VLEPP — STATUS REPORT

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1. In the last 10—15 years the electron-positron colliding beam experiments have become one of the main sources of fundamental information in elementary particle physics. And their significance will only increase in the future[1]. The main direction of the method development remains an increase of the achievable reaction energies. With the use of traditional now cyclic storage rings, in comparison with proton-antiproton storage rings, the basic obstacle for further energy increase is a catastrophic growth of energy losses because of synchrotron radiation. Under the optimal conditions the overall dimensions and therefore the cost of the facilities is quadratically increasing with the increasing of their ultimate energies. Obviously a storage electron-positron ring at the energy of 2×150 GeV is fiscally infeasible.

The new principled solution of the high energy problem is the creation of a facility with colliding linear electron-positron beams. In this case the synchrotron radiation is negligible and the cost of the facility is proportional to the ultimate energy. However in spite of simplicity of the proposal, there are many complicated problems to be solved. In particular, to achieve the equivalent luminosity it is necessary to accelerate high intense beams with the number of particles of 10^{12} and very small emittance, so to get the cross section area of the order of 1 μ^2 at the collision point. Also the value of the accelerating gradient in linear accelerators must be very high ($\sim$100 MeV/m) because the total facility length is determined by this value.

The problems of creating the colliding linear beams were first investigated at the Institute of Nuclear Physics and in 1978 the project of the colliding linear electron-positron beams facility (VLEPP) was presented[2].

The main VLEPP facility elements are two identical linear accelerators. In one of them the electron beam is accelerated and the positron beam is accelerated in another one. The electron beam is moving to meet the positron beam. At the collision point between the accelerators the detectors are installed.

2. Let us treat the specific features, effects, problems and potentialities of the VLEPP project. A lay-out of the installation is depicted in Fig. 1. In the basic VLEPP mode of operation the beams are accelerated in the two linear accelerators, which are several kilometers long with an energy gain of about 100 GeV per 1 km. The linac accelerating structure consists of the separate accelerating sections. Each accelerating section is 1 m long and is fed by the individual high power RF generator. The wave length of RF-source is 5 cm. The synchronism of the RF-power sources is provided by the special line. Quadrupole lenses are installed between the accelerating sections. In each linear accelerator only one bunch of polarized electrons or positrons is accelerated per one cycle. The bunch length is 0.5 cm and the number of particles in the bunch is 10^{12}.

After collision at the interaction point with a very strong focusing ($\beta_{min}=0.5$ cm) providing the 10 mkm^2 effective beam area, the bunches are slightly deflected

