INSTITUTE OF NUCLEAR PHYSICS OF THE SIBERIAN DIVISION
OF THE ACADEMY OF SCIENCES OF THE SOVIET UNION

PROGRESS REPORT CONCERNING WORK AT THE 3.5 GeV INSTALLATION FOR COLLIDING ELECTRON-POSITRON BEAMS (VEPP-3)

G.I. Budker, I.Ya. Protopopov and A.N. Skrinskij

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Magnetic system of the storage device: N.A. Kuznetsov, B.V. Levichev and Yu. A. Pupkov; vacuum system: G.A. Blinov and M.D. Malev; RF system: M.M. Karliner, V.M. Petrov, I.K. Sedlyarov and I.A. Shekhtman; control and measurement systems: M.M. Karliner, A.S. Medvedko and V.P. Prikhod'ko; tests on the storage device, using protons: S.G. Popov and B.N. Sukhina; electron-optical channel and conversion: T.A. Vsevolozhkaya, L.L. Danilov, V.N. Pakin, A.P. Panov, G.I. Sil'vestrov and E.M. Trakhterberg; injection and ejection system: B.I. Grinshanov and A.V. Kiselev; injector: M.Yu. Gel'tsel', G.B. Glagolev, A.A. Livshits, E.P. Mel'nikov, V.I. Nifontov, G.N. Ostrejko, V.V. Petrov and G.I. Yasnov.

Development work on the project for a 3.5 GeV installation with colliding electron-positron beams (VEPP-3) commenced in 1966[1].

Construction work on the machine began in 1967[2].

The installation consists of a storage ring, a 500 MeV synchrotron-injector (B-4), electron-optical channels, and a system for converting electrons into positrons.

An over-all layout of the installation is shown in Fig. 1.

The installation is housed underground in a shielded tunnel. The two semicircular parts of the storage ring are housed in tunnels, 2.5 m × 3 m, with a radius of about 8 m. A large hall, of area 9 × 25 m^2 and 6 m high, with a removable overhead shielding, encloses the two straight sections and the centre of the oval.

The injector is situated in the central area of this hall, the area being separated from the storage ring by lead walls.

To accommodate detecting devices, a 2 m pit has been sunk into the floor, at one of the straight sections.

The magnets of the storage ring are suspended from the ceiling of the tunnel, and the beam height is 2.3 m above floor level. The control desk, the RF generators, and the power supplies for both storage ring and injector, are located in a hall at a level above the installation (Figs. 2 and 3).

The storage ring is a strong-focusing system, consisting of two half-rings with a radius of 802 cm separated by two straight sections 1200 cm long. Each half-ring consists of eight magnet units spaced at 18 cm intervals, and each magnet unit consists of four sections, focusing, bending, defocusing, and again bending.

The characteristics of the various sections are shown in the table of parameters.

The magnetic-field intensities of the sections are different; this has been done to achieve radiation damping of the radial betatron oscillations.

As for the design of the magnet, it consists of two halves separated along the median plane, each half with a one-turn winding, of a cross-section of 25 cm^2, on each side of the gap. A cross-section of the magnetic circuit with the winding is shown in Fig. 4, for each of the various sections of a magnet unit.

Each coil is connected to the corresponding coil of the next magnet by a coupling unit made of flexible cable of large cross-section.

The magnet poles were machined on a planing machine. The focusing and de-focusing sections were machined by a wide profile-cutter.

The photograph (Fig. 5) shows one half of a magnet unit during assembly.

The two long straight sections each contain four sets of quadrupole doublets. The maximum free space between the lenses at the centre of both straight sections is 2.7 m, and is intended for experimental use.

One of the straight sections contains the RF cavities, the injection systems, and the beam-control system.

Figure 6 shows a picture of a straight section with the lenses in position.

The frequencies of the betatron oscillations of the storage ring are horizontal: 5.2; vertical: 5.1. Additional windings located in the magnet coils can be used to shift the operating point by ±0.5 at full field.

Correction windings located in the magnets and lenses enable independent correction, in each element, of the position of the median plane, the field, the gradient, and square and cubic non-linear terms.

Each magnet of the storage ring is suspended from the ceiling by three adjustable brackets, and is attached to the inside wall of the tunnel by two adjustable supports (Figs. 7 and 8).

To enable precise positioning of the magnets in the horizontal plane, a system of geodetic reference points has been incorporated in the ceiling with an accuracy of 0.1 mm.

Each magnet bears two horizontal and three vertical marks, which are used to position it in relation to the geodetic reference system.

The lenses in the straight section are suspended by arms fixed to the walls of the tunnel and hall.

The vacuum chamber in the magnets is made of sections of stainless steel tubing; it is 1 mm thick and has a cross-section 80 mm wide, 29 mm high.

Between the magnets are stainless steel boxes, welded to the chambers through sylphon bellows.

Inside the chamber, at its outer side, radially, is a radiation absorber, a water-cooled gold-plated copper tube. The shape of this radiation absorber matches that of the chamber and it has a radial width of 7 mm. This absorber can remove 0.5 MV of synchrotron radiation.

