Paper submitted to the
International Accelerator
Conference, Yerevan
August/September, 1969

CERN/PS/FES/int. 69-8
31.7.1969

THE FAST EJECTION SYSTEM, IN PARTICULAR CHANNEL A, OF THE SERPUKHOV ACCELERATOR

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Abstract :

A description is given of the fast ejection system now being constructed for the 70 GeV Serpukhov accelerator, in the framework of the collaboration between the IHEP and CERN. This system will be able to eject any number of the 30 proton bunches into anyone of the three planned fast ejection channels A, B and C. The paper gives the layout and main trajectories for the three channels and summarizes the main technical characteristics of the ejection system and the beam transport system of channel A up to the beam focus on the external target.

Contents :

1. ACKNOWLEDGEMENT

The design and construction of the described system of channel A has been undertaken in the framework of the collaboration between the European Organization for Nuclear Research (CERN) in Geneva and the Institute for High Energy Physics (IHEP) near Serpukhov.

Numerous persons have contributed directly or indirectly to the plans. The main contributors to the actual design study are :

IHEP : Messrs. Yu.S. Fedotov, V.I. Gridasov, V.V. Komarov, O. Kurnayev, K.P. Myznikov, V.M. Tatarenko, V.L. Ushkov.

CERN : Ejection

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Beam Transport

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We are very grateful for the active help we had from other members of the involved groups and for the support of the directions of both institutes.

2. GENERAL

Fast ejection of the accelerated proton beam into three channels A, B and C has been planned[1]. Channel A will be used for the radio frequency separated beam for the bubble chamber "Mirabelle", channel B is intended for neutrino experiments, channel C will serve the 2 m hydrogen chamber. Channel B coincides with a slow ejection channel[2] which is meant to serve counter experiments at the beginning of the gallery.

The fast ejection in the three indicated directions involves up to five deflections magnets (fig. 1) : Kicker magnets KM 14 and KM 16 located in straight sections 14 and 16, a mobile septum magnet SM 24 in straight section 24, two stationary septum magnets SM 26 and SM 28 in straight sections 26 and 28. One of the kicker magnets or both in tandem deflect the proton beam into the aperture of SM 24. This magnet is moved from the ring center side into its working position, where the septum is close to the central orbit. SM 24 amplifies the deflection of KM 16 and directs the beam into the aperture of SM 26. The latter magnet acts as a beam switch which, by choice of its field level, directs the beam into either of the channels A or C or into the aperture of SM 28. For this SM 26 may be unexcited or weakly excited, such that the beam avoids the strongly non linear field region in unit 27. SM 28 bends the beam into channel B.

The ejection exit windows for channels A and B are at the ends of respectively units 27 and 29. From there on, external proton beam transport systems (fig. 2) guide the beam to the external targets[3].

For adjustment of the exit angle into the experimental hall and to improve the beam optics, a horizontal deflector magnet HD1 and a quadrupole lens Q1 are located in each of the straight sections 28 and 30.

The external target position of channel A chosen for the RF separated beam, is around 30 m from the ejection exit window in straight section 28. Since the target cross section is about 1×2 mm, the proton beam is brought there to a focus by means of a quadrupole triplet Q2, Q3, Q4. Pairs of horizontal and vertical deflectors HD2, HD3 and VD1, VD2 are added for fine adjustments.

The use of a three stage system[4)] with the mobile intermediate magnet SM 24 permits to minimize the deflection required from KM 16 to a value corresponding with a radial beam displacement at SM 24 of one beam diameter plus one septum thickness. SM 24 permits to make SM 26 and SM 28 stationary and to direct the beam into their apertures with a comfortable margin. The position of these two magnets right outside the injection beam envelope on the ring center side allows in principle a range of exit trajectories, all avoiding the strong non linear field regions in units 26, 28 and 30. The intermediate magnet SM 24 gives also versatility to the system. In a later stage it will be possible to eject at other points of the ring by just installing one mobile septum magnet there, and possibly adding a stationary one.

From an exploitation point of view, since the accelerator has a low repetition rate of 9 ppm, it is important to provide for multiple shot and multiple channel operation within one acceleration cycle. This will be done by multiple pulsing of KM 16 according to a technique developed at CERN[5)]. For each shot the magnetic pulse duration may be chosen in steps of 170 ns between 20 ns and 5 μs and the magnetic field of KM 16 rises to its nominal value (or falls to zero) in the time interval between passage of two subsequent bunches. This permits extraction of any number of accelerated proton bunches between 1 and 30. The magnets SM 24 and SM 26 can also be pulsed repeatedly and their field may be programmed from pulse to pulse in view of the desired direction and the chosen ejection energy, which may be between 30 and 75 GeV. The external proton beam transport magnets of channel A can also be multiply pulsed but only at one field level, i.e. corresponding to constant energy in flat top operation.

For reasons of radiation safety and lack of space the pulse generators and power supplies for the magnets and other auxiliary equipment could not be placed in the ring tunnel or experimental hall. In view of the large number and variety of such equipment a special ejection building will be constructed close to the ejection area. Therein will also be a local control room, in which the major part of the electronics for ejection and related equipment will be located.

