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PROGRESS REPORT ON THE 3.5 BeV ELECTRON-POSITRON COLLIDING-BEAM INSTALLATION (VEPP-3)

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by

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

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The figures alluded to in the text were not available.

TRANSLATED FOR

STANFORD LINEAR ACCELERATOR CENTER

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

Magnetic system of the storage ring: N.A. Kuznetsov, B.V. Levichev and Yu.A. Pupkov.

Vacuum system: G.A. Blinov and M.D. Malev.

High-frequency 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.

Proton run on storage ring: S.G. Popov and B.N. Sukhina

Electron-optical channel and conversion: T.A.Vsevolozhskaya, L.L. Danilov, V.N. Pakin, A.P. Panov, G.I. Sil'vestrov, and E.M. Trakhterberg.

Injection-extraction system: B.I.Grishanov and A.V. Kiselev

Injector: M.Yu. Gel'tsel', G.B. Glagolev, A.A. Livshits, E.P.Mel'nikov, V.I. Nifontov, G.N.Ostreiko, V.V. Petrov, and G.I. Yasnov.

Development of the project on building a 3.5 BeV electron-positron colliding beam installation VEPP-3 was started in 1966[1].

The building operations began in 1967[2].

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

A general view of the installation is shown in Figure 1.

The installation is located in a shielded underground enclosure. The storage half-rings lie in a 2.5 x 3 m^2 tunnel having a radius of about 8 m. The straight section passes through a room of 9 x 25 m^2 and a height of $\sim$6 m. The room is provided with a demountable shielding roof.

The injector is located at the central part of this room, separated by lead walls from the storage ring.

The detection equipment is placed in a well having a depth of 2 m and located in one of the straight sections.

The storage-ring magnets are suspended from the ceiling of the tunnel, and the beam axis lies at a height of 2.3 m above the floor. The control panels, the high-frequency generators, and the electrical supplies for the storage ring and injector are located in a room above the installation (Figures 2 and 3).

The storage ring is a strongly-focusing system consisting of two half-rings 802 cm in radius and separated by two straight sections 1200 cm long. Each half-ring consists of eight magnets separated by 18 cm gaps. These magnets are the periodicity elements of the focusing structure. Each of them consists of four segments; focusing, bending, defocusing, and bending.

The parameters of the various segments are shown in the Table.

Different magnet segments produce different field strengths. This ensures radiative damping of radial betatron oscillations.

As regards the construction, the magnet consists of two halves separated along the median plane. Two coil rails (25 cm^2 in cross section) are located in each half. The cross sections of the magnet and coil in different parts of the magnet are shown in Figure 4.

Each rail is joined to the corresponding rail in the next magnet through a decoupler consisting of a flexible conductor of large cross section.

The pole faces were finished on a planing machine. The focusing and defocusing segments were finished with a wide profiled cutter.

A photograph of one half of the magnet during assembly is shown in Figure 5.

The two long straight sections contain four pairs each of quadrupole lenses joined by doublets. The maximum distance between the quadrupole lenses in both gaps is 2.7 m. This space is provided for carrying out experiments.

The resonators, the injection systems, and the beam-control systems are placed in one of the gaps.

A photograph of a straight section with the lenses in position is shown in Figure 6.

The frequencies of betatron oscillations in the storage ring are 5.2 and 5.1 in the horizontal and vertical planes respectively. Additional coils placed in the magnets can be used to displace the working point by ±0.5 at full energy.

Correcting coils located in the magnets and lenses can be used to adjust independently in each element the position of the median plane, the field, the field gradients, and the quadratic and cubic nonlinearities.

Each storage-ring magnet is suspended from the ceiling on three adjustable suspensions, and is joined to the inner wall of the tunnel by two adjustable supports (Figures 7 and 8).

The magnets are positioned in the horizontal plane against a geodesic grid displayed to within 0.1 mm on the ceiling of the tunnel.

Each magnet has two horizontal and three vertical fiduciary marks which are used to position it relative to the grid.