Along the inner radius, inside the chamber, there is a distributed magnetic-discharge pump, which uses the main magnetic field of the storage ring. This distributed pump has a pumping speed of 1.5 l/sec per cm of length, up to a pressure of 10^{-10} Torr and a magnetic field intensity of 10 kOe. Water-cooled tubes protect the pump's electrode system from being heated by reflected synchrotron radiation. The over-all radial width of the pump is 15 mm.

A cross-section of the vacuum chamber is shown in Fig. 9.

The water outlets and supplies for the magnetic discharge pump are housed in the boxes between the magnets. These boxes also contain pick-up electrodes for measuring the position of the beam and the current.

Welded to these boxes are the main magnetic discharge pumps with a pumping speed of 100 l/sec.

After manufacture, each section of vacuum chamber, consisting of the tube and the box welded to it, was evacuated, outgassed for 30 hours at 400°C then installed in a magnet unit. When the magnet unit was installed in the tunnel, the vacuum section was opened up just prior to being welded to the next section and was then immediately outgassed a second time. The pressure obtained in two such sections, after welding, was 2×10^{-9} Torr after 24 hours of pumping.

The anticipated effective pressure in the whole storage ring, with a circulating current of 0.5 A and at maximum energy, is 5×10^{-9} Torr, giving a beam life of more than 4 hours.

The high-frequency system operates on the 19th harmonic of the revolution frequency ($f \simeq 75$ MHz). At the present time a cavity similar to that of the VEPP-2 has been made, which will allow the voltage to be increased to 600 kV with the existing 150 kW generator. This will give an energy of 2 GeV. By adding an amplification stage (up to 1 MW) and replacing the cavity, a maximum energy of 3.5 GeV will be possible.

Furthermore, there is an additional low-power high-frequency system, operating on the first harmonic of the revolution frequency. This system serves to bunch the positrons after they have been accumulated.

The B-4 synchrotron, which is an up-to-date version of the B-3M synchrotron[3)], provides the particles for injection into the storage ring.

There have been improvements in construction and design and the electrons reach an energy of 500 MeV in this machine that has an equilibrium orbit of 100 cm radius. Its pre-injector is an ELIT pulsed accelerator, capable of supplying up to 3 MeV, with a current of 3 A in a pulse lasting 1 msec[4)].

To overcome coherent effects during injection, spiral electron storage was introduced, with subsequent betatron acceleration up to 10 MeV.

These changes should increase by several times the accelerated current in relation to synchrotron B-3M. (The accelerated current of the B-3M is 1 A.)

Further synchrotron acceleration is achieved on the second harmonic of the revolution frequency. Single-revolution ejection is effected vertically with preliminary deflection of the beam to the ejection magnet. The ejection magnet has a septum 2 mm thick, and with a field of up to 35 kG, deflects the beam 23° in a vertical plane. Figures 10 and 11 are pictures of the B-4 during and after assembly.

Transportation of the electrons (Fig. 1) for injection into the storage ring is by means of two quadrupole doublets and a magnet with a 90° bending angle. The magnet is so designed that the energy dispersion inside it does not hinder capture of electrons with an energy spread of up to ±0.5%.

The conversion of electrons into positrons takes place in an external tungsten target. To achieve focusing on to the converter, the electron beam is moved in a horizontal plane into a parallel position 3 m away by means of two magnets with a 63° bending angle. Two quadrupole triplets between the magnets enable this movement to be achieved achromatically.

The second magnet, which has a radius of 12.5 cm, focuses the electron beam on to the converter. The positrons are collected from the converter by a magnet with a 7.5 cm radius and 45° bending angle. Both magnets of the conversion system are iron-free single-coil systems with $n = 0.5$ and fields of up to 130 kG.

The positrons are focused, after conversion, for their injection into the storage ring by means of a quadrupole triplet and a magnet with a 45° bending angle. In the radial plane of the storage ring, the energy correlation of the particles corresponds with the values of the ψ function of the storage ring and its derivative at the point of injection; this means that particles of all energies are admitted without the excitation of additional betatron oscillations.

The particles are injected into the storage ring (Figs. 12 and 13) vertically, near the maximum of Floquet's vertical function.

The septa of the injection magnets are 2 mm thick.

To avoid a large build-up in amplitude of the stored beam during single-revolution injection, impulse deflecting plates are located at a quarter of a betatron wavelength from the point of injection; these bring the stored beam to the knife-edge of the injection magnet and an inflector returns the beam to the equilibrium orbit simultaneously with the injected beam. The vertical acceptance is 8.5 mrad-cm for an amplitude of the residual oscillations of the main beam less than one-third of the chamber's dimension. The energy spread captured is ±2%.

Storage of the positrons will be achieved with the subsequent filling of the buckets of the 19th harmonic of the revolution frequency, which enables a large number of injection cycles to be effected during the attenuation time. The planned storage rate is 5×10^8 positrons per second (0.5 mA/sec).