For a comprehensive and coherent control of the ejection channels and the relevant auxiliary accelerator equipment these should be grouped geographically. Since the existing main control room has insufficient reserve space and is not easily extendable, all ejection beam channels and other beam consuming operations will be controlled from the local control room in the ejection building. A number of machine displays and controls will for this purpose be repeated in the local control room.

The overall arrangement and trajectory layout[1] and the technical desing studies of the fast ejection system[6] and the pulsed beam transport system[7] have been completed so that all main parameters are now frozen. Aperture sizes and performance tolerances[8] have been chosen such as to cope with expected accelerator beam emittances. The construction of the ejection building and a number of other preparations for the reception and installation of the equipment for channel A have been started.

3. THE FAST EJECTION SYSTEM A

The system consists of a kicker magnet KM 16, two septum magnets SM 24 (mobile) and SM 26 (stationary), the respective pulse generators and charging supplies, the hydraulic actuator and its pumping station, the vacuum tanks and their pumps. Electronic controls comprize programming and timing, beam observation and display, interlocks and electric systems checkout. The main data of the system are collected in table 1.

The three ejection magnets are located in the ring tunnel in the accelerator vacuum system, which is locally enlarged to rectangular vacuum tanks. The ejection building houses the pulse generators and charging supplies in one of the equipment rooms, the electronic system in the local control room, and the hydraulic pumping station. The high voltage and current pulses, the high pressure hydraulic oil and low level signals are transmitted through a tunnel connecting ejection building to accelerator ring.

It is aimed to make a full aperture kicker magnet. It will have a ferrite yoke and will be divided into a number of modules for voltage reduction. A possible configuration is shown in fig. 3. Each magnet is excited by discharging a delay line through it (fig. 4), the pulses being transmitted through low impedance coaxial HV pulse cables. The variable pulse length is obtained by dividing the delay line pulse between the magnet and a dumping resistor by timing of the gaps. The HV supplies charge the delay lines to a fixed voltage but stepwise pulse strength regulation can be programmed by exciting the appropriate number of magnet modules.

The two septum magnets are of similar construction (fig. 5) but the mobile one is shorter. The magnet yokes are of laminated transformer steel, the septum of a number of copper tubes brazed together. They are excited by capacitor discharges (fig. 6), the current being transmitted to the magnets by low inductance strip transmission lines. The H.V. charging supplies can be programmed to charge to different preselected voltages for subsequent pulses by stopping the charging at the relevant moment.

The actuator must smoothly displace the septum magnet SM 24 over typically 100 mm in 300 ms. An electrohydraulic servosystem is therefore used. The actuator is located right outside the vacuum tank (fig. 5) and acts on the magnet in the tank by a shaft through a seal. The actuator follows a programmable electric cycle.

The vacuum boxes will be made out of stainless steel and metal seals will be used where possible. The top cover will have a neoprene gasket but is also compatible with a metal one. To cope with the outgassing of the ejection magnets and to provide short pumpdown times after opening, the tanks are fitted with an adequate number of sputter ion, turbo molecular and mechanical pumps. Section valves at either side of each vacuum tank reduce the pumpdown volume. The seal at the septum magnet SM 24 constitutes a delicate problem.

In addition to this, parts of the accelerator doughnut chamber will be enlarged, bifurcations for the beam exits will be constructed and some boxes for electrostatic pickup stations will be modified.

A synoptic and flexible programming system combined with a number of beam observation stations at relevant points of the trajectory, followed by data processing, display and logging facilities, ensure a comprehensive and coherent operation of the ejection system.

The timing system is based on a number of preset counters counting a pulse train coming from a quartz clock, which may be started by a B-pulse from the accelerator in order to ensure energy stability. A number of special preset units supply pre- or post-pulses, locked to the ejection pulse, and permit to synchronize various auxiliary ejection and accelerator operations as well as experiments.

There will be adequate safety interlocks and complete technical systems checkout facilities.

Presently, prototypes of kicker magnet, septum magnets with their pulse generators and power supplies, actuator and pump station vacuum tanks and pumps are either working or being assembled. Design of the electronic system is well underway and prototype production is progressing. Substantial preparations for installation of the system have already been made.

4. THE PULSED BEAM TRANSPORT SYSTEM A

The proton beam is guided (fig. 2) from the ejection exit window in SS 28 onwards and focused on the external target by means of a small aperture beam transport system[7] of pulsed magnetic deflectors and quadrupole lenses. A pulsed system has been selected as the most economical means for achieving conveniently the required high magnetic field gradients and in order to achieve a compact magnet construction with reduced space, power and cooling requirements. The high current excitation pulses are provided by means of H.V. capacitor discharge circuits located in one of the equipment rooms of the ejection building at a cable distance of 300 m from the magnets.

The trajectory[9] for the selected target position requires theoretically no deflection of the beam after ejection but if necessary small adjustments and corrections of the trajectory can be made in the external beam line by means of three deflectors HD1, HD2, HD3 in the horizontal plane and by two deflectors VD1, VD2 in the vertical plane. Each correction magnet can give a max. deflection of $\pm$ 3 mr at 75 GeV/c.

