ACCELERATOR DEVELOPMENTS IN NOVOSIBIRSK

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I. GENERAL REVIEW

The part of the program of the Novosibirsk institute of nuclear physics dealing with accelerations consists of the development of plasma accelerators, ironless pulse accelerators, machines with colliding beams and special accelerators for industrial uses.

Inspite of the fact that the Institute of nuclear physics exists in Siberia since 1961 these works were began several years before in Moscow at the Laboratory of New Methods of Acceleration in Kurchatov's Institute of Atomic Energy. On the bases of this the Laboratory of the Siberian Institute was organized later.

The work on plasma accelerators at our Institute consists of machines with a so-called stabilized electron beam. The main idea of this work is an attempt to use a high field self-focusing relativistic closed electron beam for the capture of accelerated ions in orbit. This work is developeding slower than we would desire, How we can only report about 130 A closed current of relativistic electrons. The assembly of a high-voltage internal injector on a machine with spiral accumulation is approaching completation. We hope to increase in one year the magnitude of circulating currents by an appreciable moment. It thus may provide a possibility for beginning the investigation of beam shrinkage.

The work on ironless accelerators is concentrated mainly on single-coil accelerators where the shape of the magnetic field is produced by a corresponding shape of conductive surfaces. This can be done owing to the short-pulsed condition of operation and corresponding small skin-depth.

At the last Conference we have reported about several accelerators which were operating or being prepared for operation. Up to the present time four ironless accelerators were put into operation at Novosibirsk. Besides that some models of the projected proton accelerators were tested including models of accelerators with proton colliding beams.

As a result of these work we have now a confidence in the fact that for laboratories, like ours, construction of ironless accelerators on high energy is move rational than construction of iron accelerators.

Some experimental advantages of iron accelerators do not compensate at all sharp increase of their cost in comparasion with ironless accelerators. I do not assert that it applies in general, but we found this suitable in our case.

However we suspended design works on a ironless proton accelerator on 500-100 BeV with 200 kgauss magnetic field and ironless accelerator with colliding proton beams 2×12 BeV. At the recent time we obtained very satisfactory results in development of accelerators for industrial uses. Recently that electron accelerator of high-voltage transformer type with accelerating tube was put into operation. This accelerator operates at industrial frequency (50-60 cps) and produces 1,5 MeV electron with 25 kWt power in external beam extracted in air. Coefficient of conversion of electric power into radiation is more than 90%. This is a tank (diameter 1,2 m, height 2 m) without any external high voltage or radio-frequency devices. In near future we suppose to put into operation another accelerator of the same type with the energy of 3 MeV as well as pulse accelerator of the same type with considerably smaller size.

I shall devote the later part of the paper to the description of the works with colliding beams as well as some ideas about storage of high positron and proton beams which are in close connection with these problems. At the present time in the Institute two colliding beams machines are in operation. On VEP-1 machine with colliding electron-electron beams large angle electron-electron scattering experiments are in progress. On VEP-2 machine with colliding positron-electron beams, with a maximum energy of 2×700 MeV experiments are only beginning.

The machine for light particles and machine with colliding proton beams are under design. On all our colliding beam machine we don't coupled at all the energy of injector with a limiting energy of storage ring. Tre injector energy is substancially lower, the acceleration up to the limiting energy is carried out by incresing magnetic field of the storage particle. This is cheaper and does not complicate the operation to any appreciable degree.

II. STATUS REPORT ON ELECTRON STORAGE RING VEP-1 (*)

At the last Conference on accelerators in 1963 we reported (1) on the construction of the machine VEP-1 designed for electron-electron scattering experiments up to 2×130 MeV energy. By that time the preliminary experiments on the storage of electrons in a single ring were carried out on this machine. This work, which was carried out in the last 2 years, proceeded mainly along the following lines:

1) storage of electrons in two rings simultaneously,

2) study of beam-beam interaction effects (2) and

3) measurements of luminosity by the small angle e-e scattering.

At present time, experiments on electron-electron scattering over 40°-90° angles are started on the machine VEP-1.

1. Machine VEP-1

A schematic view of the machine VEP-1 is shown in Fig. 1. It is composed of two coupled high-vacuum magnetic rings, special electron synchrotron B-2S electron optical channel and a system of a single-turn beam ejection from accelerator with its injection into the storage ring. All these elements are described in detail in our reports presented at the last Conference on accelerators (1) (3).

The magnet storage ring have the radius of 43 cm and 3×4 cm^2 aperture. Facing the orbit contact point in the common part of magnet poles are the slits for the coming out electrons which are scattered at the point of collision. The machine is in such a position that the median plane of the storage rings is axial with one ring placed above the other.

Storage ring resonators operate at the second harmonic of electron revolution frequency. Besides resonators and inflector, each magnetic ring has several mechanical probes, as well as an optical beam observation system and plates for beam position and transverse size control, and also the arrangement for measuring the frequency of particle betatron oscillations. Also, by means of special modulation of h.f. voltage on resonators, one can increase the amplitude of radial-phase oscillations. The problems of electron beam observation in the storage ring and control of beams' parameters are described in greater detail in a separate report presented to this Conference (4).

Electron injection energy in the storage ring is 43 MeV. A special ironless synchrotron B-2S with the spiral accumulation of electrons (3) is used as an injector. The pulse beam ejected from the synchrotron has at least 5 nsec duration and current about 300 mA (over 10^{10} particles). The energy spread does not exceed 0,2%. Accelerator repetition rate is one pulse per 15 sec.

Most of the work with beam in the storage ring was carried out with injection energy. In this case, each injector pulse was used for filling electrons into one of the storage rings. The work carried out with higher energy is broken into the cycles about 10 mm duration each. About half of the cycle time is employed for measurements, the rest is used for storing electrons and varying the magnetic field strength in the rings.

2. Storing of electrons

Though one could inject into the storage ring current above 100 mA in a single pulse, the average injection intensity per pulse was not above 10 mA. Stability of the injection regime leaves much to be desired. The maximum current in any storage ring was up to 200 mA. Limitations are caused by the instability in the interaction between beam and resonator (5).

In Fig. 2 are shown the results of measurements of electron lifetime in the storage ring depending on the beam current value at 43 MeV energy.

In Fig. 3 is shown the transverse size of beam at the same energy and its dependence on the value of the accumulated current. The measurements are carried out by means of photomultiplier and the fast moving diaphragm located in front of it to which the picture of the beam observed is projected. These results are in agreement with the estimations of pressure increase in the beam due to the compensation of its charge by ions of the residual gas.