When the required current has been stored, the positron beam is moved into a single bucket by means of an additional cavity operating on the first harmonic of the revolution frequency.

The electrons are injected at the maximum energy of the injector. They are stacked in one of the buckets so that collisions occur in the interaction regions.

To reduce the effects of collisions during storage of the electrons, the electron and positron orbits are separated by special high-voltage plates situated in the long straight sections and the frequencies of the betatron oscillations are shifted apart. When the electrons have been stored, the energy of the ring is set at the value required for the experiment on hand and the beams are brought together.

The anticipated luminosity, at the collision point at maximum energy, is 10^{35} cm^{-2} d^{-1}, which would give tens of pairs of mu-mesons per 24 hours in the detectors.

Consideration is being given to the possible replacement of the vacuum sections at the collision regions by special sections to reach a vacuum of over 10^{-11} Torr.

Work is in progress on an alternative system of focusing in the long straight sections to give a substantially decreased beam cross-section at the interaction point.

At the present time the principal systems of the installation have been produced, installed in position and tuned. The storage ring was tested with a circulating beam of protons at an energy of 1.5 MeV. Work has started on the injection of electrons into the B-4 injector-synchrotron.

* * *

Note

The List of References has not been received at CERN.

<u>Table of the basic parameters of the storage ring</u>

Maximum energy		3.5 GeV
Radius of the half-rings		802 cm
Length of each straight section		1200 cm
Betatron oscillations per revolution:		
	radial	5.28
	vertical	5.11
Magnet structure $(FMDMO)^8$ (I) $(FMDMO)^8$ (I)		
Orbit density coefficient		0.065
Mechanical structure of magnet units:		
focusing section:		
	length	48 cm
	field	6.9 kG
distance to asymptote		3.5 cm
bending section:		
	length	105 cm
	field	18.9 kG
defocusing section:		
	length	52 cm
	field	11.8 kG
distance to asymptote		6.2 cm
bending section		
	length	*)
	field	18.9 kG
Field-free distance between magnets		15 cm
External dimensions of vacuum chamber		8×2.9 cm^2
Useful aperture		5.5×2.7 cm^2
RF power first stage		150 kW
second stage		1 MW
Harmonic		19th
Number of cavities		1

*) Figure missing in copy received at CERN.

Table of the basic parameters of the storage ring (cont.)

Energy loss per revolution	2 MeV
Bunch length (approximate)	30 cm
Radial dimension of beam	0.8 cm
Magnet supply power	1.7 MW
Magnet current (max.)	25 kA
Weight of iron	50 tons
Weight of copper	4 tons
Positron injection energy	250 MeV
Electron injection energy	500 MeV

Figure captions

Fig. 1 : General layout of the VEPP-3 installation.

Fig. 2 : Control desk. *)

Fig. 3 : Power supply system.

Fig. 4 : Magnet cross-sections. I: radial-focusing section;
II: bending section;
III: defocusing section.

Fig. 5 : One half of a magnet unit.

Fig. 6 : Straight section in the storage ring.

Fig. 7 : Magnet suspension system. *)

Fig. 8 : Magnet units installed in the tunnel (the geodesic reference marks can be seen).

Fig. 9 : Cross-section of the vacuum chamber.

Fig. 10 : B-4 during assembly.

Fig. 11 : General view of the injector (ELIT-3 and B-4). *)

Fig. 12 : Diagram of electron and positron entry into the storage ring. *)

Fig. 13 : Point of entry into the storage ring. *)

*) Figures not received at CERN.

