields are less than 1°/o of the nominal field.

The half sine wave current pulses (22 kA for SM24 and 36 kA for SM26) have a 200 µs base, giving a 0.1°/o field variation during the 5 µs KM pulse. They are derived from conventional capacitor discharges using ignitrons and crowbar diodes (fig. 6).

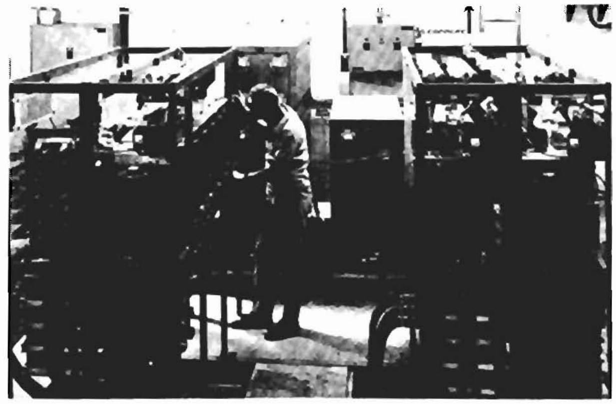

Fig. 6 Pulse generators for SM26 and SM24.
Front : ignitrons and crowbar diodes.
Bottom : pulse cables
Background : charging supplies.

The pulses are transmitted 200 m to the magnets through a large number of low impedance coaxial cables in parallel.

Shot to shot current reproducibility is 0.1°/o by regulating the capacitor charging voltage. The principle is similar to the KM but a thyratron short circuits the secondary (isolated by diodes from the capacitors) when the reference voltage is reached. Pulse to pulse field variation is done by programming the reference voltage.

Actuator and Guiding of SM24

The main ram has a thrust of 4 t, a stroke of 200 mm and an overall time constant of 100 ms. In typical operation the stroke is 150 mm and placing and withdrawing time both 300 ms. A servoamplifier, following an analogue signal from a programmer, drives an electrohydraulic servovalve which in turn drives the main distributor spool. There is position, velocity and acceleration feedback. The 210 bar hydraulic pump station can supply 3 full movements per acceleration cycle.

SM24 is supported outside the vacuum tank (fig. 7) by a chariot guided on hydrostatic bearings. In case of emergency stops the magnet withdraws, locks and leaves the accelerator aperture free. The foundation of the moving mechanism is separate from the one of the vacuum tank.

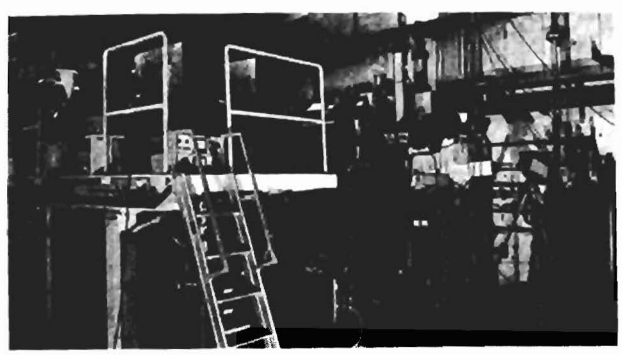

Fig. 7 Vacuum tank of SM 24 with hydraulic actuator and guiding system on support.

Vacuum

The 0.9 m^3 stainless steel vacuum tanks for the three magnets have metal seals almost throughout, except for a neoprene gasket at the coverplate. Section valves may isolate the tanks from the doughnut chamber. There is a stainless steel bellows between the moving actuator shaft and the tank of SM24. The tank of KM16 has 80 coaxial pulse feedthroughs (8 per module), now of epoxy resin, later to be replaced with ceramic ones.

Each tank has a turbo molecular pump of 250 l/s (10^{-3} - 10^{-4} Torr) backed up by a rotary pump of 35 m^3/h. Presently 6 sputter ion pumps of 500 l/s (10^{-5} - 10^{-7} Torr) are mounted on the tank of KM16 and two each on those of SM24 and SM26.