The radial size of the beam is larger than the axial one due to the contribution from the ra-

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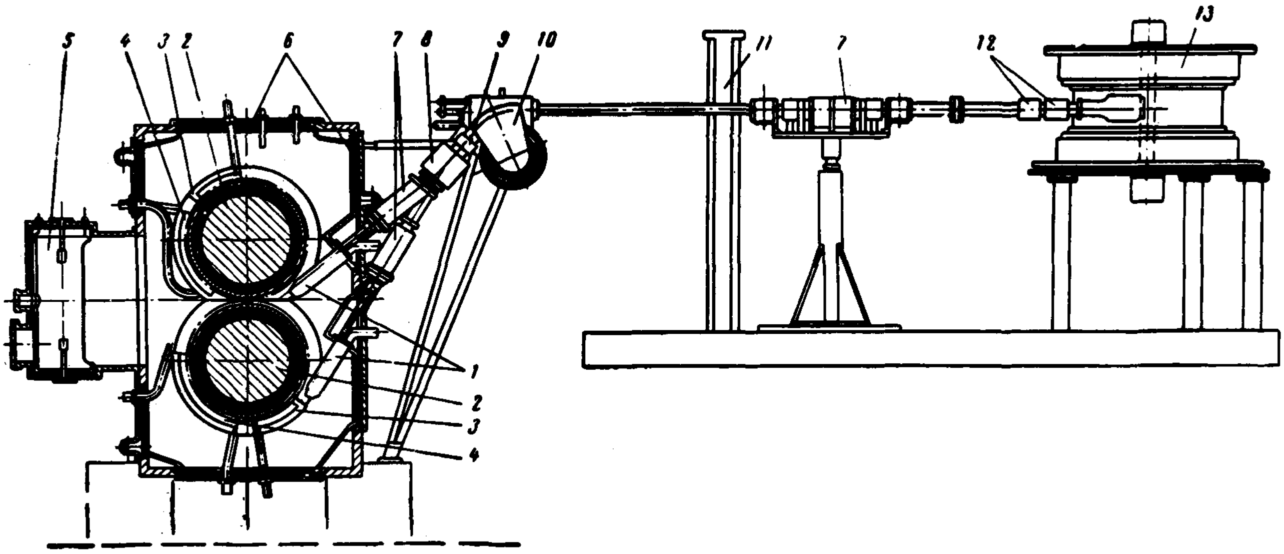

Fig. 1 - The schematic view of VEP-1 machine - 1. Compensating magnets; 2. Storage ring magnets; 3. Resonators; 4. Inflectors; 5. Titanium pump; 6. Outer vacuum chamber; 7. Quadruple lenses; 8. Commutation magnet; 9. Correcting coil; 10. Bending magnet; 11. Radiation and magnetic screen; 12. Correcting magnet; 13. Injector—synchrotron B-2S.

dial-phase oscillations. Their amplitude also grows with the increase of beam currents which can be seen from Fig. 4 showing the dependence of azymuthal size of the bunch on the beam current value. The measurements are carried out with the resolution about 1 cm by an image intonsifier. It is interesting to note that the artificial increase of the transverse size of beam results in the decrease of phase size of bunch.

With the increase of electron energy the transverse size of beam decreases which results in the increase of AdA-effect role, in our case, leading to the sharp reduction of beam's lifetime. The artificial increase of radial beam size improves the situation.

3. Luminosity measurements

The final tuning of the machine and the check of the collision efficiency are carried out by means of the detection of small angle e-e scattering. The large cross-section of this process allows one to find without tiresome procedures the optimal condition of operation by varying numerous parameters of the machine.

The geometry of the experiment is shown in Fig. 5. Each magnetic ring has two scintillation counters placed at $^1/_4$ of betatron wave-length from the point of beams' collision in beam direction. These counters are connected in pairs to 2 coincidence circuits with the effective time of resolution being $2\tau = 4{,}5$ nsec. (the distance between the two bunches on the orbit). The system of counters detects electron pairs wich are scattered at the angle about 1,5°. The effective cross-section of the scattering integrated over the solid angle of two pairs of counters is $200/\gamma^2$ barn, which corresponds to 30 mbarn for the electron energy of 43 MeV. This work is carried out at the background level (accidental coincidence) compared with the value of the measured effect. The backround measurement is carried out by parallel coincidence circuits with the delay in one of the channels.

As a measure of efficiency of the interaction process may serve the number of counts of such system normalized for the integral of a product

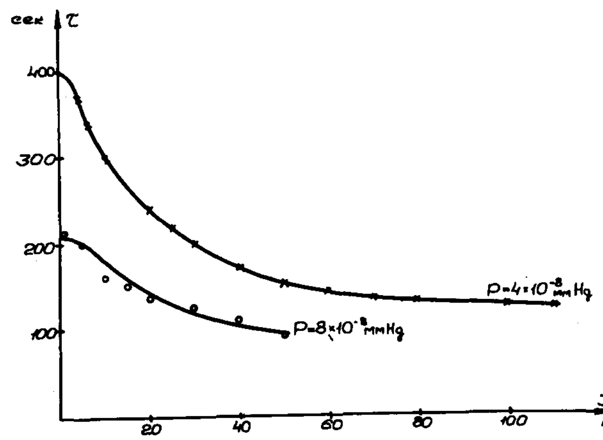

Fig. 2 - Lifetime dependence on the beam current; resonator voltage is 5 kV; energy is 43 MeV.

of beam current over the time of measurements. A convenient measurement unit for this integral appeared to be a coul-amp. Within 1 hour the machine can produce up to 3 coul-amps. The average current in each ring is about 30 mA. The work with higher currents is unreasenable due to a sharp intensification of " beam-beam phenomena " (2).

The results of interaction efficiency measurements are given in Fig. 6, depending on the beams' radial, axial and phase displacement. The shape of the curves is in a good agreement with the bunches dimension data. The absolute counting rate is several times less compared with the expected one. The divergency seems to be due to inaccuracy of the geometry of experiments. The assumption on the specific coherent oscillations diminishing the interaction efficiency contradicts the experimental data on the influence of the beam transverse size on the interaction efficiency. Regardless of the fact whether the increase of the transverse size is due to artificial excitation of betatron oscillations or « beam-beam phenomena » (2) the observed decrease of the counting rate is in a good agreement with the calculations made for a "purely incoherent" size.

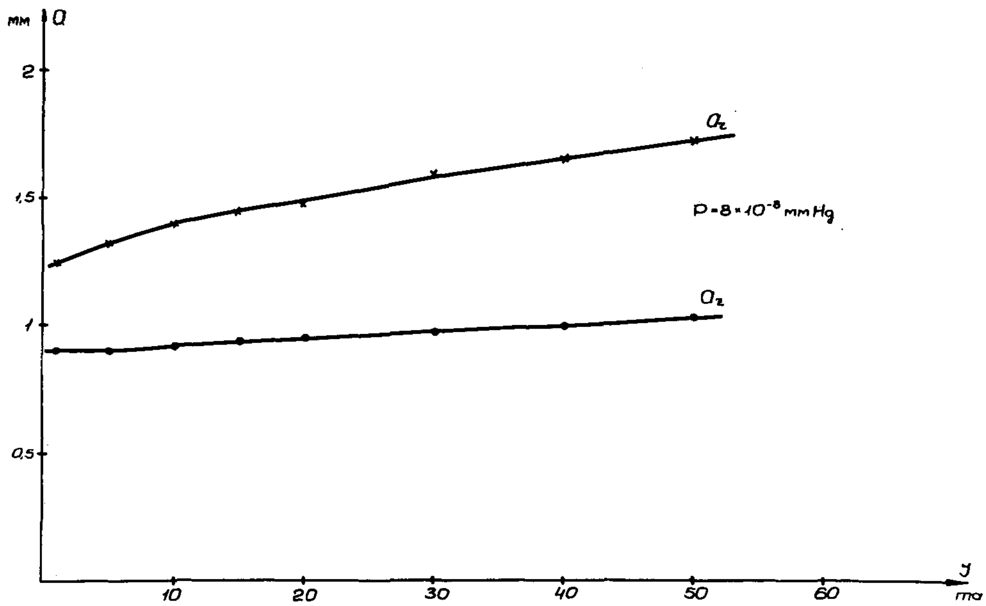

Fig. 3 - Radial and axial bunch dimensions dependence on beam current value; energy is 43 MeV.