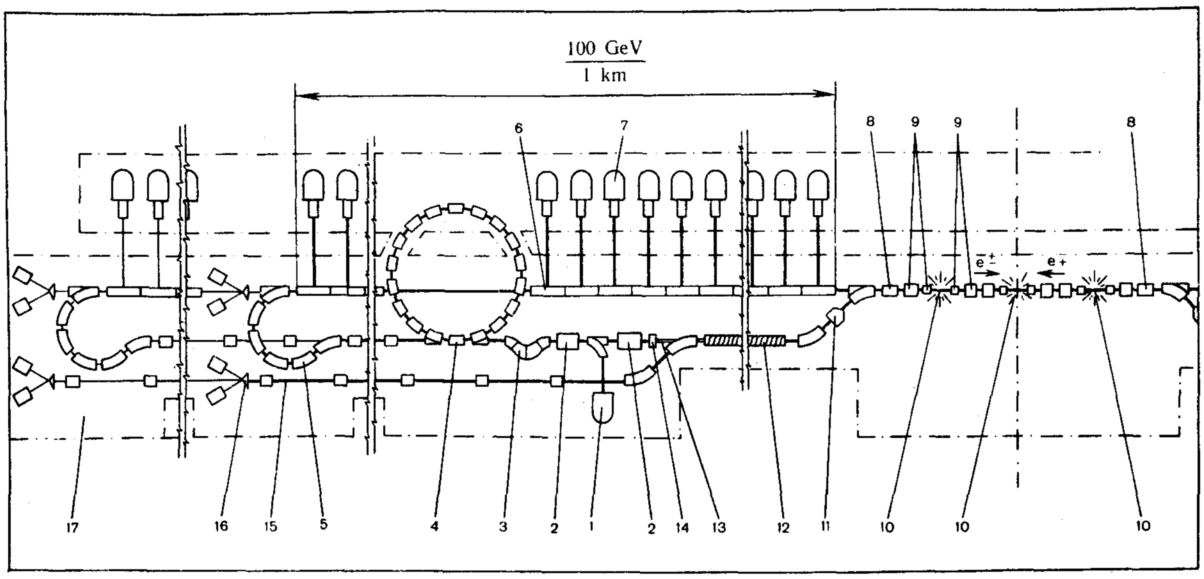

Fig. 1. The general lay-out of the VLEPP facility:
1—initial injector; 2—intermediate accelerator; 3—debuncher-monochromatizer; 4—storage ring; 5—buncher; 6—accelerating sections; 7—RF-generators; 8—pulse deflector; 9—focusing lenses; 10—collision points; 11—spectrometer; 12—helical ondulator; 13—the beam of γ-quanta; 14—conversion target; 15—residual electron (positron) beam; 16—electron (positron) beam experiments; 17—the second stage.

by a pulsed magnetic field from the acceleration line and are directed into conversion systems. Each of these systems consists of a long helical magnetic ondulator. While passing through the ondulator, the particles emit about 1% of their energy in the form of circularly polarized photons with an energy of about 15 MeV. The remaining polarized beams are then removed from the photon propagation line, and are directed either to the stationary target experiments hall or to the beam collector. The photon beam enters a target-converter. The upper part of the spectrum of the produced $e^{\pm}$ will be longitudinally polarized. These particles are collected by a short-focus lithium lens, «captured» by the accelerating section and accelerated to an energy of 1 GeV with the effective conversion coefficient equal to 1. The bunch is then lengthened to 10 cm with a bending expander and the energy gradient along the bunch is compensated by means of an appropriate accelerating section. Simultaneously, this method allows to decrease proportionally the requirements on the energy acceptance of the damping ring. The polarization of the particles is then transformed into the transverse (vertical), and the particles are injected correspondingly into electron or positron damping-rings. In this storage rings the beams are cooled down to the required, very small emittances (the required emittance in the vertical direction is about 300 mkm·mrad at an energy of 1 GeV). The cooled beams are directed into bending bunchers, the bunches are shortened from 10 cm to 0.5 cm, the $e^{\pm}$ polarization is transformed as required in the given experiment and the bunches are injected into the main linear accelerators. The cycle is repeated 10 times per a second. In this case the luminosity will be of the order of 10^{32} cm^{-2} c^{-1}. It is possible to increase the frequency of cycles up to 100 Hz, and therefore to increase the luminosity 10 times higher by means of additional power.

3. Let us analyse the main problems of the single bunch acceleration in the linear accelerator. The longitudinal bunch dynamics is determined by an accelerating field excited in the structure by an external generator and by a radiation bunch field. The self-field of an ultrarelativistic bunch has no practical influence on the motion of the «own» particles. The radiation field in an accelerating structure having the azimuthal symmetry can be represented in cylindrical coordinates as a sum over azimuthal harmonics, for example for $\bar{E}$

$$\bar{E} = \sum_{m=0}^{\infty} E_m \cos m\varphi .$$

The harmonics of the longitudinal electric radiation field $E_{\parallel m}$, which determine the longitudinal dynamics of the particles, are proportional to $r^m\delta^m$, where δ is the deflection of bunch trajectory from the symmetry axis and r is a coordinate of the observation point. It is seen that the longitudinal motion is mainly influenced by the azimuthal-symmetric harmonic ($m=0$).

The calculations[4,5,6], which have been made by solving directly the Maxwell equations for a diaphragmed waveguide excited by the given motion of an ultrarelativistic bunch with smooth longitudinal charge distribution, have shown that one can transfer to the accelerated particles a substantial fraction of the energy stored in the accelerating structure and simultaneously to provide a sufficiently high monochromaticity by selecting the bunch and the accelerating field parameters. Fig. 2 illustrates the distribution of the averaged longitudinal field along the bunch in the designed project, $N=10^{12}$, $\sigma \simeq 4.6$ mm, with an amplitude of the mean external field of 100 MV/m. In this case the energy gain is 80 MeV/m with a monochromaticity of $\pm 1\%$, and the bunch carries away about 30% of the stored energy.

4. The transverse motion of intense bunches in a linac proves to be much more complicated and rich[4,7], and the solution of the problems of conserving the very small value of the transverse emittance during accelerating gives rise to a considerable complication of the installations. Let us discuss in somewhat greater details this problem.

The transverse bunch dynamics is determined by the radiation fields of a bunch and fields of quadrupole lenses. The field of external generator and self bunch field have no influence on the «own» particles.