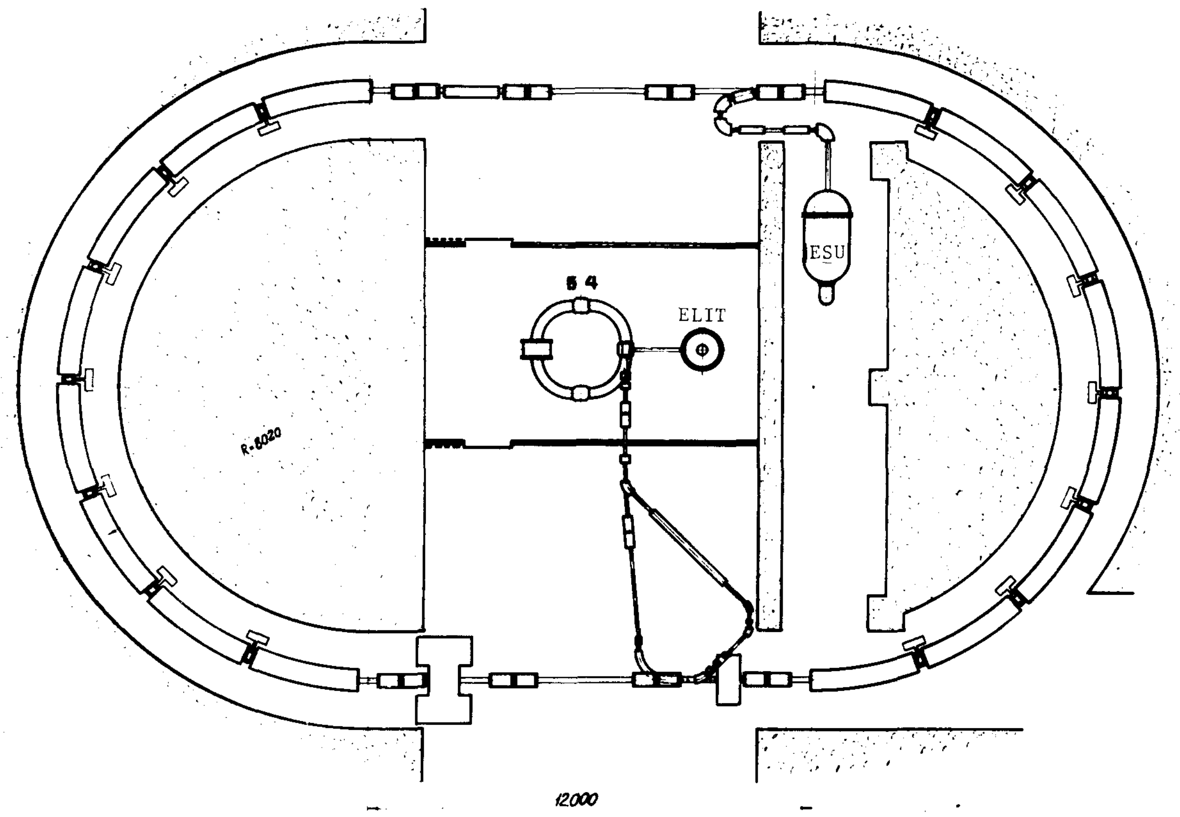

Fig. 1

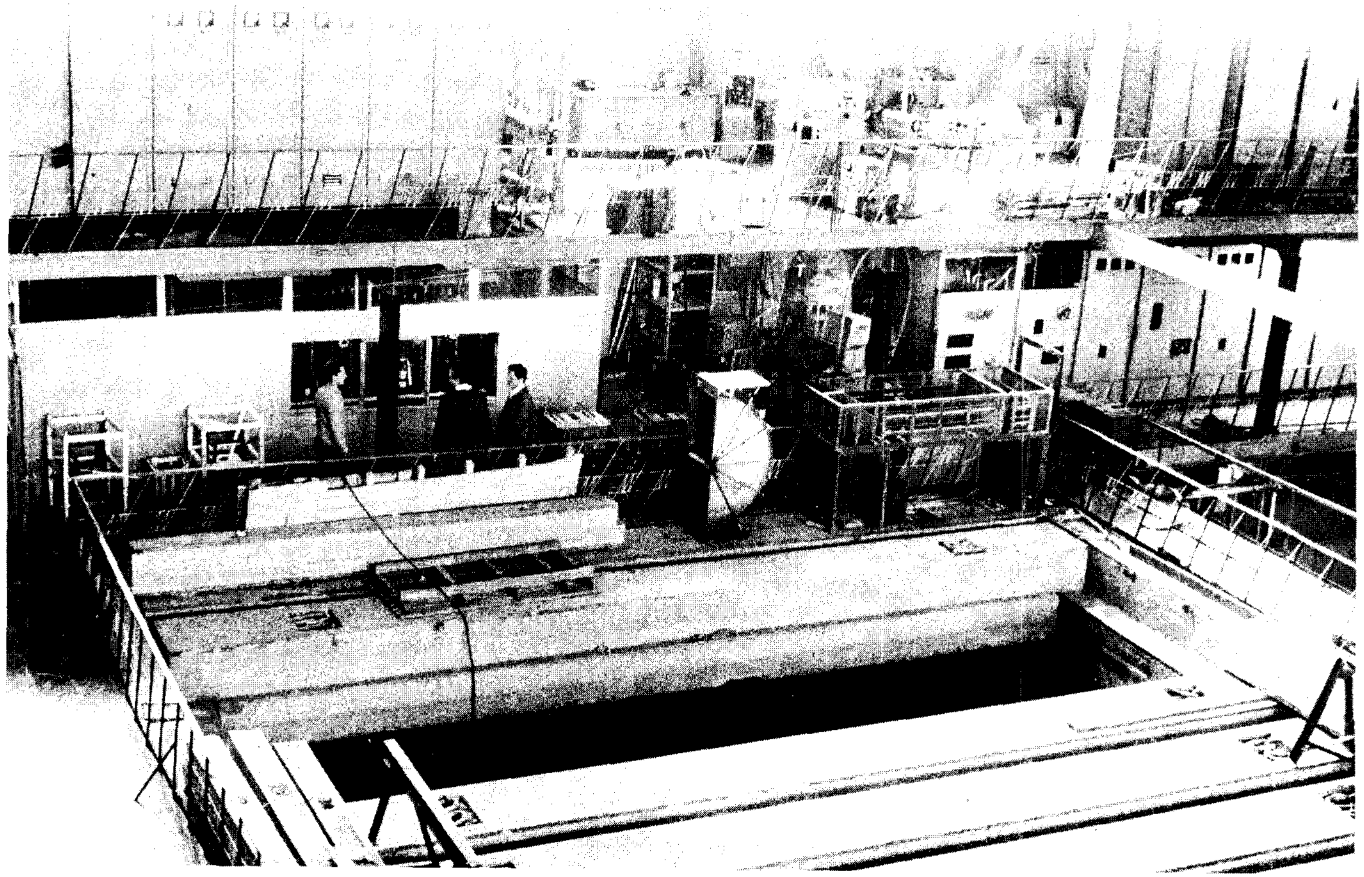