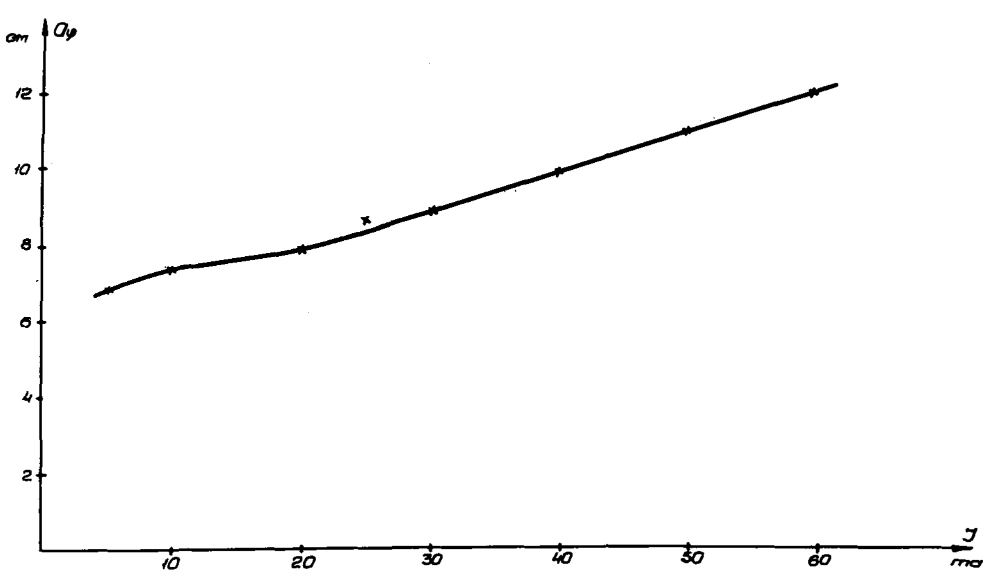

Fig. 4 - Azymuthal bunch dimension dependence on beam current, resonator voltage is 5 kV; energy is 43 MeV.

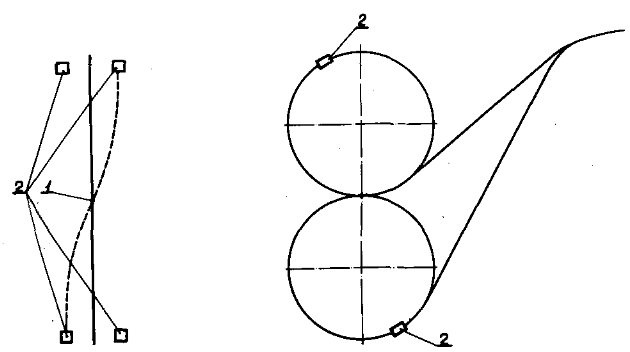

Fig. 5 - The layout of counters for electron scattering at small angle - 1. Place of collision; 2. Counter scintillators.

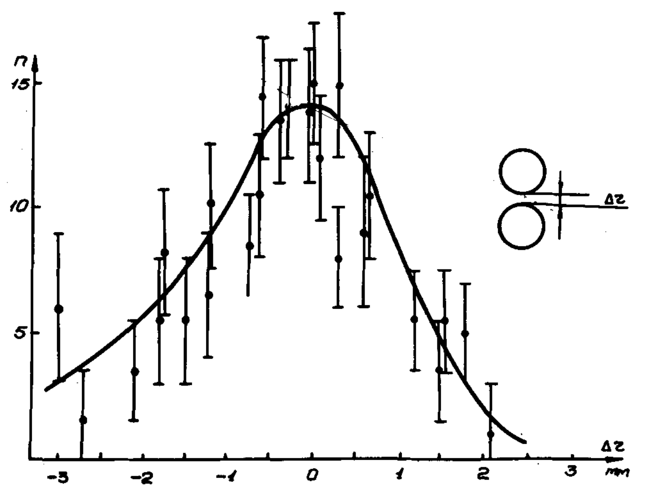

Fig. 6a

Luminosity magnitude determined in the division of the observable counting rate by the effective cross-section of the process is 10^{27} cm^{-2} $sec.^{-1}$ of the order of magnitude.

This value does not contradict the preliminary experimental results on the double bremsstrahlung.

4. Preliminary experiments on electron-electron scattering

In Fig. 6 is shown the scheme of an experiment on the measurement of the angular distribution of e-e scattering over 40°-90° angles. The detection system consists of 4 cylindric spark. chambers with vertical axis passing through the point of beam collision. The optical axis of the camera coincides with this axis; the used system of prismas has an axial symmetry. The second coordinate of the track is measured by fan-shaps mirror assembly placed under the spark chambers.

Spark chambers are triggered on the coincidence between the two groups of scintillation counters (5 counters in each).

The solid angle of the detection system is limited by a slit aperture in the body of the storage ring magnet. The effective cross-section of the Muller scattering integrated over this solid angle is $100/\gamma^2$ mbarn.

In the preliminary experiments carried out with the electron energy of 43 MeV the system of spark chambers was triggered over 100 times per coul-amp, in this case about 10 pictures corresponded to the detection of the electron-electron scattering, which is not in disagreement with our idea on the value of luminosity. Con-

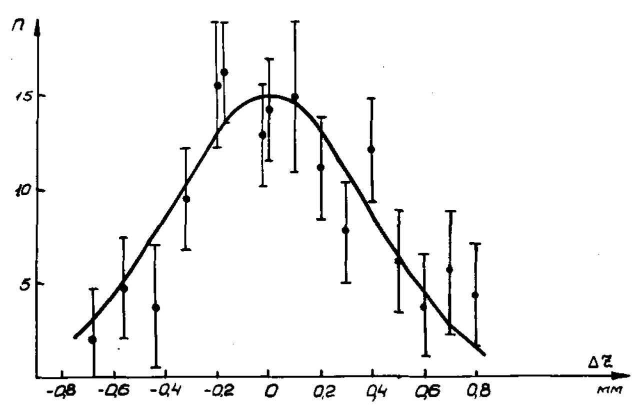

Fig. 6b

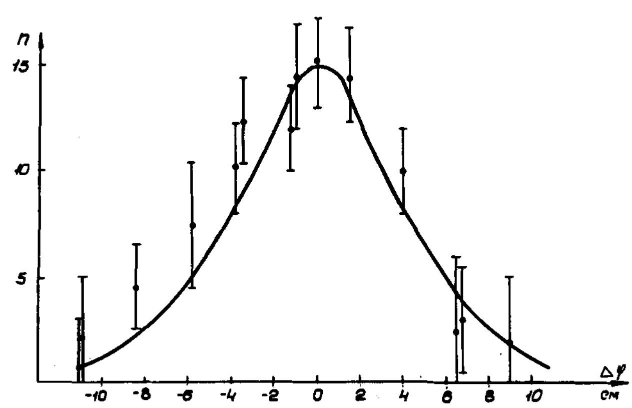

Fig. 6c

Fig. 6 - Collision efficiency dependence on beam separation in radial (a) and axial (b) directions as well as on bunch separation in phase (c). Over the ordinate axis is the number of counts per one milliculam. The measurements were carried out at 15 mA current in each beam. Solid lines are the calculated curves; normalisation is carried out in peak counts.

trol measurements with dephased beam indicate that the background does not exceed 10%.

The preliminary results of angular distribution of scattered electrons obtained from spark chamber pictures are shown on Fig. 8.

The derivation from Möller scattering are within statistical errors.

There is going 100 MeV experiments on the machine now. Now are begin experiments with electrons at 100 MeV.