Focusing is achieved by means of a small horizontally focusing matching lens Q1 in SS 28 and a final focusing stage consisting of a non-symmetrical triplet Q2, Q3, Q4 in front of the target. The beam has an approximately circular cross section of 10 - 15 mm diameter in the first lens Q1. The available aperture must be used to its full limit in the last focusing stage. The situation is particularly critical in Q3 and, depending on the final accelerator beam emittance, some sort of a compromise will be made in practice between the size of the beam envelope in Q3 and the quality of the focusing spot on the external target.

The pulsed magnetic deflectors and quadrupole lenses have laminated magnetic circuits and multi-turn coils of water-cooled copper conductor. A cross-sectional view of a quadrupole lens is shown in fig. 7 and the main parameters are listed in table 2. For manufacturing reasons the lenses of the target focusing stage are divided into modular units of 1.5 m length.

The pulsed magnet current supplies[10)] are of the capacitor discharge type and operate at a voltage of 5 kV max. Thyristors are used as main discharge switches and a separate energy recovery circuit, consisting of a low-loss reactor in series with a solid-state diode across the storage capacitor, permits substantial part of the energy to be restored to the capacitor after each pulse. The d.c. power supplies for recharging the capacitors between the beam bursts are current and voltage stabilized by means of thyristor controllers on the primary side of the H.V. transformer. A fine control stage is provided by means of a bleeding valve in series with a resistor across the output terminals.

A number of beam intensity transformers and other beam observation equipment such as fluorescent screens viewed by television systems are located at relevant points along the beam line. The receivers of these are in the local control room, grouped together with the controls necessary for efficient operation of the channel.

Manufacturing is well under way for the major part of the equipment and following delivery and testing at CERN the system will be installed and brought into operation for experiments with Mirabelle.

Table 1

Main parameters of the fast ejection system A

Working range of the whole system 30 - 75 GeV

	Parameter	symbol	unit	value
KM 16	Aperture	h×w	mm^2	~100×140
	Kick strength	K=B×l	Tm	0.36
	Beam displacement at SM24 at 75 GeV	ΔR_{24}	mm	25
	Max. rise and fall time (3-97 %) incl. jitter	τr	ns	150
	Max. spatial variation of kick	ΔK_r	%	± 3
	Max. time variation of kick	ΔK_t	%	± 3
	Residual kick after pulse	ΔK_o	%	± 10
	Number of repeated shots within 1 accel. cycle	n		3
	Interval between repeated shots	t_n	ms	250
	Pulse length corresponding to a bunch number of			1-30
	Time, number of bunches and excitation level to be discretely adjusted for each pulse			
SM 24	Aperture	h×w	mm^2	~25×45
	Kick strength	K=B×l	Tm	1.0
	Max. spatial variation of the kick	ΔK_r	%	± 0.1
	Max. time variation of the kick	ΔK_t	%	± 0.2
	Number of repeated shots	n		3
	Interval between shots	t_n	ms	250
	Timing + excitation level to be chosen for each shot.			
SM 26	Kick strength	K	Tm	3.6
	All other specifications like for SM 24			
Actuator	Time for moving in or out	T_m	s	0.3
	Precision in working position	Δx	mm	± 0.5
	Number of movements per accel. cycle	n		3
	Starting moment, shape of movement and stroke programmable			
Vacuum	Max. end pressure in ejection tanks	$\bar{P}_{max}$	mm Hg	10^{-5}
	Max. pumpdown time to 10^{-4} (after initial outgassing)	$t_{10^{-4}}$	h	2
Electronics	Ejection energy precision	ΔE	%	±0.15

Table 2

Main parameters of the beam transport system A

General

Proton momentum range	: 30 - 75 GeV/c
Emittance of the external beam, design value	: $\pi \times 10^{-6}$ rad.m.
Required target cross-section	: 1.0 mm × 2.0 mm
Pulse repetition period	: 500 ms (4 pulses at 500 ms intervals during 1.5 s flat top of each PS cycle)
Length of external beam line	: Approx. 65 m

Magnets	Lenses Q1	Q2	Q3	Q4	Deflectors HD1,2,3	VD1, VD2
Magnetic aperture diameter (mm)	30	70	70	70	60	60
Magnetic flux density at 75 GeV/c (T)	1.04	0.51	1.03	1.33	0-2.0	0-2.0
Magnetic field gradient at 75 GeV/c (T/m)	69.3	14.5	29.6	38.0	-	-
Magnetic equivalent length (m)	0.78	1.57	2x1.57	2x1.57	0.46	0.46
Excitation current for B = 1.5 T (kA)	3.35	3.35	3.35	3.35	1.8	1.8
for B = 2.0 T (kA)	-	-	-	-	2.46	2.46
Inductance (mH)	0.23	2.45	2x2.45	2x2.45	2.5	2.5
Resistance (mΩ)	38	134	2x134	2x134	71	71
Cooling water pressure (kp/cm2)	25	25	25	25	25	25
Pulsed current supplies						
Energy stored in capacitors (kJ)	2	5	11	16	7	7
D.C. charging voltage, max. (kV)	5	5	5	5	5	5
D.C. power supply rating (kW)	50	100	2x100	2x100	50	50
Stability (pulse-to-pulse reproductibility)	±0.1°/o	±0.1°/o	±0.1°/o	±0.1°/o	±0.1°/o	±0.1°/o
Pulse duration (ms)	0.7	3.5	4.9	5.7	4	4