The lenses in the straight section are suspended from two brackets fixed to the walls of the tunnel and room.

The vacuum chamber in the magnets consists of sections of stainless steel pipe 1 mm thick and having a cross section of 80 x 29 mm^2.

Between the magnets, the chambers are joined by bellows welded to a stainless-steel box.

The radiation detector, which is in the form of a water-cooled gold-plated copper tube, is placed on the outer periphery of the chamber. The detector is shaped to fit the chamber profile and occupies 7 mm in the radial direction. It takes up 0.5 mW of the synchotron radiation.

An ion* pump utilizing the natural field of the storage ring is

*Translator's note: Literally "magnetic discharge"

placed on the inner periphery of the chamber. The distributed pump ensures a pumping rate of 1.5 l/sec per cm of length, producing a pressure of 10^{-10} torr in a magnetic field of 10,000 Oe. The pump electrode system is prevented from being heated up by reflected synchrotron radiation by water-cooled tubes. The total size of the pump in the radial direction is 15 mm.

A section through the vacuum chamber is shown in Figure 9.

The water inlets and outlets, and the supplies for the ion pump, lie in the compartment between the magnets. The compartment also contains pickup electrodes for measuring the current and beam position.

The compartment is evacuated by an ion pump at the rate of 100 l/sec.

Each section of the vacuum chamber, consisting of a tube and the compartment welded to it, was evacuated and outgassed for 30 hours at 400°C prior to insertion into the magnet. The section was opened after the magnet was set up in the tunnel immediately before welding to the adjacent section, and was immediately re-evacuated. A pressure of 2×10^{-9} torr was achieved in two sections after 24 hours of pumping following the welding operations.

The expected effective pressure in the storage ring for a circulating current of 0.5 A and full beam energy was 5×10^{-9} torr. This gives a beam life of over 4 hours.

The high frequency system operates on the 19th harmonic of the rotational frequency (approximately 75 MHz). The currently available resonator, which is similar to that in the VEPP-2 installation, can be used to develop 600 kV using the existing 150 kW generator. This enables us to reach 2 BeV. The maximum energy of 3.5 BeV will be achieved by adding a power amplifying stage (up to 1 MW) and replacing the resonator.

Moreover, there is an additional low-power high-frequency system operating at the first harmonic of the rotational frequency. This system is used to convert the stored positron current into a single bunch.

The B-4 synchrotron is a modernized version of the B-3M. synchrotron[3], and is used as the injector for the storage ring.

Constructional and technological improvements have enabled us to increase the electron energy on a 100-cm equilibrium orbit to 500 MeV. The fore-injector is a pulsed accelerator of the ELIT type, working at an energy of up to 3 MeV and a circulating current of up to 3 A. The pulse length is 1 msec (ref.4).

To overcome coherent effects during injection we used helical electron storage, followed by their betatron acceleration to 10 MeV.

These modifications should lead to a severalfold increase of the accelerated current as compared with the B-3M synchrotron. (The accelerated current in the B-3M is 1 A).

Further synchrotron acceleration is carried out using the second harmonic of the rotational frequency. Single-turn injection is carried out along the vertical, with preliminary deflection of the beam toward the extraction magnet. This magnet has a 2 mm wall, and with a field of 35 000 Oe it deflects the beam through 23° in the vertical plane. Photographs of the B-4 during assembly and in the completed form are shown in Figures 10 and 11.

Electron transport (Figure 1) for injection into the storage ring is achieved by two quadrupole doublets and a 90° bending magnet. The magnet is designed so that the energy spread produced in it does not prevent the capture of electrons with up to 0.5% energy spread.

Conversion of electrons into positrons takes place in an external tungsten target. To ensure focusing on the converter, the electron beam is displaced parallel to itself in the horizontal plane through a distance of 3 m by two 63° bending magnets. This is carried out achromatically owing to the presence of two quadrupole triplets between the magnets.

The second magnet (radius 12.5 cm) focuses the electron beam on the converter. The collection of positrons from the converter is carried out by a magnet having a radius of 7.5 cm and a bending angle of 45°; both magnets in the conversion block are iron-free, single-turn systems with $n = 0.5$ and fields up to 130 000 Oe.