We'll first examine the action of radiation fields. The azimuthal harmonics of the transverse components of these fields $E_{\perp m}$ and $H_{\perp m}$ are proportional to $mr^{m-1}\delta^m$. Correspondingly the first harmonic turns out to be a determined one. Therefore the appearence of transverse forces in a first approximation proves to be connected with the presence of the coherent shifts of the bunch segments relative to the symmetry axis of the structure. The transverse force is proportional to the value of the shift and is uniform near the structure axis.

The radiation fields of an ultrarelativistic bunch in the diaphragmed waveguide, which act the bunch particles can be considered as a result of the self-field diffraction on the diaphragms[8]. The field, which yields the transverse forces, appears upon the bunch trajectory deviation from the symmetry axis. Such a diffracted field, excited by an infinitely short bunch element, can

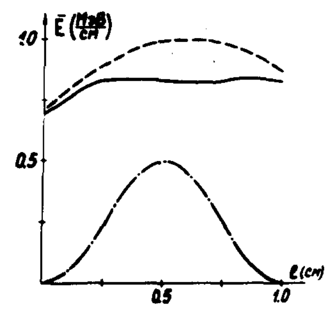

Fig. 2.

reach this element in a free space at the distance of γr_d, where r_d is the radius of a hole in the diaphragm. It is clear that in our case this field will be already infinitely small because of its attenuation when passing through a large number of diaphragms. For this reason the self-action of the bunch element is equal to zero. The actions exerted by the bunch elements that follow closely the exciting element is also incomplete because of the mutual compensation of the electric and magnetic field forces of a wave that follows the relativistic particle at a small angle to its trajectory. The effective transverse field will be maximal for the particles which are left behind at a distance of the order of $2r_d$ from the exciting element. Fig. 3 gives the distribution of the averaged effective gradient of transverse field, acting on the particles of the bunch travelling with a steady shift relative to the symmetry axis of the accelerating structure. The quantity $\bar{G}$ is given as a function of the particles position inside the bunch for the structure with a large aperture. This type of structure will be used in the initial part of the linear accelerator. The action of this field is directed along the shift causing it, i. e. strives to increase to an even larger extent the deviation of the «tail» elements of the bunch shifted as a whole.

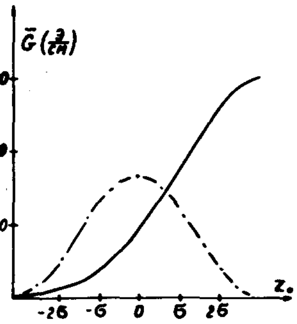

Fig. 3.

It is evident that such a structure of radiation fields gives rise to the appearance of the instability of transverse coherent oscillations of the bunch travelling in the system accelerating sections—quadrupole lenses. This instability manifests itself in an unlimited growth of the oscillation amplitude raising from the unchanged initial amplitude for the «head» particle up to the maximum for the tail one. The process of development of this instability is demonstrated in Fig. 4. This instability leads to a completely inadmissible increase in the emittance of the beam after acceleration. The methods used in conventional linacs against similar phenomena fail in acceleration of single bunches. The most effective method to overcome this obstacle, which was first suggested at Novosibirsk[4], is introducing a large particle energy gradient along the bunch. This leads to the frequency gradient of individual transverse oscillations of the bunch elements and thereby introducing a certain similarity of the Landau damping. Since the force acting on the «tail» elements upon oscillation of the bunch as a whole is directed along their displacement, preferable would be the sign such that this additional force is compensated by an increase of the focusing action of quadrupole lenses. Therefore the particles of the bunch's «head» should have a higher and the particles of the «tail» a lower energy compared with a mean one. The relative difference in the energies of the bunch particles, which corresponds to such a situation, can be estimated according to the formula

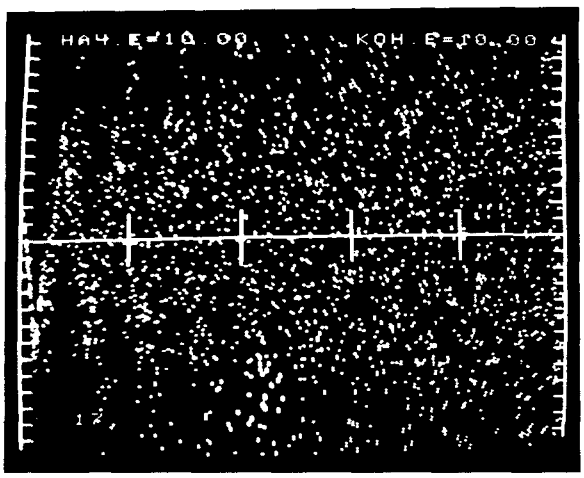

Fig. 4.

$$\frac{E_{head}-\bar{E}}{\bar{E}} = \frac{\beta_F^2\, e\, G_{max}}{2E} \approx r_e\, \frac{N}{\gamma}\, \frac{\beta_F^2}{r_d L_d}, \qquad (1)$$

where $G_{max} \sim N$, β_F is the beta-function of the transverse oscillations at the given stage of acceleration, L_d—the period of the accelerating structure.