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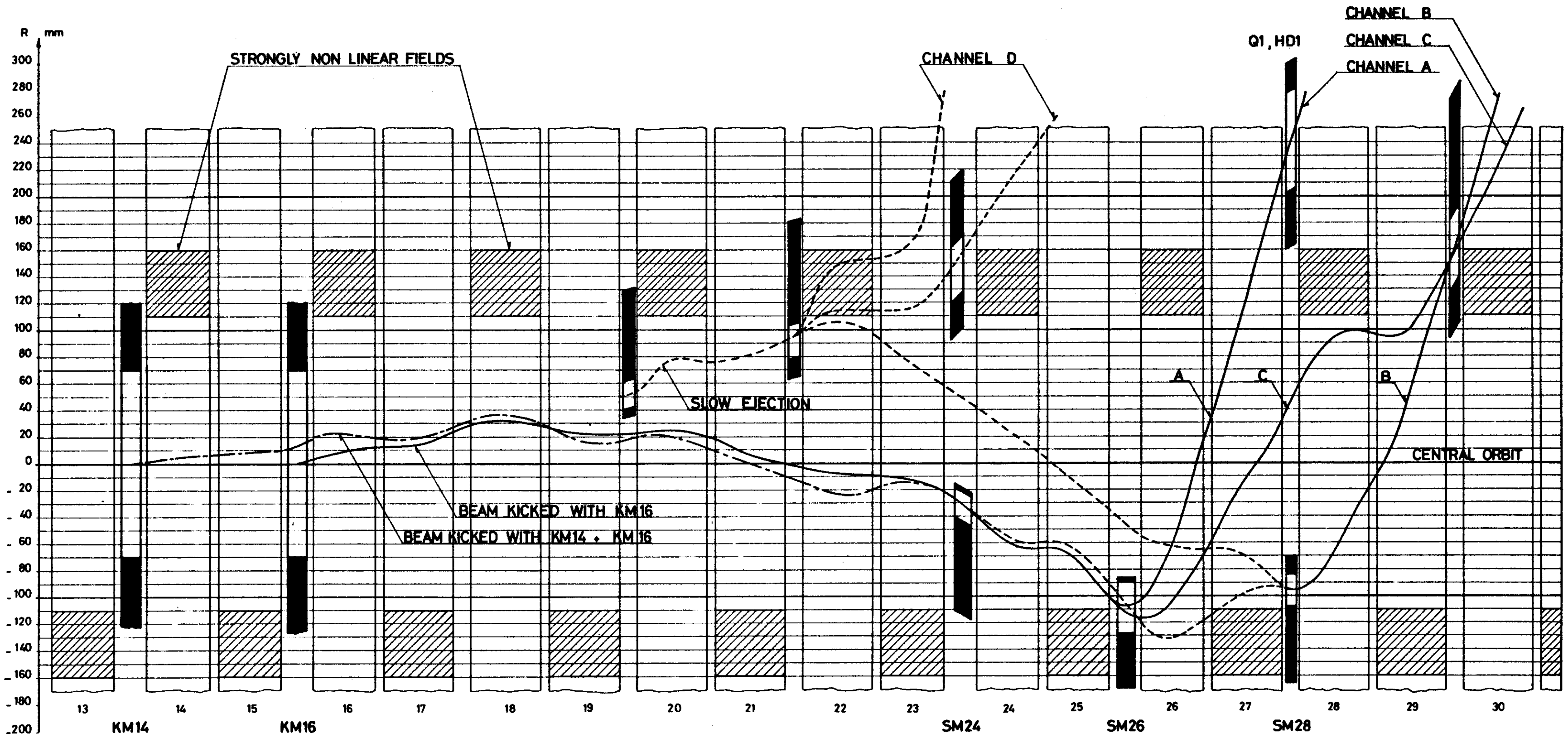

Fig. 1 <u>Layout and trajectories for the fast ejection system</u>

Equipment and trajectories for the slow ejection channel D are also shown. The channels may be served with either, KM14 or KM16, or with both.