Fig. 3

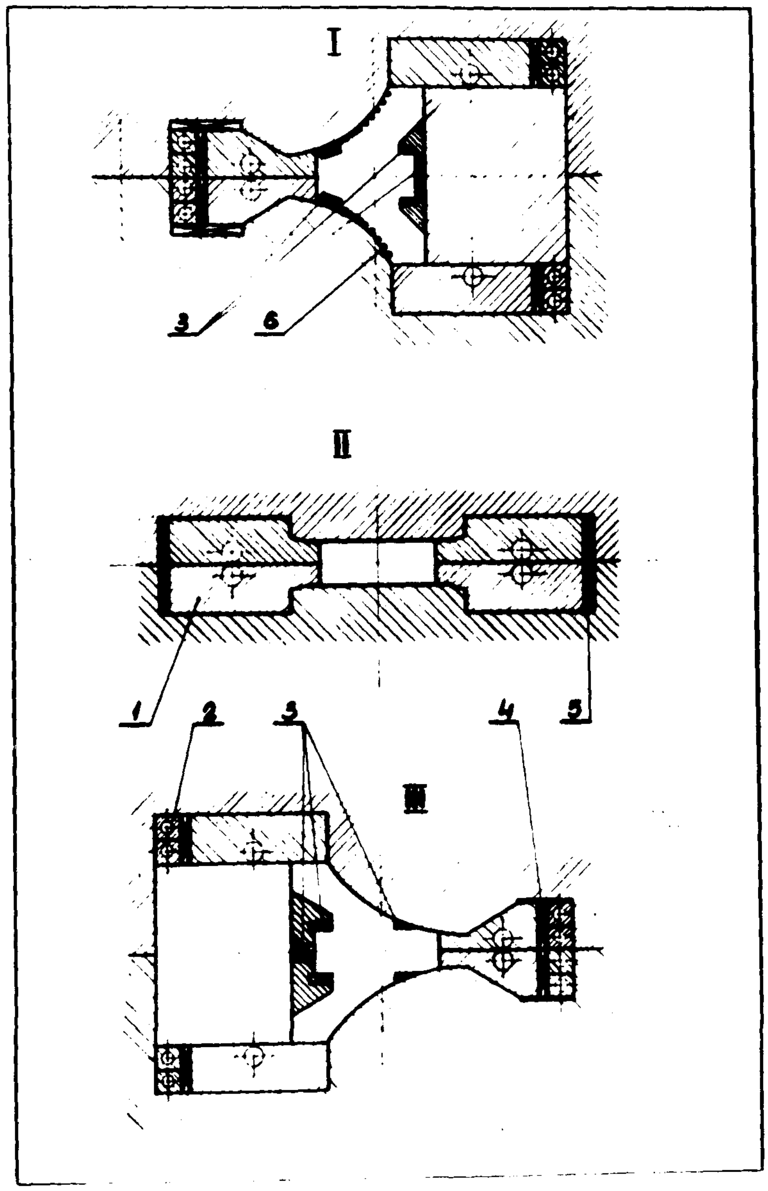

Fig. 4