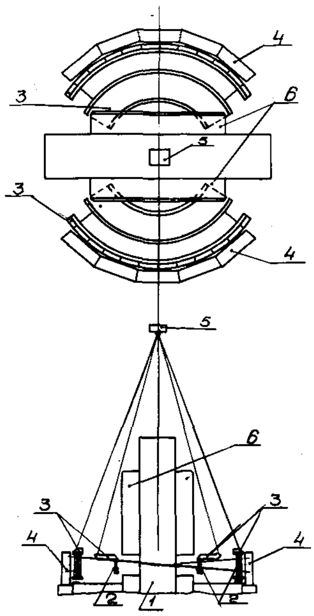

Fig. 7 - The layout of the registration system - 1. Vacuum chamber; 2. Spark chambers; 3. Prisms; 4. Scintillation counters; 5. Camera; 6. The upper ring magnet.

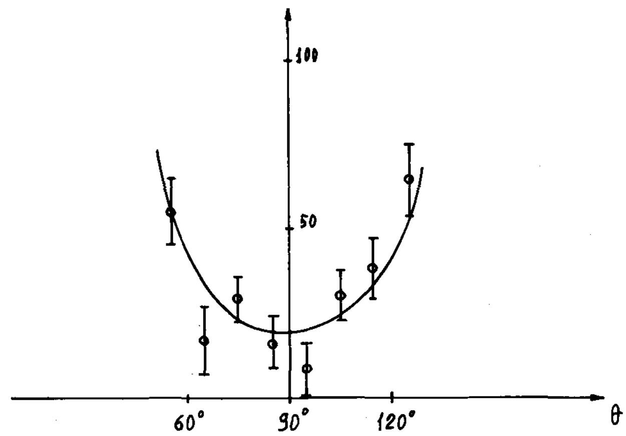

Fig. 8 - Angular distribution of electron-electron scattering at the energy 2×73 MeV. The calculated curve of Moller scattering is shown.

III. STATUS REPORT ON POSITRON-ELECTRON STORAGE RING VEPP-2 (*)

At the last Conference on Accelerators in 1963 we reported (6) on the construction of the machine VEPP-2 designed for positron-electron scattering experiments with energy up to 2 × 700 MeV. By that time the assembling of the machine VEPP-2 was completed. The work carried out in the last 2 years proceeded mainly along the following lines:

1) put-on of synchrotron-injector,

2) gain of high electron currents in the storage ring,

3) study of the instabilities in the regime of beam-resonator interaction (5) and (4) experiments on positron storage. At present time the work on the study of beam-beam phenomena and on the measure of luminosity by small angle positron-electron scattering, is still going on.

1. Machine VEPP-2

The schematic view of the machine is shown in Fig. 9. It is composed of special-type synchrotron B-3M with the external injector, high-vacuum magnetic ring-storage ring, the system of a single-turn ejection of beam from the accelerator and its injection into the storage ring, electron-optical channel and a converter for the electron beam conversion to positron beam. All these elements are described in greater detail in our papers presented at the last Conference on Accelerators (6, 7). The special-type synchrotron B-3M used as accelerator-injector operates presently in unforced regime with up to 130 MeV energy. The ejected beam pulse has for the time being less than 20 nsec duration and 100 mA current (over -10^{10} particles). The energy spread does not exceed 0,2%. The repetition rate of acceleration is up to three pulses per sec. The work on the operation of the synchrotron B-3M is reported in a separate paper presented at this Conference (8).

The storage ring is a weak focusing racetrack with 4 straight sections. The radius of the equilibrium orbit is 510 cm, the length of the straight section is 60 cm, and the chamber aperture-8 × 12 cm². Two sections are used for the electron-positron injection while in the third one there is RF resonator. The section opposite to resonator is designed for experiments.

Storage ring resonator operates at the first harmonic of particle revolution frequency equal

* V. L. Auslender, G. A. Blinov, G. I. Budker, M. M. Karliner, A. V. Kiselev, A. A. Livshitz, S. I. Mishnev, A. A. Naumov, V. S. Panasyuk, Ju. N. Pestov, V. A. Sidorov, G. I. Silvestrov, A. N. Skrinsky, A. G. Khabakpashev and I. A. Shekhtman.

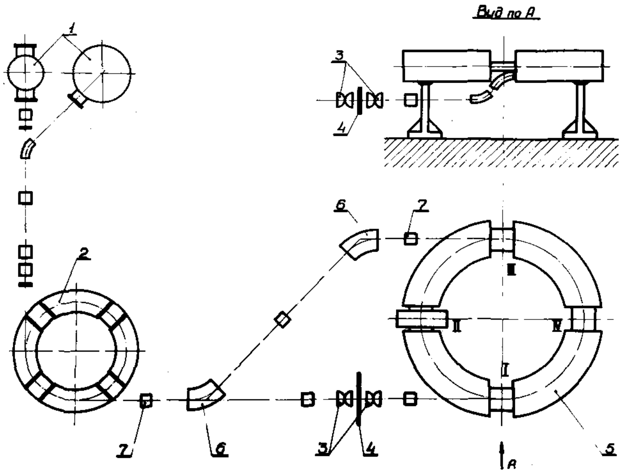

Fig. 9 - A schematic view of VEPP-2 machine - 1. Injectors; 2. Synchrotron B-3M; 3. Parabolic lenses; 4. Corrector; 5. Storage ring; 6. Bending magnets; 7. Quadruple lenses.

to 25,1 Mc/s. A coaxial, half-wave resonator is highly loaded by a condenser consisting of two discs; the Q-value is about 4000. For the time being RF generator with 20 kW power provides the peak voltage (about 35 kV) on a resonator.

Two inner windings of the electromagnet in each quadrant are supplied separately. This provides the displacement of the median plane in each quadrant by ± 1 cm. The radial position of the orbit is corrected by shunting the corresponding quadrants. For the control of relative vertical position of electron-positron orbits there are "separating plates" applied by a direct voltage up to 50 kV. These plates are located in the quadrants free of inflectors and provide the adjustment of the crossing angle ut po 10^{-2} rad as well as the separation of beams at the process of storage.

Eight current windings located in the straight sections (Fig. 10) may be used to adjust betatron oscillation frequency within $\Delta\nu \approx 0{,}1$ and they provide the dependence of the frequency both on the radius $d\nu/dR \approx 0{,}03$ (quadratic nonlinearity) and on betatron oscillation amplitude $d\nu/d(a^2) \approx \approx 0{,}04$ (cubic nonlinearity). In this section there is also mounted an electrostatic quadruple providing the splitting of betatron oscillation frequency of electron-positron beams by 0,05. The figures involved are given for the electron energy of 100 MeV.

In all other respects the system of beam parameters' control is similar to that used on the machine VEP-1 (4).

A large lifetime of the beam permits one to disconnect the working energy of the storage ring with both ejection energy and storing energy. The working energy required is established by the rise of magnetic field ring after storing.

2. Storing of electrons

The most of the work on the study of the process of injection into the storage ring was carried out with 100 MeV energy. This energy corresponds to the damping time of radial betatron oscillations about 1 sec, which determines the chosen repetition rate of injection pulses (1 pulse per 2 sec).

The rate of electron filling is about 30 mA per injection pulse. Electron current about 0,5A (10^{11} particles) was obtained in the storage ring. Limitations occured due to instability in the beam-resonator interaction (5). Transverse beam instabilities were not observed.

The lifetime at natural sizes and currents exceeding 1 mA and values being far from the resonance is determined, in principle, by AdA-effect (9). The dependence of the beam lifetime on the intensity of the stored current is shown in Fig. 11. With 100 mA current and 100 MeV energy the beam lifetime is 450 sec. These data are obtained with a pressure about $3 \cdot 10^{-8}$ tor without baking the chamber. After baking the life time of small current is larger then 3 hours.