Focusing of positrons from the conversion block prior to entry into the storage ring is accomplished by a quadrupole triplet and a 45° bending magnet. In the radial plane of the storage ring this produces an energy correlation between the particles in accordance with the values of the ψ-function of the storage ring and its derivative at the point of injection, so that particles of any energy are admitted without the excitation of additional betatron oscillations.

The particles are admitted into the storage ring (Figures 12 and 13) along the vertical near the maximum of the vertical Floquet function.

The walls of the admitting magnets have a thickness of 2 mm.

The buildup of a large stored-beam amplitude during single-turn injection is prevented by deflecting plates located at a distance equivalent to a quarter of the betatron period from the point of admission. These plates are pulse-operated and deflect the stored beam toward the admitting magnet. The inflector returns it to the equilibrium orbit simultaneously with the admitted beam. The vertical acceptance is then equal to 8.5 mrad.cm with the amplitude of the residual oscillations of the main beam not exceeding 0.3 of the linear dimensions of the chamber. The energy spread range is $\pm$ 2%.

<u>Storage</u> of the positrons will be carried out with successive filling of the separatrices of the 19th harmonic of the rotational frequency, so that a large number of injection cycles can be fitted into the damping time.

The planned storage rate is 5×10^{8} positrons per second (0.5 mA/sec). Once the required current has been stored, an additional resonator operating at the first harmonic of the rotational frequency will be used to take the positron beam into one of the separatrices of the 19th harmonic.

Electron injection is carried out at the full energy of the injector. The electrons are fitted into one of the separatrices so that the collision occurs during the detection interval.

To reduce the effects of collisions on electron storage, the electron and positron orbits are separated by applying a suitable voltage to special plates in the long gaps, and the betatron frequencies are shifted in opposite directions. Once the electrons have been stored, the energy is set to the required value, and the beams are brought together again.

The expected transmission*, which is restricted by collision effects,

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*Translator's note : (?) Literally "luminosity".

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is 10^{35} cm^{-2} day^{-1} at full energy, which results in 10 - 100 muon pairs per day.

Provision is made for subsequent replacement of parts of the chamber in the collision region by special sections evacuated to better than 10^{-11} torr.

A modification of the focusing system in the long gaps, with substantially reduced beam cross section at the point of collision, is in the course of preparation.

The basic systems have now been constructed and have been placed in position, ready for operation. The storage ring has been tested with 1.5 MeV protons. Work on electron storage in the B-4 has begun.

Table of Main storage ring parameters

Maximum energy			3.5 BeV
Radius of half rings			802 cm
Length of straight section			1200 cm
Betatron oscillations per orbit :			
	along radius		5.28
	along vertical		5.11
Magnetic structure $(FMDMO)^8$ (I) $(FMDMO)^8$ (I)			
Orbit packing factor			0.065
Structure of periodicity element :	focusing segment:		
		length	48 cm
		field	6.9 kgauss
	distance to asymptote		3.5 cm
	bending segment		
		length	105 cm
		field	18.9 kgauss
	defocusing segment:		
		length	52 cm
		field	11.8 kgauss
	distance to asymptote		6.2 cm
	bending segment:		
		length	95 cm
		field	18.9 kgauss
	field-free segment:		
		length	15 cm
External size of vacuum chamber			8 x 2.9 cm^2
Useful aperture			5.5 x 2.7 cm^2
High-frequency power:	turn I		150 kw
	turn II		1 MW
Harmonic			19
Number of resonators			1

Energy loss per turn	2 MeV
Bunch length	~30 cm
Radial beam size	0.8 cm
Power consumption by magnets	1.7 MW
Magnet supply current	25 kA
Weight of iron	50 t
Weight of copper	4 t
Positron injection energy	250 MeV
Electron injection energy	500 MeV

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Post Office Box 4097
Woodside, California 94062
Telephone: (415) 851-1040