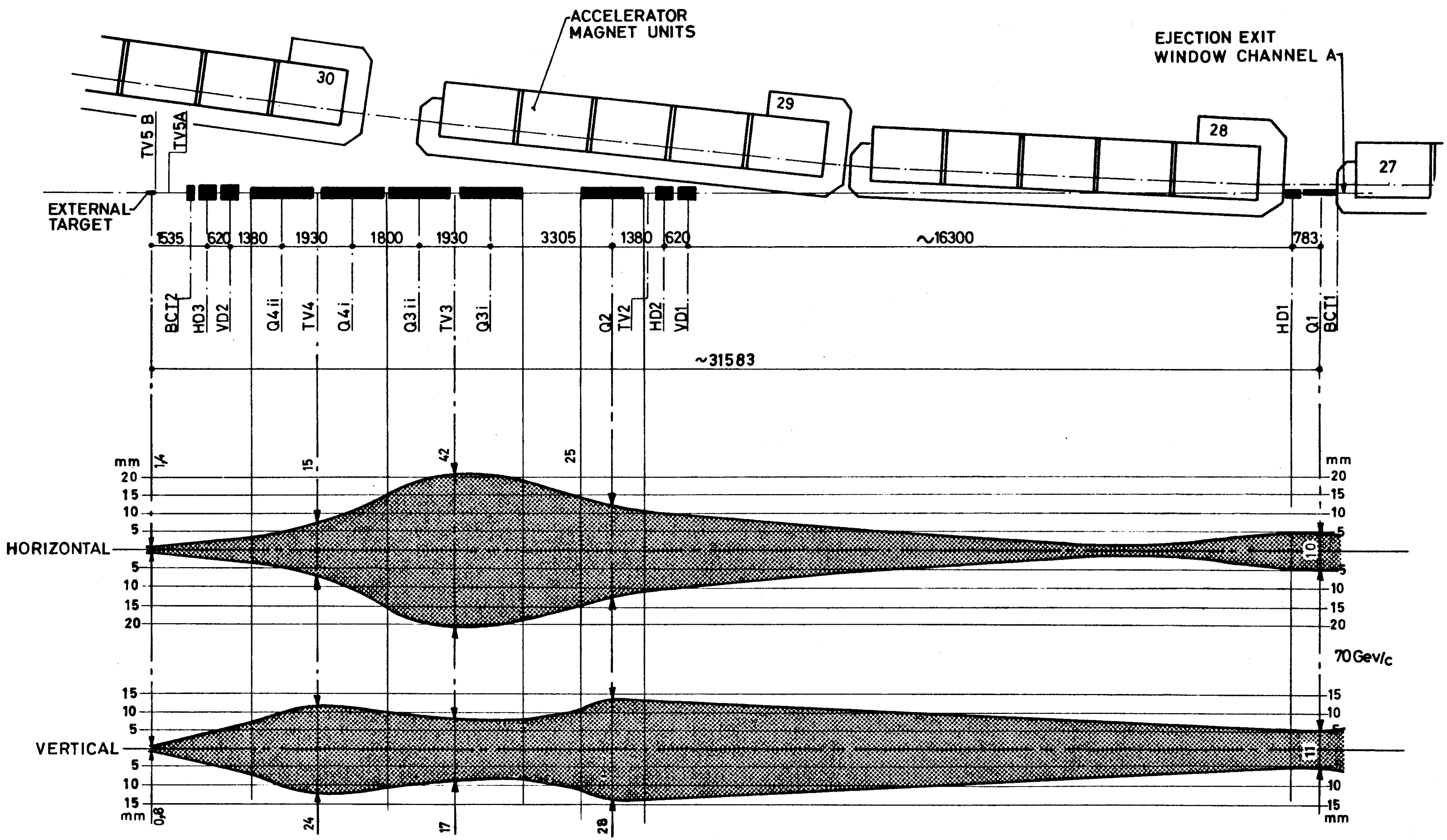

Fig. 2 Layout and beam envelopes of the external proton beam transport system

Q = quadrupole lens; HD = horizontal deflector; VD = vertical deflector; TV = television camera; BCT = beam current transformer; VP = vacuum pump; BS = beam stopper.