Computer simulations, which have been performed for the complete process of acceleration in the VLEPP linacs, have shown that in order to suppress this instability at the standard parameters it is sufficient to introduce the energy gradient of the particles along the bunch such that the head's and tail's energies differ by $\pm 15\%$ from the mean at an initial energy of 1 GeV. This gradient can be gradually decreased during acceleration according to formula (1).

The needed gradient can be imparted to the bunch by a correct choice of its phase in the first accelerating sections with respect to the field excited by an external generator, and controlled, in the same way, in the further process of acceleration.

5. The action of a variety of factors which perturb the transverse motion of a bunch, and connected with various errors in the position of the focusing elements and accelerating sections (in our case, highly-intense bunches with a large gradient of transverse frequencies with the stringent requirements on the resultant emittance of a beam) needs to be considered in very detail[4,9].

Let us quote the main sources of such stochastic perturbations and make very rough estimations under the assumption that there is no feed-back beam position correction yet, and the perturbations of individual acting elements are independent.

1) Let us evaluate the influence of random shifts of the optical axes of quadrupole lenses. We will assume that the focusing is made with quadrupole lenses of constant length and with constant gradient. For simplicity, these lenses are set at equal distances apart. At a low energy, the polarities of the lenses alternate, thereby providing the focusing in the centre of the stability domain. As the energy and focal length of particular lenses increases, there are first joined in the same-polarity pairs with alteration of pair polarity, then form the sets with three lenses in each, and so on. If the transverse shifts of individual lenses are completely independent, the resultant mean square of the transverse momentum $\overline{(\Delta P_\Sigma)^2}$ will be approximately equal to the rms momentum $(\Delta P_i)^2$ due to one lens kick multiplied by half the number of lenses $N_L/2 = L/2L_1$, where L is the length of an accelerator, and L_1 is the distance between the neighbour lenses (1/2 takes into account the unequal effectiveness of a single strike at different phases of transverse oscillations). The corresponding mean-square value of the angle at the accelerator exit will be equal to $\overline{\theta^2} = \frac{\overline{\Delta P_\Sigma^2} c^2}{E_{fin}^2}$. If β_F^{fin} stands for the beta-functions of the accelerator focusing system at the exit, we obtain for the low-intensity bunch that the particle at the accelerator exit will be, in average, on the phase ellipse whose area is $\beta_F^{fin}\,\overline{\theta^2}$. If the errors in the lenses are constant in time and the energy of particles slightly varies, the particle at the exit will then trace around the entire boundary of this ellipse. In the case when the energy spread in the beam is so large that such «scatterings» over the phase of the transverse os-

cillations occur several times in the process of acceleration— namely such a situation is planned for VLEPP in order to eliminate the coherent instability—then the particles in the bunch occupy completely the finite ellipse on the phase plane. Hence, the emittance of the beam at the linac exit is estimated as follows:

$$\varepsilon = \frac{\delta_L^2 \beta_F^{fin}}{2F_{in}^2}\left(\frac{E_{in}}{E_{fin}}\right)^2 \frac{L}{L_1}, \qquad (2)$$

where δ_L is the rms error in the position of the optical axis of lenses, and F_{in} is their initial focal length.

This emittance can be somewhat decreased if we switch off the end lenses in long series (the end lenses mutually compensate with those of neighbour series). As a consequence of the fact that the oscillations acquired on the last section of the accelerator have no time to dephase, the real emittance with respect to the centre of the beam will be a little less; note that the coherent part of the oscillations should be taken into account when the colliding bunches are aimed at each other.

Of course, the correct estimations can be made in computer calculations with due regard for the forces acting from the side of radiation fields (see the foregoing section).

2) Misalignment of the accelerating sections, occurring because of the errors δ_{str} in their adjustment relative to the optical axis of the focusing system, also results in the appearance of the nearly uniform transverse momenta (on account of the transverse component of the accelerating field in the misaligned section). The final effect is similar to that taking place because of the errors in the position of the lenses. From this point of view, the statistically independent errors in the position of the ends of the sections will be equivalent to those of the lenses, which satisfy the condition

$$\delta_{str}^{eq} = \frac{E}{F_L\, dE/dL}\,\delta_L .$$

Correspondingly, the allowable errors, reffering to this effect, in the position of the sections for VLEPP, will be more than one order of magnitude larger compared with those in the position of the lenses.