The rise of energy up to 550 MeV with the peak voltage on the resonator of 20 kV was realized after the beam storage. The energy rise of the beam causes an intense outgassing of the vacuum chamber walls of the storage ring which reduces with the prolonged training.

During the work with the intense electron beam a very peculiar phenomenon could be observed in the storage ring VEPP-2. In the excitation of betatron beam oscillations by a single pulse on the inflector the damping of the larger part of initial oscillation amplitude takes place within times much less than the time of the natural radiation damping. In Fig. 12 is shown the dependence of the damping time on the value of the stored current in the presence of ions and without them. The dependence of the damping time on values is far from dangerous resonance within the accuracy of measurements was not detected. It is quite possible that this effect is associated with the resonant excitation of electromagnetic oscillations in some elements of vacuum chamber.

3. Storing of positrons

The electron beam is converted to positron one on a tungsten plate about one radiation length thick placed into a focal plane of two "parabolic" lenses (6). With the focal length of 7 cm beam diameter on the converter plate is no more than 1 mm. After switching these lenses on, the injection efficiently increase about 20 times.

The work was carried out with electron energy of 200 MeV and positron energy of 100 MeV. The filling rate obtained for the positrons is about 0,3 μA per injection pulse which corresponds to the effective coefficient of conversion of 10^{-5}. The maximum stored positron current is 0,1 mA (10^{8} particles).

Presently the work is carried out in the direction of the increase of positron filling rate.

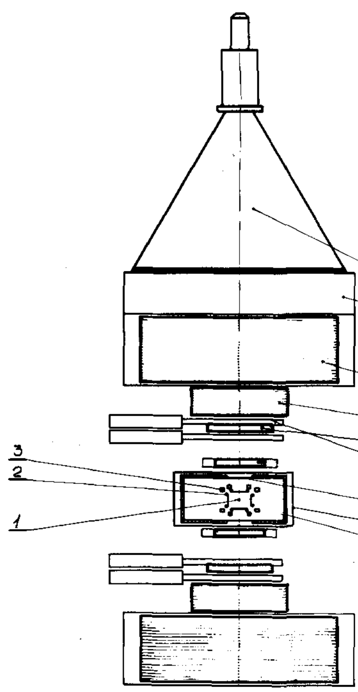

Fig. 10 - Vertical cross-section of interaction region and detection system - 1. Colliding beams; 2. Electrostatic quadruple; 3. Windings; 4. Inner vacuum chamber; 5. Vacuum chamber; 6. « Window »; 7. Scintillation counter; 8. Thin plate spark chambers; 9. « Shower » spark chamber; 10. « Range » spark chamber; 11. Lead shielding; 12. Scintillation counter.

4. Experimental methods

For the experiments on positron-electron scattering the system of spark chambers covering the solid angle of 2 × 0,7 sterad near the vertical direction has been prepared.

The thin plate spark chambers are located first on the way of the outcoming particles. These spark chambers are designed for the determination of the scattering angles and coordinates of the interaction point. The magnetic field directed along the line of colliding beams allows the determination of charge sign of the detected particles. The particle intensification is carried out depending on the character of their interaction with the plate of the "shower" and the "range" spark chambers. A rather complex system of mirrors permits one to use one camera.

The whole system of spark chambers is triggered on 4 scintillation coincidence counters (40 × 40 cm²) and anti-coincidence counter (120 × 120 cm²) providing the cosmic rays vetoing. Between the counter and the chambers there is a lead layer 20 cm thick.

At 2 × 300 MeV energy and 1 × 100 mA² current in the storage ring, such a sytem of chambers permits the detection of several events of the elastic positron-electron scattering per hour. The same counting rate is expected for the π-pairs in the maximum of the cross-section corresponding to the production of the intermediate ρ-meson.

A system of measurements of positron-electron scattering at small angles was used for tuning beam collision in the storage ring measurements of luminosity and its control during the work similar to that used on the machine VEP-1 (10). The scintillation counters of this system are placed into the injection straight section of the storage ring and detect positron-electron pairs scatterd at the angle of about 1,5°.

In order to reduce the load from the intense electron beam, positron counter was shielded with load and divided into two separate coinci-

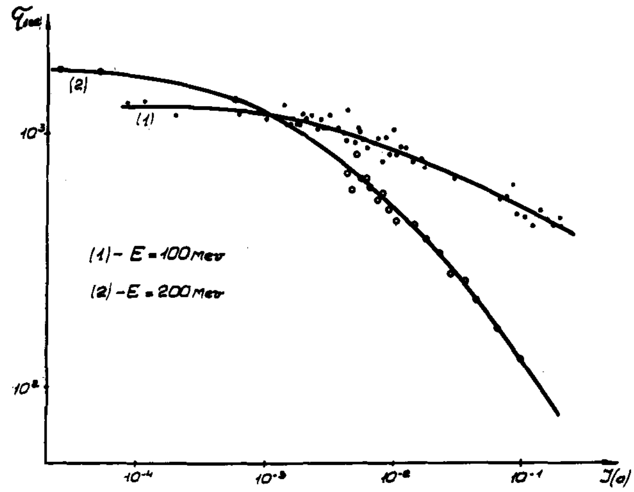

Fig. 11 - Electron lifetime depending in beam intensity.

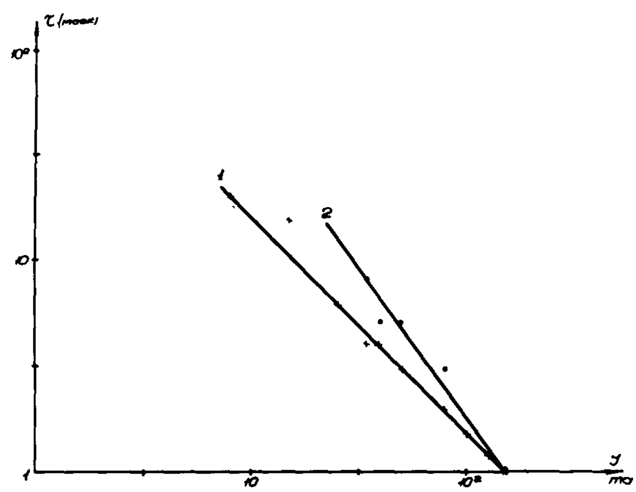

Fig. 12 - Dependence of « fast » damping time on beam intensity - 1. with ions; 2. without ions.

dence counters placed at 10 cm from each other in beam direction. The preliminary study of the background conditions is quite satisfactory.

IV. HIGH CURRENT POSITRON SOURCE

The method of positron production which is used on VEPP-2 machine and other accelerators has an essential disadvantage, low coefficient of conversion of initial electron beam into narrow heavly monoenergetic positron beam which there is necessary for injection into accelerators and storage rings.

The method of production of nearly monoenergetic positrons in a narrow angular interval proposed below removes this disadvantage and practically eliminates the positron storage problem. Besides that there appears the possibility of construction of positron accelerators or conversion of existing accelerators into positron accelerators with the same intensity.

The main idea is that positrons produced by electron beam of comparatively low energy (5-10 MeV) in wide range of energies and angles are slowing down in a special target to thermal on hearly thermal velocity and after that they are extracted from target by electric field and accelerated up to injection energy.

Much attention should be given to positronium formation and gas molecule with positron formation. These processes result in positron's going out of play. Positronium formation may be done low during the process of slowing down by the choice of gas.