Pumpdown time to 10^{-3} - 10^{-4} Torr is less than 60 min. The empty tanks reached 10^{-6} Torr after a few weeks. With KM16 one reached $5 \cdot 10^{-6}$ Torr after two months (repeated opening). With SM24 one reached $3 \cdot 10^{-6}$ in a week.

Programming and Timing

For each shot a preset counter counts B (field) or T (clock) pulses. When the preset number is reached it opens a gate for RF pulses (from accelerating voltage). These in turn are counted by fast preset scalers which then give pulses to the KM triggers (front, tail and clipping), thus permitting to synchronize rise and fall time between the bunches. B+T pre- and postpulse units produce pulses at chosen pulse numbers before, respectively after ejection, thus permitting coarse synchronization of auxiliary equipment, e.g. start pulses for charging supplies, movement of SM24, beam transport, etc. RF pre- and postpulse units similarly permit fine synchronization with the KM pulse, e.g. triggers for SM24 and SM26, RF separators, beam diagnostics,etc.

The magnet parameter selector permits for each shot the choice of the ejection B or T pulse, the voltages for SM24 and SM26, the number of KM modules to be powered, the first extracted bunch (bunches are labelled) and the number of bunches to be extracted.

A programming matrix permits at choice a sequence of up to 10 different fast and slow ejections and target operations within a master cycle of ten accelerator cycles.

The hydraulic programmer generates an analogue signal consisting for each shot of a sinusoidal rise and fall time separated by a flat top. The amplitude of the movement, risetime, falltime, flat top time and position after falltime may be chosen independently for each shot. The start position for the next shot is the end position for the previous one so that the programme is continuous.

Beam Diagnostics and Data Handling

TV cameras view luminescent flip screens on the upstream end of SM24 and at the upstream and downstream ends of SM26.

Beam transformers are placed in the accelerator (SS14) and at the exit window of channel A (SS28). Optional ones may be placed at other exit windows (e.g. channels B and C) or at the end of the external beam line. Intensity is measured bunch by bunch before, during and after ejection so that efficiencies of internal and external beams are obtained per bunch.

Electrostatic pickup electrodes at the upstream side of SS16, SS24, SS26 and SS28 yield, for the bunch selected to be measured, the radial position of the circulating or deflected beam.

Fast radiation monitors in the same straight sections permit to monitor beam loss and to distinguish between fast bursts (from the kicked beam) and slow bursts (from the circulating beam).

Beam profile monitors upstream on the moving SM24 and at the exit window in SS28 may permit to find the emmittance of the circulating and deflected beam.

The analogue signals of various monitors are digitized and fed to a mini-computer, which calculates all results for all shots and makes statistics over a chosen interval.

Most results are given out over a trunk cable (bunch of coaxial cables) and may be read out on nixies with fixed or variable addresses. Three similar variable address units driving simple pen recorders permit monitoring at choice of any three signals on the trunk cable. Nixies are used for cycle to cycle display of a selected shot.

Coherent "snapshots" off all parameters of one shot may be printed out on the teletype.

There is a large CRT analogue display of the internal and external bunch efficiencies.

Monitoring

A large number of electrical and magnetic pulses and charging signals may be called by push button selection onto a number of display oscilloscopes. Fast pulse signals, integrated by wide band passive integrators if obtained from electrostatic or electromagnetic pickups, go through a coaxial channel selector using matched reed relays.

A kick analyser has time windows for the rise and falltime and a level window for the amplitude of the magnetic pulse of the 10 KM modules and for their sum. If the instants of the 50°/o level of the kick or the flat top level fall out of the relevant windows, a fault signal is given which may be counted for statistics and may act on interlocks if the fault density exceeds a chosen level.

The SM pulse analyser gives a fault signal when two pulses related to rise and falltime of the KM fall outside a time window given by the 0.1°/o points around the top of the SM current pulses. The faults may be counted and interlocked.

Controls and Interlocks

The controls for the electrohydraulic actuator permit manual and programmed operation and feature an intricate chain of interlocks for startup, shutdown and for emergency stops.

The vacuum controls permit a manual or automatic pumpdown cycle, pressure monitoring and interlocking with magnet charging supplies and accelerator.

Acknowledgements

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