3) With the shift of the axes of the sections, the particles in the bunch acquire a strike, connected with the radiation fields, in the direction opposite to the section shift (the strike is zero for the «head» particles, and is maximal for the «tail» ones). The acquired transverse momentum, in its average value, will be equivalent to that from the shifted lens if the relation

$$\delta_{str}^{eq} = \frac{4E}{eG_{\max}L_1F_L}\,\delta_L$$

is satisfied. Since the strikes are not equal for different particles along the bunch, the phase ellipse is filled considerably more rapidly than in the preceding cases.

The influence of the transverse strikes on the total emittance can be decreased sharply if the centre of gravity of the bunch is matched with the optical centres of the lenses on the whole length of an accelerator. The admissible errors of such a matching exceed more than by one order of magnitude the allowable deflections of the lenses in the case of their uncorrelated position errors.

Such a correction of the beam and lenses can be made only during many operation cycles of a collider by successive approximations. For the shorter periods of time, stabilization of the position of the lenses should be provided to much higher accuracy required for the case of the completely uncorrelated perturbations.

If the shift of the lenses is caused by the transverse (vertical) seismic waves, their influence will be noticeable if only their effective wavelength is of the same order of magnitude or less than the wavelength of the transverse oscillations of the beam. Otherwise, their influence is not significant.

The other kinds of perturbations (turns of the lenses, non-linearities in the lenses of the accelerator, instability of their gradients, etc.) doesn't look so dangerous as those considered above.

For the VLEPP, in working with flat beams, the required uncorrelated stability of the optical centres of the lenses constitutes fractions of a micron.

6. Let us examine now what happens in the collisions of such dense bunches[1,2,10]. The electric and magnetic fields of bunches, of the intensity under discussion and micron transverse sizes, attain megagauss magnitudes. For the particles of their «own» bunch the forces exerted by the electric and magnetic fields mutually compensate and exert no influence on the behaviour of the particles. At the same time, their action on the particles of the counterbeam add up, and the maximum effective field is doubled:

$$|\bar{H}_{eff}| = |\bar{H}| + |\bar{E}| = \frac{4N_e}{l_e(\sigma_x+\sigma_z)}.$$

Here σ_x and σ_z are the transverse half-dimensions of the beam at the oscillation point, and l_e is the length of a bunch.

Let us examine briefly three aspects of the influence of these fields.

First, in this field the particles emit synchrotron radiation and here the distance of the total energy loss proves to be very small:

$$l_{rad} = \frac{mc^2}{r_e^2\gamma H_{eff}}.$$

Consequently, instead of collision of monochromatic electron-positron bunches, we obtain for $\sigma_x=\sigma_z$ a diffuse spectrum of e^+e^- reactions together with a multitute of $e\gamma$ and $\gamma\gamma$ collisions. Therefore one must resort to flat bunches, while conserving the cross-section area to maintain the luminosity. As we have seen, the fields here decreases in proportion to the increase in the width of the bunch. The reaction energy spread will correspond here to the energy spread in the beam

$$\frac{\Delta E}{E} = \pm\frac{2r_e^3N^2\gamma}{l_e(\sigma_x+\sigma_z)^2}.$$

The maximum dimension is determined by the required monochromaticity.

Second, the field of the counterbeam of particles of the opposite sign exerts a strong focusing action. Consequently, during the time of collision of the bunches, the particles execute several oscillations. Here no increase in the effective dimensions occurs in head-on collisions for bunches having a smooth density distribution in all directions (there is even a small contraction). It has been shown by computer simulation of the self-consistent collision that the plasma type instability develops if the number of oscillations over small (vertical) size is more than 2. This boundary determines the ultimate density of the bunches. Note that the effect being discussed sharply diminishes the attainable luminosity of electron-electron (or e^+e^-) colliding beams (defocusing).

The third important effect of the coherent fields of the counterbunch is their action on the behaviour of the spins of polarized colliding beams. The rotation of the spin with respect to the velocity of the particles that arises from the anomalous magnetic moment, when the angles of the transverse oscillations of the particles in the field of the counterbunch are too large, completely depolarizes the electrons and positrons in the process of collision. The allowable angles in the beam here amount to

$$\theta_{allow} \approx \frac{1}{3}\frac{g_0}{\gamma g'} = \frac{0.15}{E_{\mathrm{GeV}}}.$$

In order to fulfil this condition for horizontal direction (in the case of longitudinal polarization), we must have

$$\alpha r_e \frac{N}{\sigma_x+\sigma_z} \lesssim 1, \quad \alpha = \frac{1}{137}.$$

Going over to flat beams solves this problem as well.