If the energy of positron is lower than definite threshold (for argon -9 eV) the positronium isn't formed.

In the case when an electric field is supplied its magnitude should be chosen in such a way that temperature of positron would be lower than positronium formation threshold.

Even in inert gases positron may produce a chemical ionized molecule. However this process takes place at positron energies lower than 1,5 eV. On accidental coincidence of numerical values the time of slowing down from 9 eV to this energy owing to elastic collision of positrons with molecules is close to annihilation life-time of positron. So this effect may be neglected. The presence of elastic field results in heating of positron gas up to several eV and the effect of molecule formation falls in addition.

Two versions of idea and their combination are possible.

In first version of steady action the electric field is supplied to the target (as a rule gas target), with such an amplitude that equilibrium energy of positrons is lower than positronium formation threshold. That determines the maximum electric drift velocity of positrons which does'nt depend on gas pressure. The slow positrons are extracted by electric field to target's edge. For gas target a sharp edge may be produced by differential pumping or by freezing. Since all positrons at the edge have practically zero energy they being accelerated by homogenous electric field produce parallel mono-energetic beam.

The target length and gas pressure are determined by the condition that during life-time of positron must leave the target moving with drift velocity. Since drift velocity is determined than extraction time is inversly proportional to target length. Positron life-time in the target is inversly proportional to density. The thickness of targets (in g/cm^2) is determined by the condition that these two times must be equal. The corresponding thickness in egual nearly to positron slowing down length with critical energy of several hundreds KeV. By locating the target into magnetic trap which results in increasment of fast positron's path inside target. There is possible to slow down positrons with initial energy of 500 KeV and more. At the initial electron energy of 6 MeV there is possible by this method to slow down main part of positrons leaving convertor. The effective coefficient of conversion of electrons into harrow positron beam is of the order of $3 \cdot 10^{-5}$. This small value is connected with small initial electron energy and small number of positrons leaving convertor. When initial electron energy is increased coefficient of conversion is sharply increased. In the case of a solid target it is impossible to use the magnetic trap effect. However, the semplicity of a solid target as compared with a gas target is worth considering.

Unfortunately the lowing down annihilation process of positron and their drift in the electric field are considerably less clear than in gases.

In the second version of pulse action the target is located inside magnetic and electrostatic trap which increased fast positron's path and totally confines slow positrons. At first there is non extractive electric field. The time of positron accumulation is of the order of annihilation life-time.

At argon pressure of 1 torr this time is about 1 msec. Then by short pulse of electric field positrons are extracted. It gives an opportunity to increase the magnitude of pulse positron current. The current gain is determined by relation between accumulation time and time of injection. This relation is large for linear accelerators and particulary large for circular accelerators with single turn injection.

For mereacing the accumulation time it is necessary to have low pressure target. At target length 1 m and pressrue which correspont to life-time of the order of 1 msec, only positrons with initial energy of several tens KeV can be slowed down in the target.

Therefore one may consider combination of these two versions where positrons with the energy of the order of 500 keV are slowed down in first version's trap with extracting electric field and after being accelerated up to 10 KeV enter into second version's trap where they again are slowed down to thermal velocities and accumulated during 1 msec.

Let us consider an example of combined method with out discussing the choice of numerical values.

There are two electron accelerators with energies of 3 MeV which produce current 1 A in pulse of 1 msec duration. It is necessary to obtain narrow monoenergetic beam of positrons of maximum intensity in a pulse of 3.10^{-8} sec duration for injection into synchrotron. This problem as well as corresponding equipment exists on our machine VEPP-2. Usual method of conversion permits to have positron currents of the order of 10^{-6} A.

Layout of experimental device is shown on Fig. 13.

1. Accelerator
2. Electron source (voltage minus 3.10^{6} V)
3. Electron beam with 1 A current leaving "3" and entering "4" with 6 MeV energy.
4. Tandem accelerator
5. Positron conversion device (voltage plus 3.10^{6} V)
6. Accelerated positron beam (energy 3 MeV)

Let us consider device "4" for conversion electrons into positrons (see Fig. 14).

There:

1. Solid convertor
2. Gas target of the first version
3. Electron beam with 6 MeV energy
4. Magnetic lines

4 a, 4 b. Magnetic plugs, otherwise known as magnetic mirror

5. Extracting electric field
6. System for differential pumping or freezing
7. Accelerating electrodes (up to 10 KeV)
8. The second version's trap
9. Electrostatic plugs for slow positrons
10. System of fast extraction and accelerating
11. System of "magnetic Blinds" for magnetic .flux shortening
12. Positron beam.

Length of each trap is about 1 m gas pressure in first trap is 100 torr (argon or xenon) gas pressure is second trap is lower the 1 torr. Effective coefficient of conversion 3.10^{-5}. Accumulation time in second trap is of the order of 1 msec. Injection time is 3.10^{-8} sec. The time ratio is 3.10^{4}. The total conversion coeff is of the order of 1. So with such a device there is possible to inject positrons with 3 MeV energy and pulsed current of 1 A which exceeds electron currents in usual synchrotrons and coincides with the limiting current of accelerator B 3 M of the Siberian Institute. At a larger initial electron energy coefficient of conversion is sharply increased and positron current may be limited by Langmyire rule or plasma phenomena.

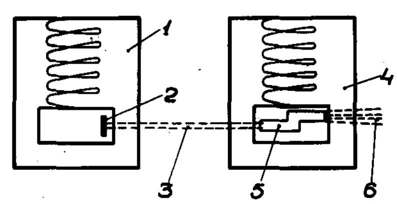

Fig. 13

The device for electron conversion is designed. Experiments shall begin in the near future.

V. EXPERIMENTAL ON THE CHARGE EXCHANGE PROTON INJECTION INTO THE STORAGE RINGS (*)

The charge exchange injection of protons into the ring chamber was realized on our experimental machine (11) in August 1964. The scheme of the experimental set-up is shown in Fig. 15. A high efficiency of proton capture in a quasibetatron and resonant regimes was obtained.

Our first experiments were carried out in a storage ring with $8 \times 4\ cm^2$ aperture in a weak focusing magnetic field with orbit radius being 42 cm. A hydrogen jet directed over the radius from the center of the ring and can be switched-on by means of electrodynamically driven valve for 300-600 μsecs. The transverse size of the jet on the orbit is 1 cm. The efficiency of proton