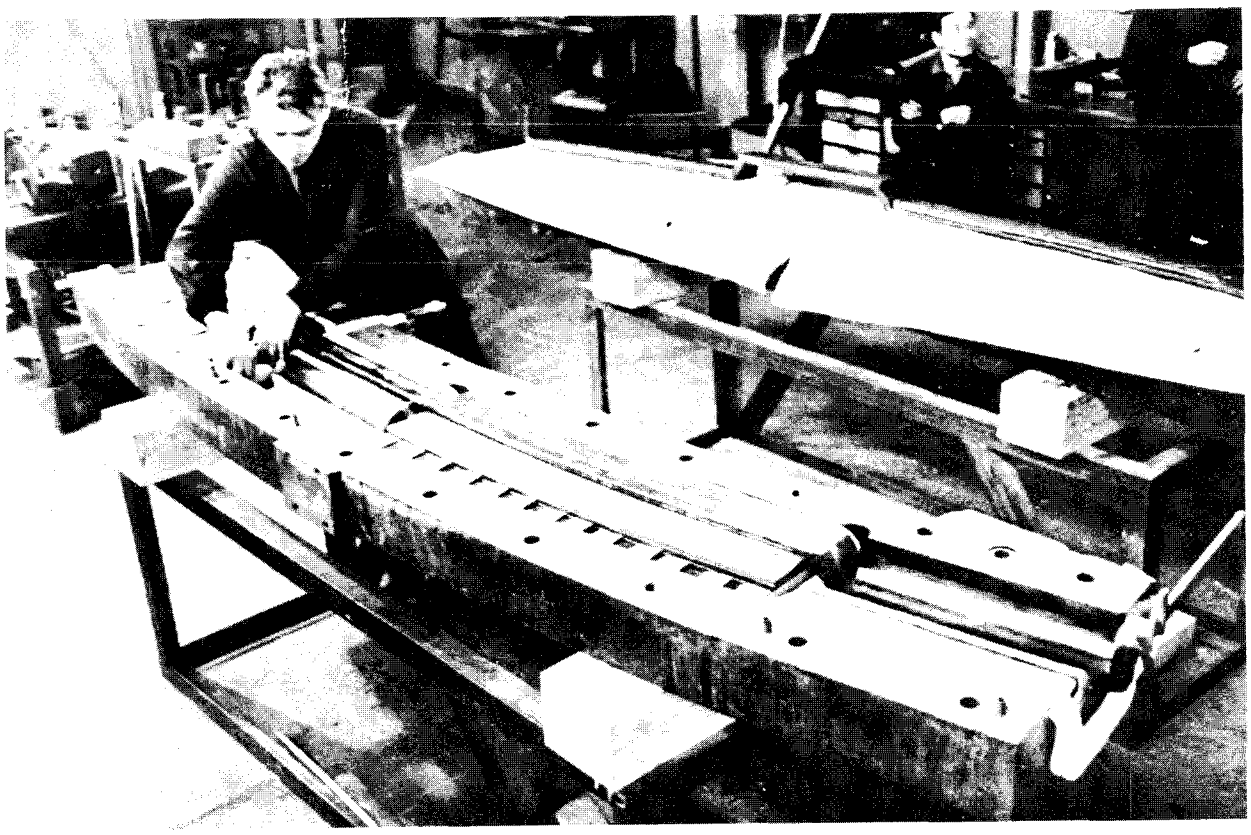

Fig. 5

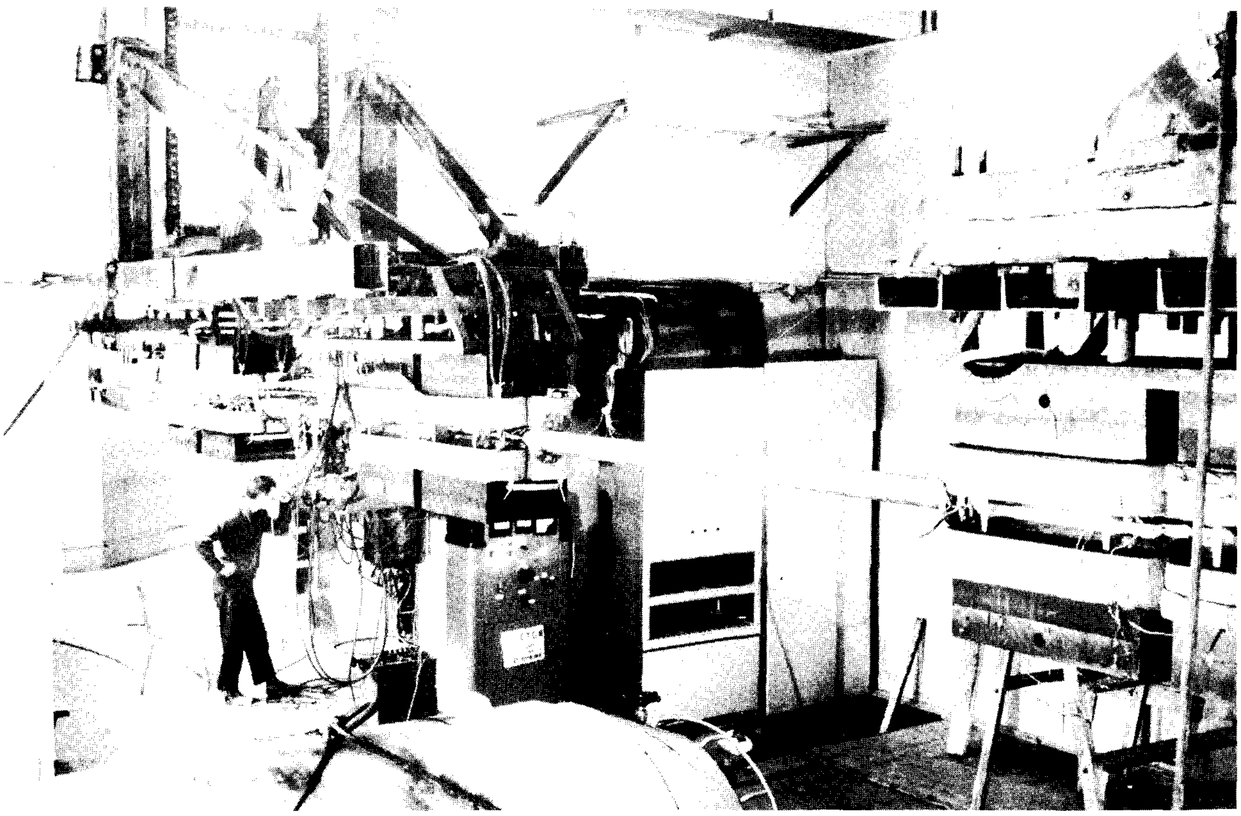