The decrease in one of the dimensions of the bunches to such small magnitudes requires a quadratic decrease in the emittance of the beam in this directions. If this requirement proves to be too difficult to satisfy technically, one can resort to the variant of collision having four bunches in each collision—an electron and a positron bunch each side. If the bunches moving from each side are superimposed on one another up to the collision point, then their coherent fields mutually compensate to the accuracy of the matching of the bunches and superimposing them. Therefore all the effects of the collision are sharply weakened (the radiation is decreased even quadratically) and cease to play a deleterious role. It is the logically simplest way to obtain four bunches by employing four independent accelerators, but one can also simultaneously accelerate electron and positron bunches in a single accelerating structure with a shift of one-half wavelength between them, with a subsequent delay in the leading bunch.

Note that in this regime half of the total luminosity will be due to e^+e^- reactions, while the other half is divided equally between e^-e^- and e^+e^+ collisions.

The energy of the second pair of e^+e^- bunches can be several times lower compared with the ultimate energy of the collider. In addition to the gain in the cost, this offers the possibility of measuring the charge asymmetry of the processes under study.

7. One of the basic problems in achievement of a high luminosity in linear colliders is to obtain an ultimately strong focusing at the collision point. Here one of the main difficulties is to eliminate the deleterious action of chromatic aberration. This is of great significance because the energy spread in the beam will be not less than 1% in the main regime.

The standard way to compensate the chromaticity by excitation of the energy dispersion, by means of the bending magnets and with the use of sextupole correction, turns out to be practically unsuitable for the $e^\pm$ of such high energy. As the most promising for VLEPP, the variant has been chosen of using, at the final stage of focusing, two very strong quadrupole lenses, and of compensating their relatively small chromatic aberration with the remaining lenses in the collision straight section. (Despite very high gradients, the smallness of the beam dimensions in these lenses provides the smallness of the synchrotron radiation losses in them.) These lenses are placed inside a detector at a very short distance from the collision point, and their (very small) aperture should be sufficient to transmit both the particles of the main beam whose emittance raises after its strong perturbing interaction with the counterbeam and the flux of photons of synchrotron radiation on this bunch, as well as the various secondary particles emitting from the collision point at small angles.

Employment of short-focus lenses solves to a considerable extent the problem of chromatic aberrations. However, without special measures, even in this case, the increase in the beam dimensions at the collision point will constitute 1.5—2 times because of the chromatic aberration for the energy spread ±0.5%. In order to eliminate completely the chromatic aberration in a first approximation, the decision has been made to build the VLEPP optics in its final part in a way such that the chromaticity of the last lens is compensated by the chromaticity of the remaining lenses of the straight sections.

Below, an example is given of the optics performing the achromatic focusing in the linear over $\Delta E/E$ approximation at the collision point in the vertical direction for an energy of 150 GeV (the sequence of distances starts from the collision point, and «+» stands for the horizontal focusing polarity):

Length (cm)	Gradient (kG/cm)
20	0
100	−122.8
70	0
80	46.74
510	0
80	−75.65
180	0
100	27.70
80	0
100	−18.19
40	0
100	11.86
400	0
100	−14.29
400	0
100	18.20
400	0
100	−27.74

For $E=150$ GeV this scheme ensures the following parameters of the focusing: $\beta_z=0.5$ cm and $\beta_x=100$ cm.

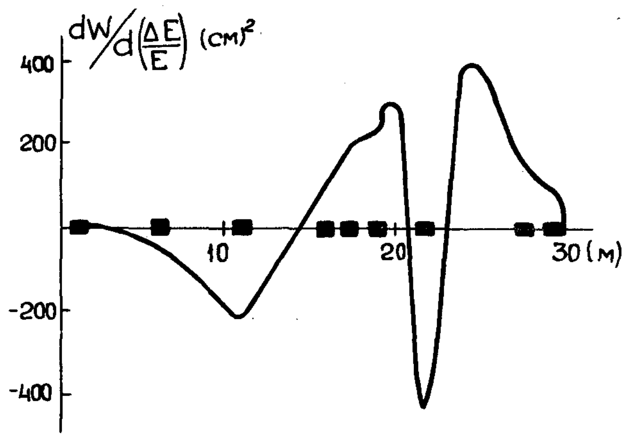

Fig. 5.