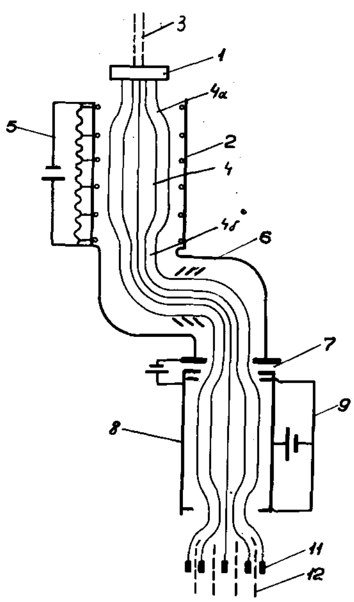

Fig. 14

ejection on the orbit from the jet grows exponentially up to 100% with the increase of jet density. The control of proton beam after the first turn indicated that beam on emitting from the hydrogen target spreads because of its finite thickness, then expands over the radius up to 1,7 cm after one quarter of the wave length of radial betatron oscillations and is focused within the initial cross-size of 3-4 mm after one half of the wave length. The vertical transverse size of the beam after the first turn is 3 - 4 mm and is not practically changed. There is no detectable proton loss. The proton beam was established on the circular orbit with the accuracy up to ± 2 mm. At the charge exchange injection into the storage ring without the accelerating field (a quasibetatron regime) protons move along the spiral path toward the inner wall due to energy losses. The storage of protons in this regime was observed by the intensity of hydrogen jet glow registered by a photoelectronic multiplier, and by wide-band induction electrodes, and also by a target at the inner wall of the ring chamber. For 1 MeV energy and injection within 20 μsec (100 turns) Fig. 16 gives oscillograms for the negative ion current to the first target as well as proton current from the jet and jet glow intensity with proton current to the inner target. By the jet glow and the similar signal from induction electrodes one can see that within 100 turns when beam is injected into the storage ring, the orbit current increases linearly; then within 150 turns the orbit current remains constant; during this period the radius of the orbit is reduced (this was observed by means of vertical induction electrodes), but there are no losses yet at the inner chamber's wall. Next, beam gets into the inner target. The charge getting into the inner target is 100 times greater compared with the charge in the proton beam at the first turn. The amplitude of the signal of the induction electrodes at the accumulation 100-fold exceeds the signal when the probe is placed after the first turn. The accuracy of these measurements is about 10%. The signal from the photoelectronic multiplier registering the light from the jet increases in the process of accumulation only 40-50 times which seems to be connected with the difference in the transverse distribution of the accumulated proton current and the first turn current. Analogous relations hold at the injection up to 250 turns. Thus, at the charge exchange injection to the quasibetatron regime the efficiency of the injection is close to 100%.

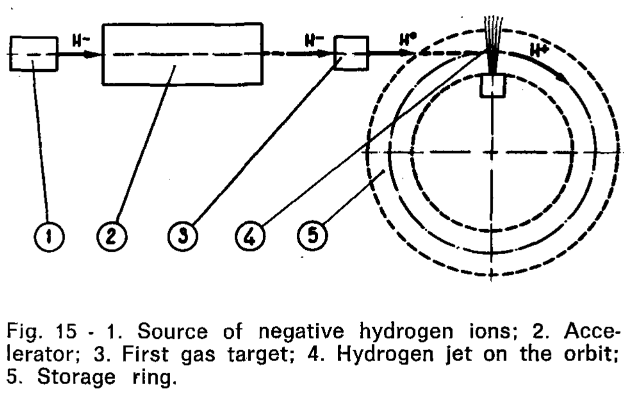

Fig. 15 - 1. Source of negative hydrogen ions; 2. Accelerator; 3. First gas target; 4. Hydrogen jet on the orbit; 5. Storage ring.

* G. I. Budker, G. I. Dimov, A. G. Popov, Ju. K. Sviridov, B. N. Sukhina and I. Ya. Timoshin.

Thereafter the charge exchange injection of protons to the resonant regime was realized. In this regime h.f. accelerating field compensates the ionization losses of proton energy. The amplitude of the accelerating voltage is up to 6 kV, h.f. frequency is the particle rotation frequency. Fig. 17 gives the oscillogram for the orbital current (signal from the resonance induction electrodes) at the injection into the resonant regime. Energy is of 1 MeV, injection time — 300 μsec. (1500 turns), accelerating voltage — 1,5 kV. Fig. 18 illustrates oscillograms characterizing the capture to the resonant regime; energy is 1 MeV, injection time — 20 μsec. Two first oscillograms are the signal from the wideband induction electrodes, both without and with the accelerating h.f. field. From the comparison of signal values it follows that the linear density of protons captured to the resonant regime at the centre of the bunch is one and a half times more than the proton density which are accumulated into a quasibetatron regime. The third oscillogram is the signal from the resonance induction electrodes, the fourth one is the signal from the inner target in the accumulation into the resonant regime. The comparison of the latter oscillograms with the signal from the inner target at the injection into quasibetatron (see Fig. 16) indicates that unlike the quasibetatron regime there arise nearly constant particle losses at the injection of protons into the resonant regime. In this case, proton move mainly toward the inner wall (signal from the outer target is many times less). The particle losses at the injection into the resonant regime are 20-25%. Fig. 19 shows oscillograms of the orbit current in the accumulation of protons in the resonant regime within 500 and 1000 turns (1 MeV energy). It is clear that the accumulated current grows linearly in the resonant regime with time.

In our experiments the thickness of the hydrogen jet is 10^{17} atom/cm^2, the total cross-section of proton losses due to scattering in the hydrogen is $4{,}5.10^{-22}$ cm^2/atom, and the effective number of injection turns is 11000, the antidamping of oscillations due to energy losses in the jet taken into account is ~ 5000.

At the injection up to 1500 turns the proton losses are not to exceed several percents and therefore in our experiments it was not possible to observe the rise of losses in the process of storing.

The constant particle losses of 20-25% at the injection into the resonant regime fairly agree with the reduction of the azymuthal dimension of separatrice due to energy losses.

In our preliminary experiments h.f. ion source with the maximum direct current of 21 μA, with its supply power being 400 W was used as a source of negative hydrogen ions. In the system of ion pumping there is no problem and the pumping voltage is up to 12 kV. The specific feature of the source is the cut off of the secondary electrons in the charge exchange channel

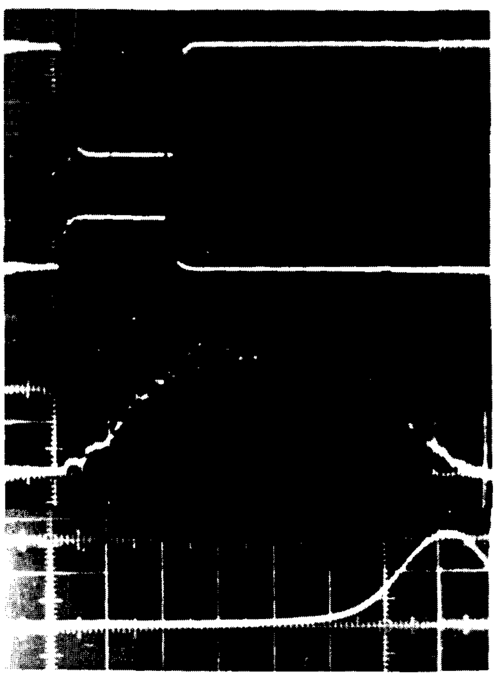

Fig. 16 - Horizontal scale: 10 μsec per cm.

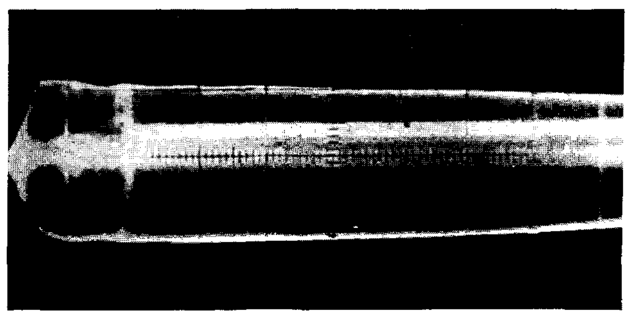

Fig. 17 - Horizontal scale: 500 μsec per cm.