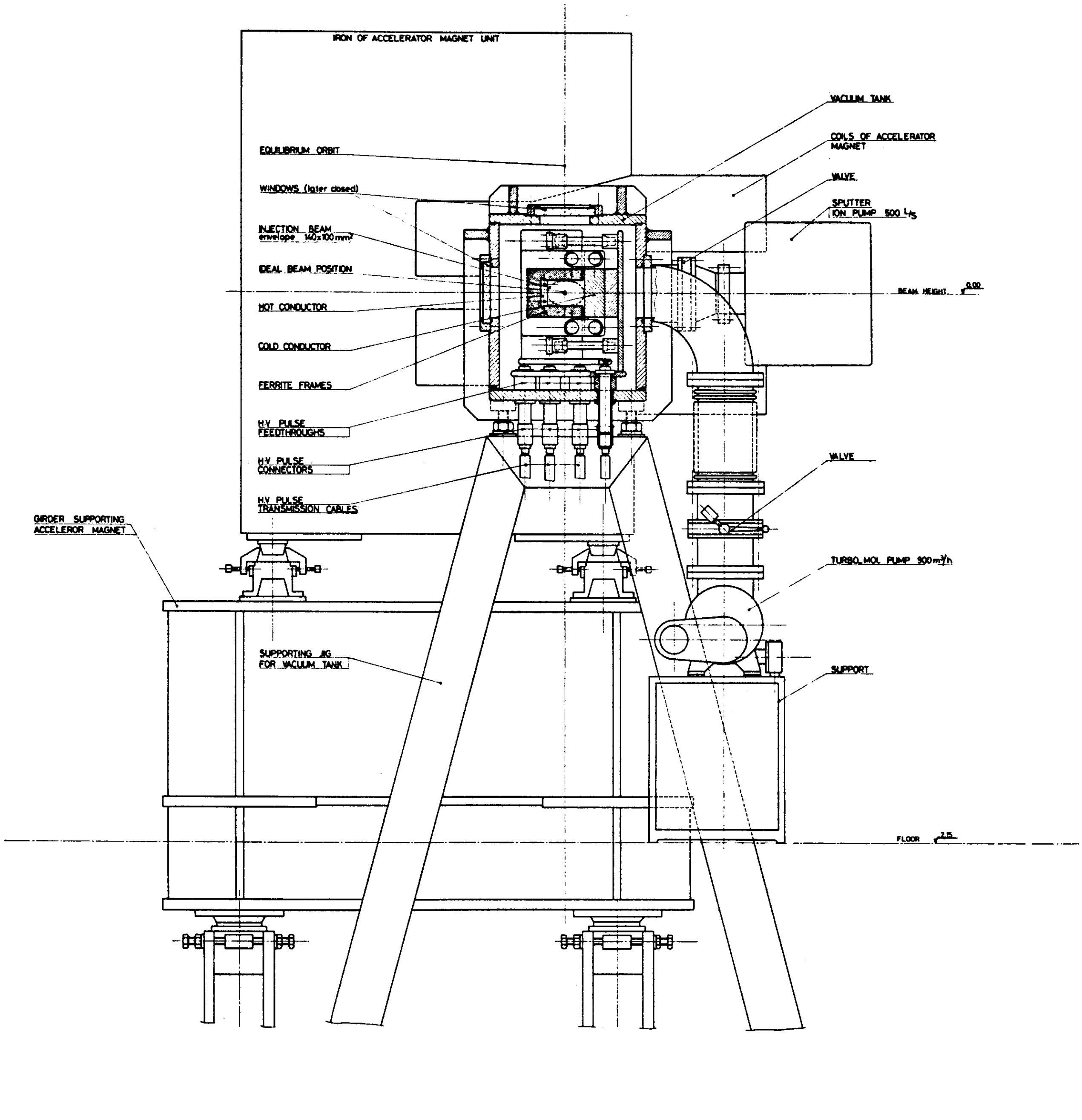

Fig. 3 Artists impression of KM 16 in vacuum tank
Sectional view.

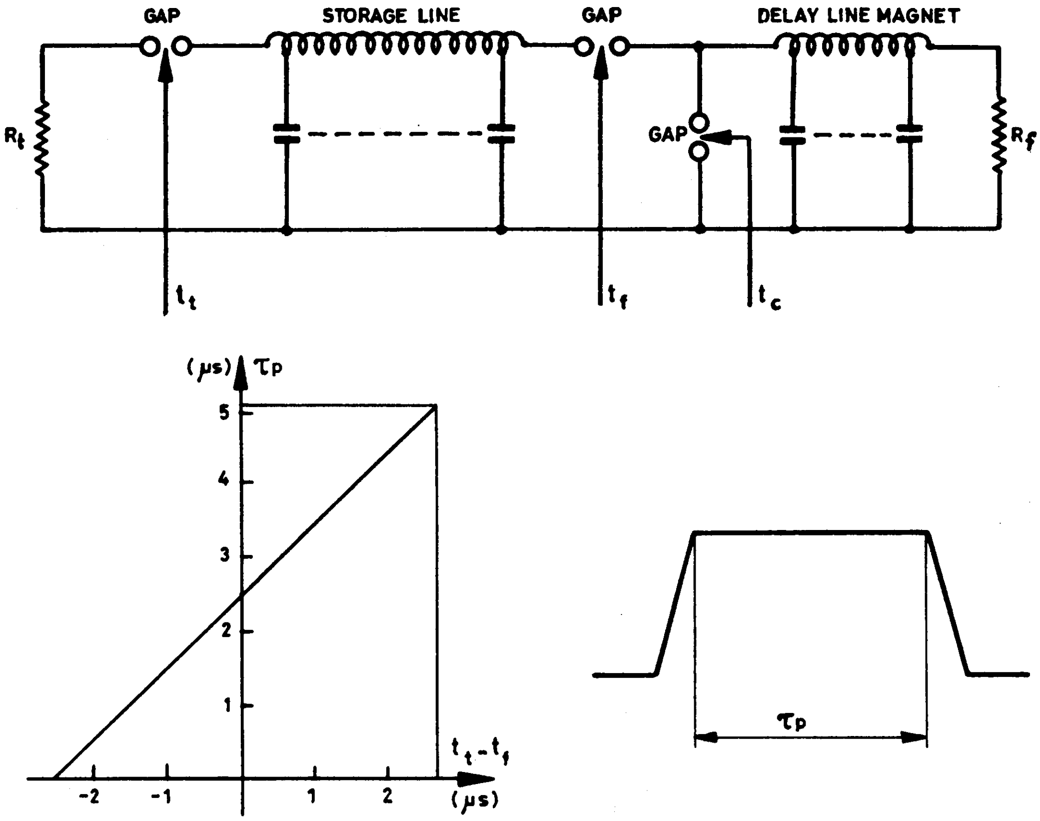

Fig. 4 Principle of delay line pulse generator for variable pulse length

By relevant timing, t_f, t_t, t_c of the three gaps the pulse is divided between the magnet branch and the dumping resistor Rt, resulting in a variable magnetic pulse length τ_p in the kicker magnet. The gap triggered at t_c clips the tail of the pulse and gives a short fall time.