Fig. 5 shows the diagram of the chromaticity of the focusing (to be precise, of the function $dw/d(\Delta E/E)$ where w is the Floke function for vertical direction) along the collision section, calculated for the above example.

After compensation of the linear part of chromaticity, the increase of the vertical dimension because of the contribution from the higher-order terms over $\Delta E/E$ has become equal to less than 10% for $\Delta E/E = \pm 1\%$. This can be considered already as a satisfactory result.

The most serious technical difficulty which arises in realizing the optical scheme, described above, of the final section of VLEPP is the development of miniature short-focus lenses with the gradients of 100—1000 kG/cm. Today we consider two kinds of such lenses. These are the permanent lenses made of $SmCo_5$ with the gradient of 100—200 kG/cm for relatively low 100—200 GeV energies (a sufficient energy variation requires the replacement of these lenses), and the pulsed lenses with the gradients up to 1000 kG/cm for an energy up to 500 GeV. With the small apertures being planned, the fields in these lenses will not exceed the technically realistic ones.

8. The necessity to focus the beams at the collision point into very small sizes compels one to impose stringent requirements on the preparation of bunches for their injection into the linacs. So, in the VLEPP project, the bunches of $e^{\pm}$, each containing 10^{12} particles, 0.5 cm long and with the very small vertical emittance of $3 \cdot 10^{-8}$ cm·rad, must be injected into the linacs at an energy of 1 GeV. It is extremely difficult to prepare such bunches directly in storage rings-coolers and, therefore, the bunch before its injection into linacs is subjected to a 20-fold longitudinal compression (see Section 2). This offers the possibility of working in coolers with the bunches of 10 cm long. This substantially simplifies the «struggle» with the coherent instabilities of different nature, and helps to suppress to the needed level the diffusions caused by a multiple intrabeam scattering.

With an energy of 1 GeV and the required parameters of a bunch, this diffusion proves to be considerably more intensive in comparison with that caused by the quantum fluctuations of synchrotron radiation. The ratio of the diffusion rate to the rate of radiation cooling determines the equilibrium emittance (first of all, energy spread and radial betatron emittance). The equilibrium vertical emittance is mainly determined by the coupling of the vertical motion with a radial one. As our experience shows, such a coupling between the amplitudes of vertical and radial oscillations can be made equal to 0.04. If this relation is considered as a given one, then from the required vertical emittance we obtain the requirements on the radial. It is possible to show that, using sufficiently high bending magnetic fields (20 kG) and assigning a sufficient rigidness to the focusing structure of a storage ring (dimensionless frequency of transverse oscillations is about 10) and preventing the emittance from increasing due to the coherent effects, one can achieve the parameters of the bunches necessary for VLEPP.

To the very important requirements on storage rings are referred a sufficient magnitude of the acceptance to receive the $e^{\pm}$ newly generated by the method described above, and the capability of conserving, at the initial level, the degree of polarization of the injected particles with vertical spins. Note that the system of primary stacking of electron bunches can be useful also for stabilization of the intensity of the VLEPP beams.

9. Let us treat now some questions and problems connected with the design of linear accelerators. The choice of the parameters of accelerators has a decisive influence on an installation as a whole. To optimize the parameters one should take into consideration many technological and economical factors in addition to physical problems. Here we can discuss only few questions and present a variant of their solution in VLEPP project.

In this project the main task is to provide a high rate of acceleration, about 100 MeV/m. Such rate allows to decrease proportionally the length of the installation and to increase proportionally the energetically admissible number of particles in a short bunch about 10% of the wavelength of the accelerator. In the preliminary experiments with a single resonator[11] the possibility of attaining the required gradient of about $1.5 \div 1.8$ MV/cm on the most tensed parts of the surface was shown and tested. So for the rate of electron acceleration achieved in Novosibirsk[12,13,14] on the many-cell section with a wavelength of about 5 cm is 90 MeV/m. It is important to note that there weren't breakdown limitations in the regular parts of the accelerating structure.

It's reasonable to obtain a high rate of acceleration[11] in the waveguides wherein the distance between the diaphragms is equal to half of the wavelength (naturally, the phases of oscillations of the adjacent resonator cells must be shifted in phase by 180°—the so-called π-structure). The needed coupling between the cells is performed by concentric, side coupling resonators, and a section of about 1 m long will be filled with an electromagnetic energy during the wave propogation from the centre to the end and backwards. This duration is much shorter than the time of dissipation in the waveguide's walls (about 0.2 μs). After the returning of the reflected wave to the place of power input almost all the energy is concentrated in the main waveguide (only small part of it remains in the coupling resonators), so a considerable part of it can be carried away by the short bunch. An important advantage of this scheme is the improving rather than damaging character of the breakdowns, because in case of breakdown in one of the cells only an insignificant part of all the power applied to this section is dissipated in the breakdown zone, while the remaining power is reflected from the breakdown-closed cell whose impedance is of reactive nature.