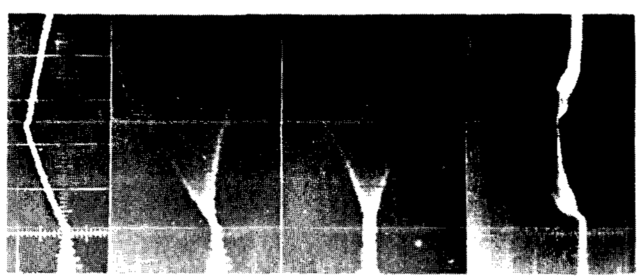

Fig. 18 - Horizontal scale: 10 μsec per cm.

of the pumping electrode with 250-300 V. Negative ion current up to 12 μA was obtained with this source on Van de Graaff accelerator. The beam was injected into the storage ring by pulses of 1-300 μsec duration by means of the cut off condenser placed in the ion transport system. The beam of negative hydrogen ions was focused at the storage ring inlet having the transverse dimension of 3-4 mm and the angular divergence of 2.10^{-3}. The beam was passed through the gas target in the form of a flow-tube, 5 cm long and 1 cm in diameter with diaphragme and differential pumping. The inlet of gas to the flow tube was realized by pulses of 1 μsec duration by means of electromagnetically driven valve. Atomic hydrogen beam was injected from the first target to the orbit with the accuracy up to the transverse position of ± 1 mm and at the angle of $\pm 2.10^{-3}$. The energy stability was ± 0,2%.

In order to obtain the maximum yield of the atomic beam, the cross-sections of charge exchange of negative hydrogen ions were measured by mass-spectroscopy techniques in a series of gases (H_2, N_2, C_2H_2, C_3H_8, CO_2, SF_6, CCl_2F_2) with 1-1,5 MeV energy. The maximum atomic beam yield appeared to be weakly dependent on the sort of gas or energy and was 50-55%. For the first target we used hydrogen and carbon gas with the optimal thickness of $2{,}5.10^{16}$ and $3{,}10^{15}$ mol/cm^2 respectively.

We have installed a source of negative hydrogen ions with 1 mA current and with pulse of 1 μsec duration in the Van-de-Graaff accelerator in order to accumulate high currents. The source of cyclotron-type is the one described in (12). Fig. 20 illustrates the scheme of this

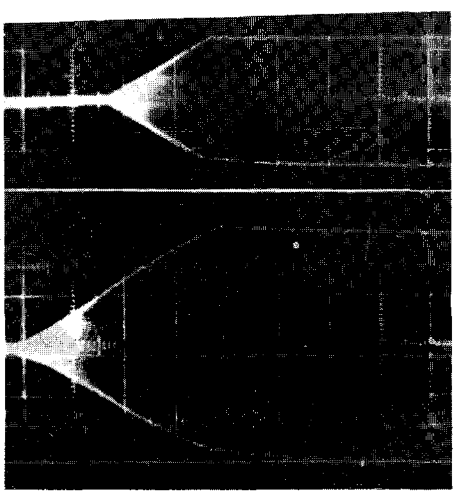

Fig. 19 - Horizontal scale: 50 μsec per cm.

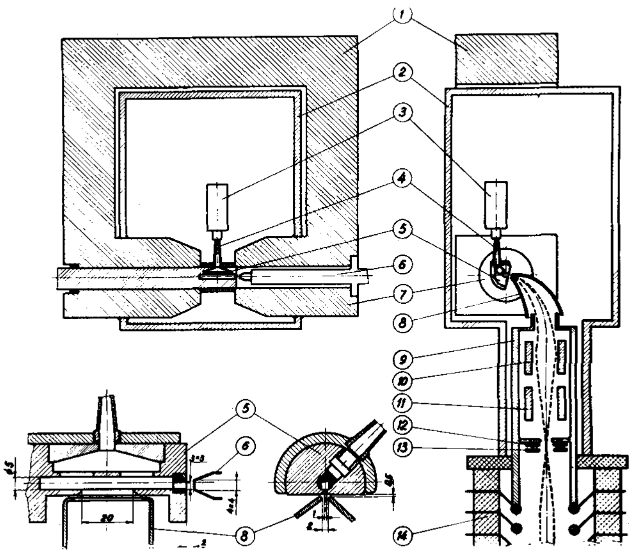

Fig. 20 - 1. Magnet; 2. Vacuum chamber; 3. Gas valve; 4. Gas inlet; 5. Anod; 6. Cathode; 7. Magnet poles; 8. Excitation electrode; 9. Electrostatic and magnetic screen; 10-11. Quadruple lenses; 12. Bias electrode; 13. Accelerating electrode; 14. Accelerating tube.

source. An arc (current of 4-5A, 300 V voltage) with tantalum thermocathode (160 W power) is set along the magnetic field (200 Gauss) in the anode channel. This arc is an intense emitter of electrons which produce negative hydrogen ions on the neutral gas. The latter arc accelerated across the magnetic field (5 kV voltage). The electron current is limited by a magnetic field and in our source is 100 mA. The inlet of hydrogen is of pulse-type (1,5 sec duration). The ion current is very sensible to gas density. The optimal depth of the hydrogen layer between the arc surface and the feelers is 10^{15} atom/cm^2. The hydrogen intensity per single pulse is 6.10^{-3} cm^3. In order to decrease the pulse loading the accelerating tube with hydrogen, the volume of the vacuum chamber of the source is enlarged to 10 l. The pumping time of this chamber is 0,2 sec. The form of the ion current pulse is sensible to cathode temperature. A beam of negative ions is emitted in the form of a band with the increased divergence angle to the plane transverse to the magnetic field. At the outlet of the accelerator at 1,5 MeV energy the phase volume of the beam is 5.10^{-3} cm rad, which satisfies our requirements.

By means of Van-de-Graaff accelerator with the described ion source of negative ion beams up to 800 μA was obtained in our machine, which makes it possible to store up to 10^{12} protons per pulse (current ~ 1 A).

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DISCUSSION

G. E. FISCHER: I would like to mention the existance of a proposal published as a report (N. CEAL 1016, Feb. 1965) by K. W. Robinson of the Cambridge Electron Accelerator of a device similar in concept to the positron source mentioned by Prof. Budker. Positrons are made by conversion from a high energy electron beam in a target located inside a magnetic bottle. Radiation damping from 200 kV to 30 kV reduces their phase space during storage after which they are extracted by a pulsed electric field or other device for subsequent acceleration. Vacuums of the order 10^{-7} torr are required. The possibility also exists that this storage device may be used by polarize electrons by spin exchange wich atomic hydrogen. It is believed that for the useful intensities described, space charge instabilities are not present.

BUDKER: The proposal of doct. Robinson have the same aim. However it is based upon principles other then the method about wich we talk. I would stress that one method is based on the idea of the transformation of all the positrons in termal ones because of the collisions with the molecules of the gas. In our method the magnetic trape have an auxiliar character to increase the effect.

SCHOCH: Prof. Budker expressed the hope to exceed the space charge limit by his charge exchange injection effect. Could be elaborate on this or on what be understands by space charge limit in this context?

BUDKER: In defined conditions one may try to compense the space charge with particles of the other sign. Because of instability, this method for electrons is of small efficiency; but in protons accelerators may give a big effect. E.g. in a proton betatron the compensation of the space charge is spontaneous.

SCHAFFER: You mentioned that no beam - resonator interaction was observed on VEP-2. What is the shunt impedance of the resonator?

BUDKER: 30 Kohm.

WIDERÖE: I cannot see when the loss of positrons during the slowing down of the positrons enters the calculation.

BUDKER: A part of the positrons remains in the solid converter. A part of the high-energy positrons leaves the trap without slowing down. The velocity of all the other positrons tends to zero.

J. H. MARTIN: I would like for Prof. Budker to restate the detailed efficiencies involved in passing through the various devices in converting an electron beam into a positron beam. I would like for him to make a similar description in producing H^+ from H^- converting through H^0?

BUDKER: This is described in details in the paper.