Fig. 6

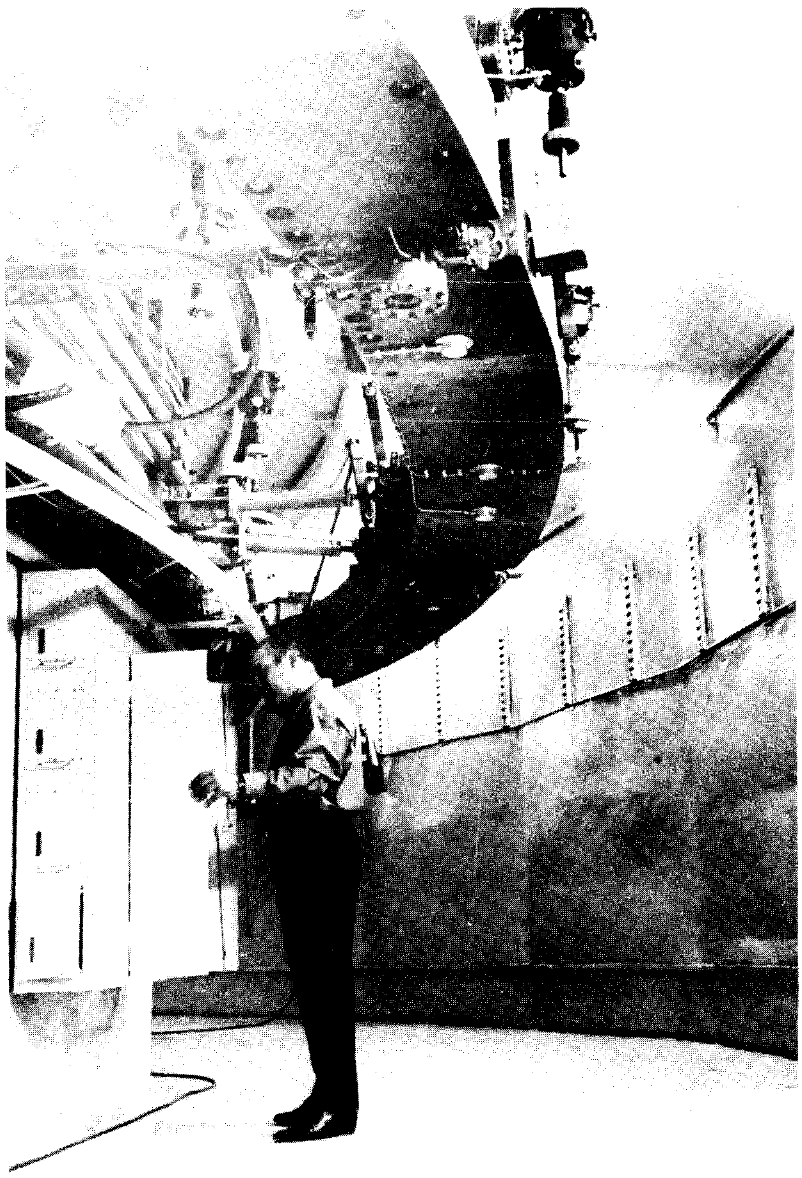

Fig. 8