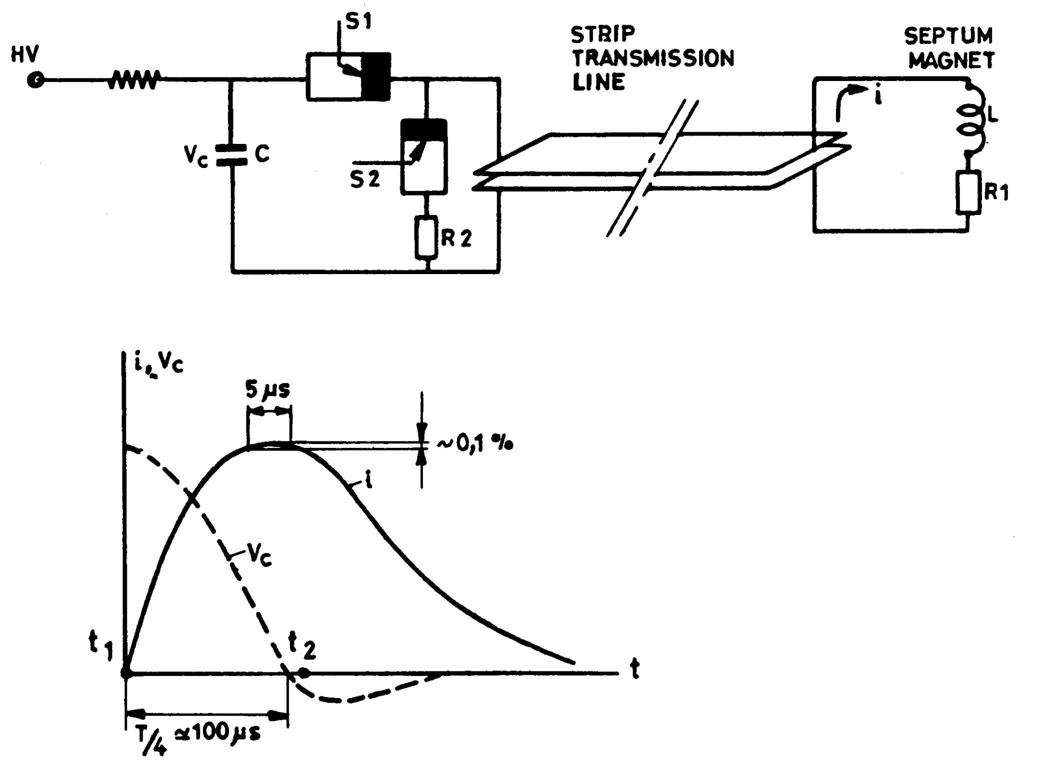

Fig. 6 Principle of the septum magnet pulse generator

Main switch S_1 and crowbar switch S_2 are closed at times t_1 and t_2 resulting in a single damped current surge i. The top of the pulse is flat to better than $0.1^{o}/o$ during the 5 μs of the kicker magnet pulse.