Another important advantage of the developed structure of the linac for the VLEPP is relatively small exceeding of the maximum strength of an electric field on the metals surface compared with the value of the accelerating gradient (the ratio is about 1.6) with a sufficiently large hole in the diaphragm for beam passage.

The choice of the high rate of acceleration doesn't lead to the growth of the mean power consumed by linacs from the mains, because the $e^{\pm}$ bunches take away about 30% of the energy stored in the accelerating section constituting about 30 J/m. However, the high rate of acceleration requires the RF generators with a very high pulsed power (over 200 MW/m). So the major technical problem associated with the creation of a linear collider is the development of RF cm-range generators of a completely new level of power (the total peak RF power of the full VLEPP project is about 4000 GW for $2E=1$ TeV). At present the commercially produced generators can't provide the operation of linear colliders. Our hopes are connected mainly with the fast developing of the high-power electron relativistic beam's techniques. It ought to be stressed that the level of generated RF power close to the required has already been achieved, but the technology of powerful RF generators should be developed to achieve fine control and stabilization of the frequency, amplitude, phase in the amplifying regime at a considerable repetition rate (about 10 Hz and higher) and a long working time.

10. It's possible to expand further the spectra of the reaction obtained on single-pass colliders. Laser technology is approaching to the creation of highly effective photon targets (at least, of small cross-section). It makes possible to convert the major fraction of the electrons for one pass immediately before collision into γ-quanta with an energy close to the total energy of the accelerated particles owing to the inverse Compton effect. It would make possible therefore to attain actual photon-photon colliding beams at superhigh energies[15,16].

Comparatively inexpensive modification of the injection part of the installation can provide additional important experimental capabilities of the linear collider — acceleration of the protons of initial energy 10 GeV up to the final energy in regular VLEPP structure. To provide the equivalent high luminosity as for e^+e^- collisions it is necessary to accelerate the proton bunch with the same intensity and emittance.

At present the polarized proton bunches production with the required parameters are already possible. The sources of negative hydrogen ions with polarized protons are now under development. The recharging proton storage technique is already developed and the circulating current of thousands times higher than the injection current can be stored. The very small final emittance of the polarized proton bunch can be achieved with the help of fast electron cooling technique. The main application of this regime will be the conducting the experiments with electrons and protons of required palarization. Experiments with γp beams are also of great interest. The γ-beams can be produced by the laser conversion of the electrons.

The possibility of polarized proton beams production makes the experiments with colliding proton beams of high interest. The linear colliders under discussion can be employed in a regime parallel to the colliding beam regime as an accelerator that yields 10^{13} electrons and positrons per second with any required polarization having the full energy E. Also, if one employs the laser conversion of the processed $e^\pm$ one can use it as a source of polarized γ-quanta of almost the full energy with sufficient monochromaticity and an intensity of the order of 10^{12} s^{-1} for experiments with stationary targets.

One can obtain very intense, well collimated fluxes of high-energy neutrinos of all types by directing the electron, or even better the photon, beams of the VLEPP onto a target. Especially interesting, these fluxes will be sharply enriched in ν_τ-neutrinos from the decay of photoproduced τ-leptons (and if they exist, in neutrinos from heavier leptons). Here the flux can be as great as $10^6 \nu_\tau/s$ in an angle $M_\tau c^2/s$ with an energy of the order of $E/4$.

In a special regime one can obtain polarized electrons, positrons, and photons of twice the energy by making the $e^\pm$ pass successively through both linacs (the sections of the second linac in this case must operate with a time shift opposite to the normal).

If one supplements the VLEPP with intense source of charged pions and cooled muons, one can also use it to accelerate them.

11. Finally, the Table of the basic parameters of the VLEPP installation is presented.

	First stage	Full project
Energy	2×150 GeV	2×500 GeV
Length	2×1.5 km	2×5 km
Luminosity	10^{32} cm^{-2} s^{-1}	
Number of collision points	5	
Frequency of cycles	10 Hz	
Number of particles per bunch	10^{12}	
Mean beam power	2×250 kW	2×900 kW
Peak RF supply power	1.000 GW	4.000 GW
Total consumed power from the supply mains	15 MW	40 MW

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