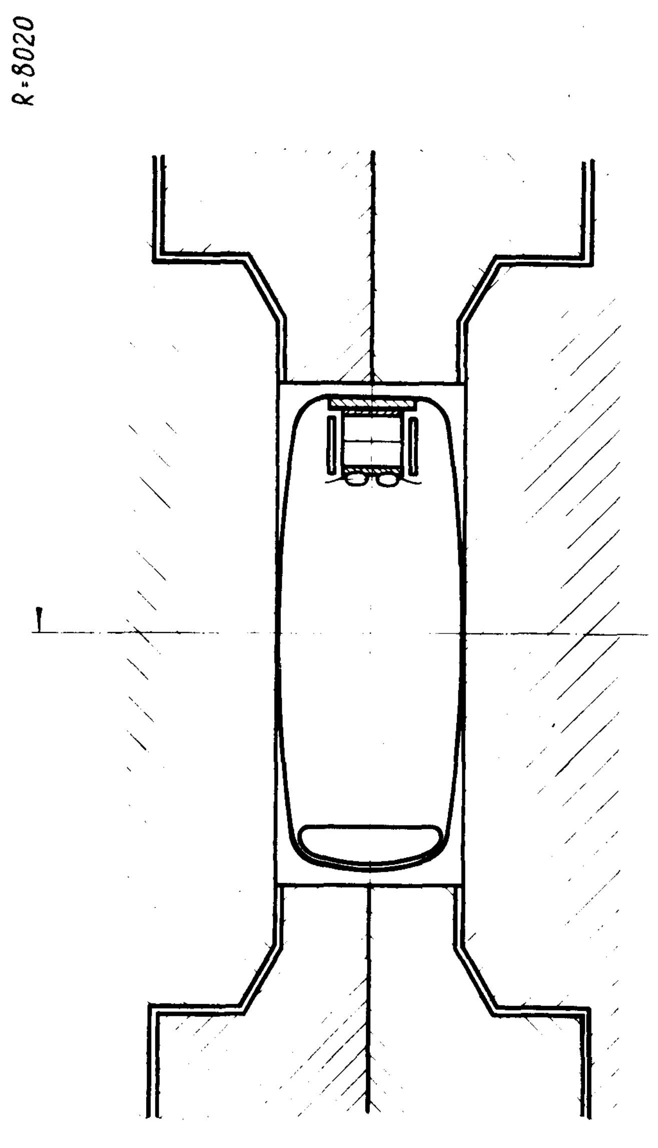

Fig. 9

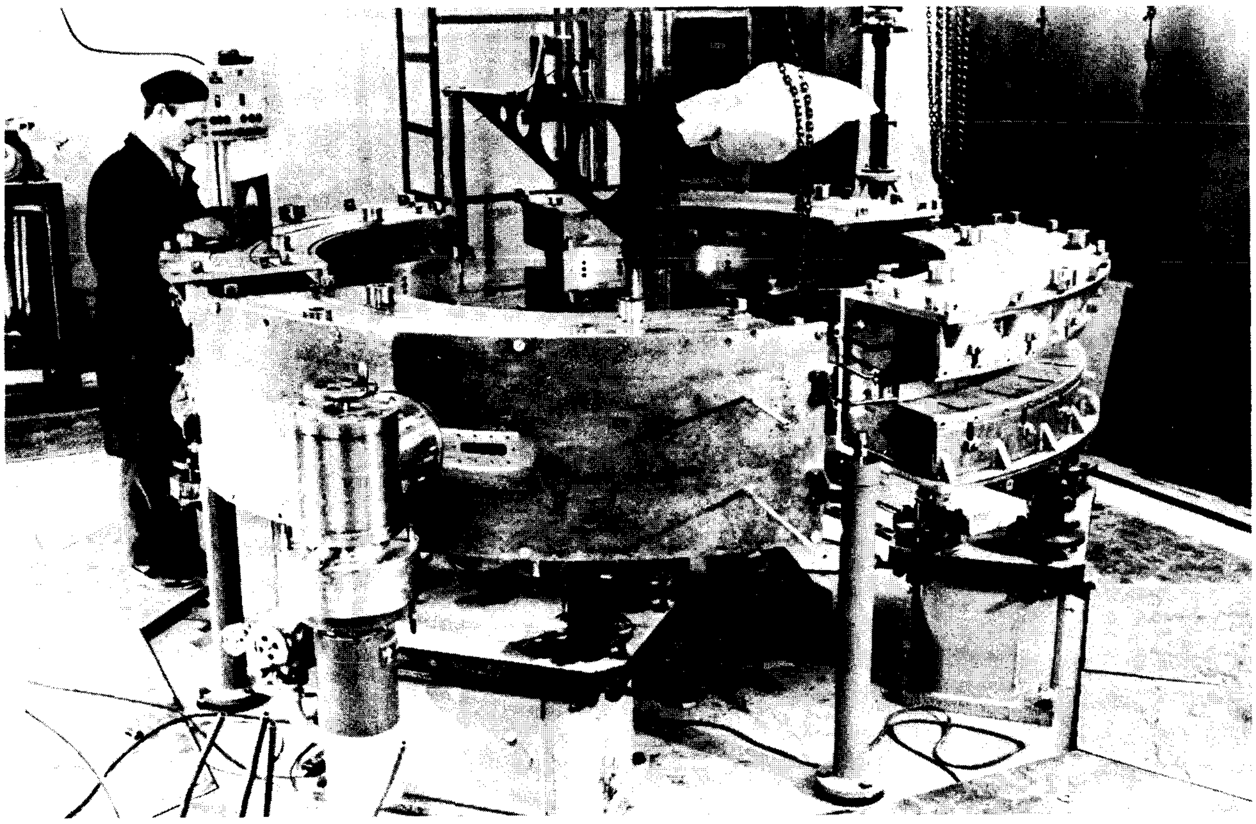

Fig. 10