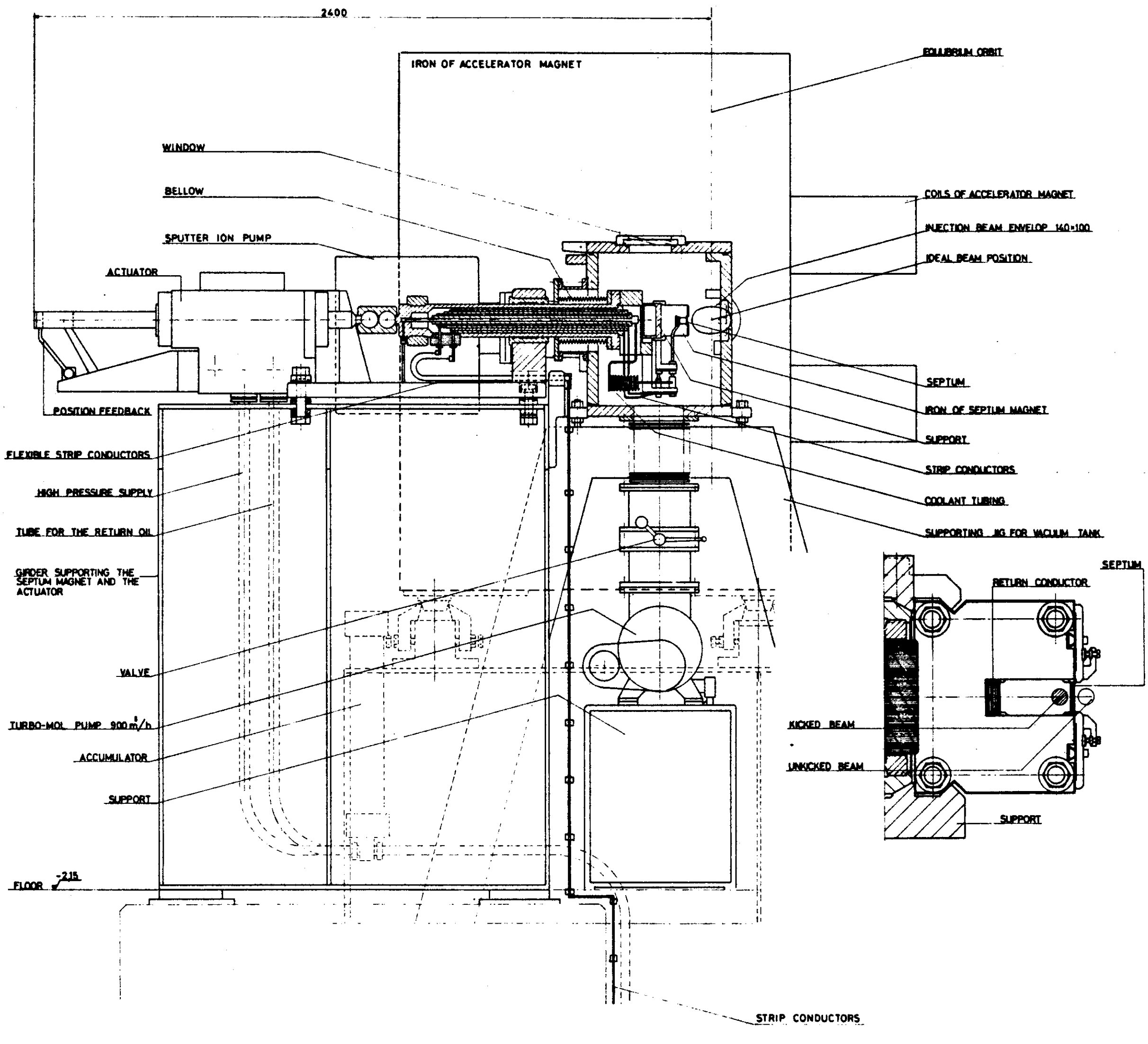

Fig. 5 Artists impression of mobile SM 24 in vacuum tank

Main figure is a sectional view of magnet with tank and actuator.
Insert is a sectional view of magnet proper.

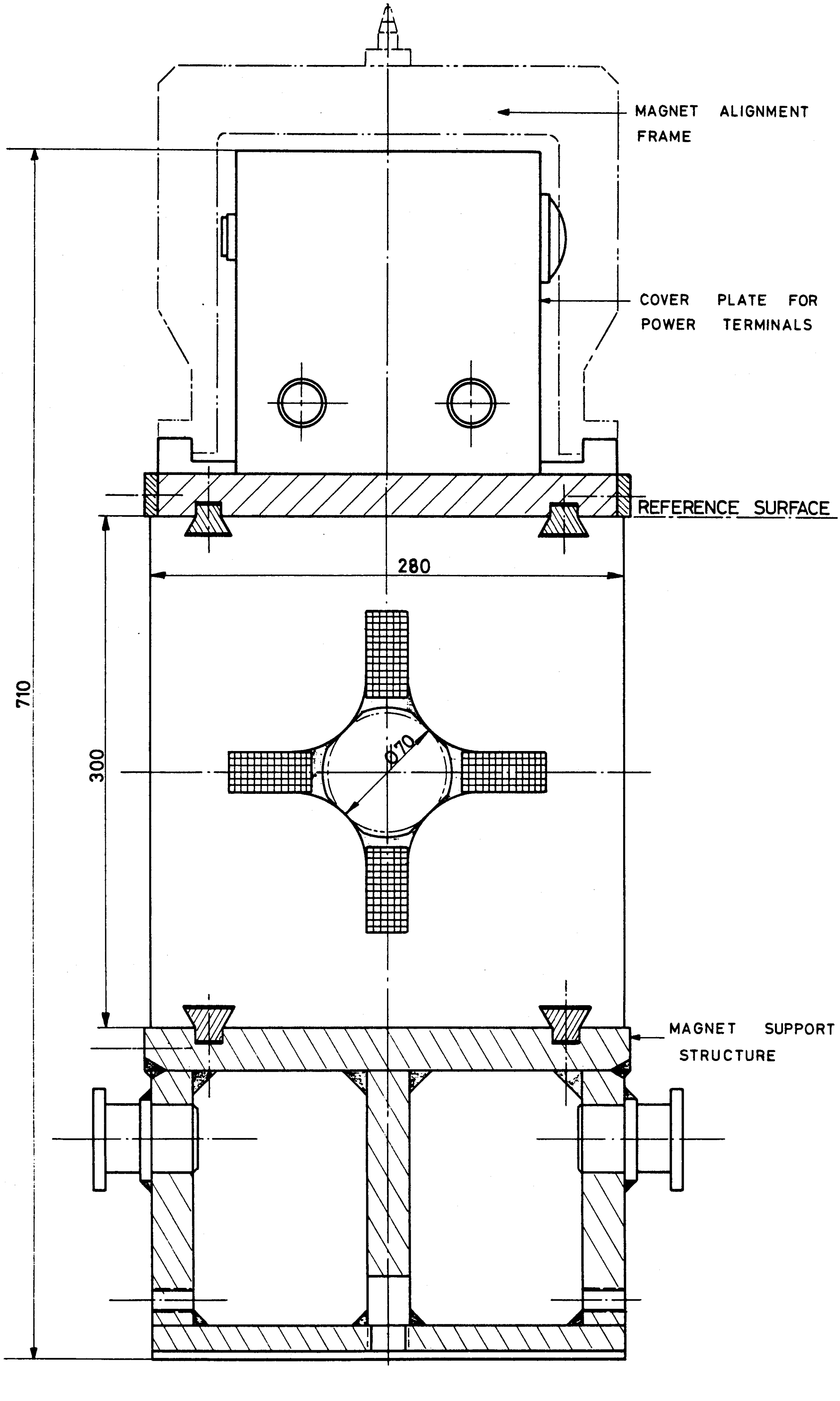

Fig. 7 Sectional view of a pulsed quadrupole lens of the proton beam transport system