ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ СО АН СССР

V.V.Anashin, I.B.Vasserman, V.G.Vesherevich,
B.I.Grishanov, A.V.Evstigneev, I.A.Koop,
V.I.Kupchik, V.M.Mejidzade, A.A.Michailichenko,
E.A.Perevedentsev, V.M.Petrov, I.K.Sedljarov,
A.N.Skrinsky, E.M.Trachtenberg, Yu.M.Shatunov

DAMPING RING
FOR ELECTRONS AND POSITRONS BEP

PREPRINT 84-114

НОВОСИБИРСК

DAMPING RING FOR ELECTRONS AND POSITRONS BEP

V.V.Anashin, I.B.Vasserman, V.G.Vesherevich,
B.I. Grishanov, A.V. Evstigneev, I.A. Koop,
V.I.Kupchik, V.M.Mejidzade, A.A.Michailichenko,
E.A.Perevedentsev, V.M.Petrov, I.K.Sedljarov,
A.N.Skrinsky, E.M.Trachtenberg, Yu.M.Shatunov.

Institute of Nuclear Physics

Novosibirsk, 630090

Abstract

The characteristics of the storage ring BEP which is under construction at Novosibirsk Institute of Nuclear Physics are given. The machine is designed for generation of high-intensity electron and positron bunches with small transverse sizes suitable for the injection in the superlinac.

Introduction

Within the framework of the VLEPP project [1] the electron-positron storage ring BEP for the energy of 700 MeV is being constructed in the Novosibirsk Institute of Nuclear Physics. The Machine is designed for working out the techniques of generation high-intensity electron and positron bunches with small transverse sizes suitable for the injection in the superlinac.

The storage ring BEP will be installed on VEPP-2M complex. It will provide about 5 times higher positron accumulation rate as compared to VEPP-2 thus replacing the latter used as a booster for VEPP-2M. The maximum beams injection energy in VEPP-2M will raise from 550 to 700 MeV which combined with installation of the superconducting wiggler magnet on VEPP-2M, will enable the luminosity enhancement up to $5 \cdot 10^{31} cm^{-2} sec^{-1}$.

The present paper describes the project of the storage ring BEP that is planned to be assembled in 1985.

I. BEP lattice, injection and lay-out

The BEP lattice consists of 12 periods each being a FODO-cell. In contrast to the mirror-symmetric lenses arrangement here the doublet scheme of lattice is employed. Combining F and D lenses in the doublets benefits in reducing two times the number of magnets and lengthening the straight sections with the storage ring circumference kept constant. In fig.1 the amplitude functions W_z and W_x are presented for one period of the lattice and also the dispersion function η and its "emittance" J_D.

The design betatron tunes $\nu_z = 3.18$, $\nu_x = 3.61$ allow for the vertical and radial emittances the values $\varepsilon_z = 10^{-8}$ cm·rad, $\varepsilon_x = 6.4 \cdot 10^{-6}$ cm · rad at 700 MeV which are wanted for the VLEPP project. This operation points stands far enough from both linear coupling resonances and integer stopbands thus relieving the sensitivity to the magnetic structure perturbations. The many-fold symmetry of the lattice reduces the number of the dangerous non-linear resonances and simplifies the storage ring tune-up.

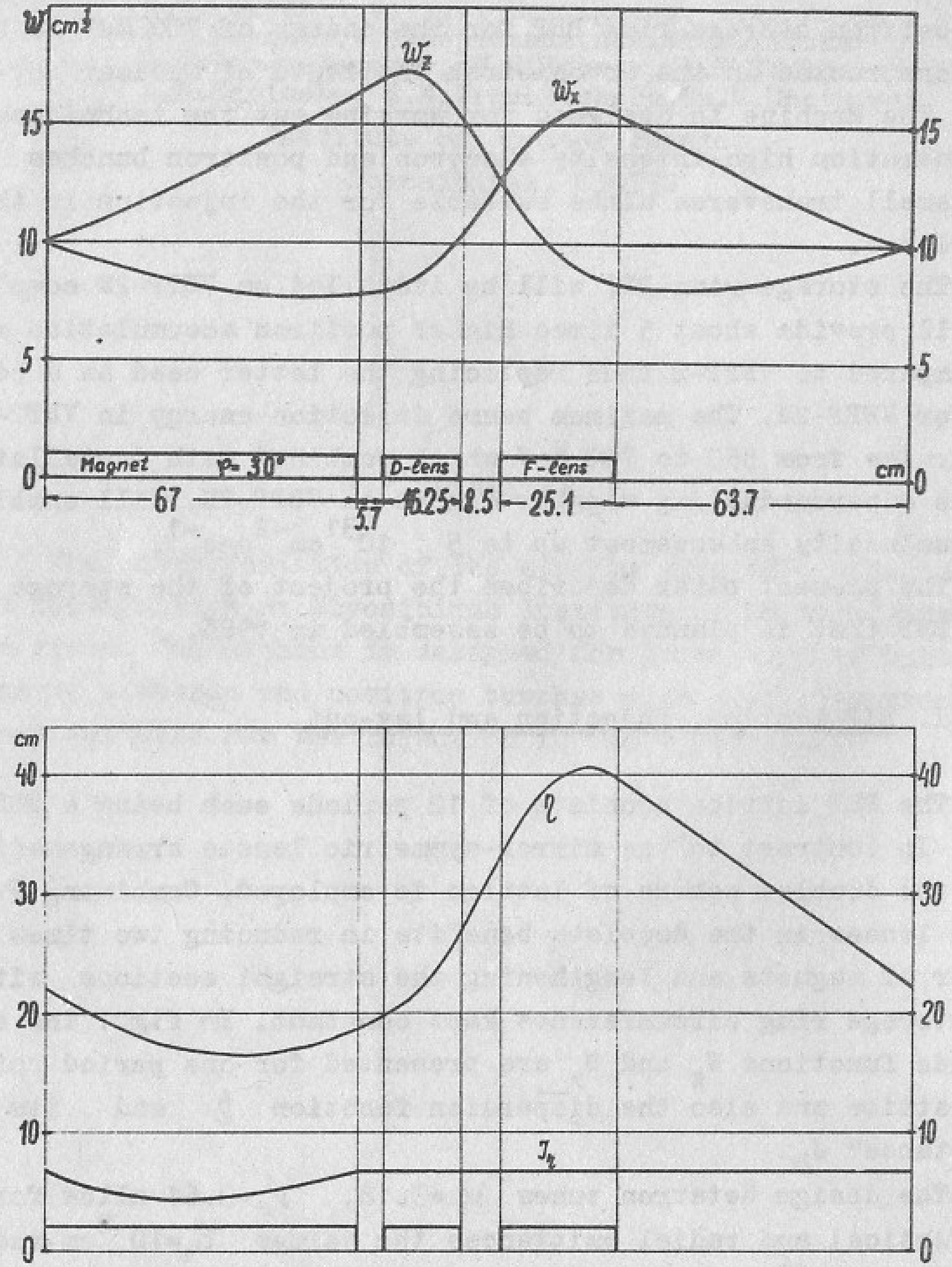


Fig.1. Amplitude functions W_z and W_x , dispersion η and its "emittance" J_η of the BEP cell.

The positron beam emittances before injection in BEP are 2.5 · 10^{-3}cm·rad and 4 · 10^{-3}cm rad (vertical and horizontal respectively) thus specifying the storag ring design admittances of 10^{-2}cm·rad and 2.5 · 10^{-2}.

The radial injection is adopted for certain advantages in the case as compared to the vertical one. Actually the vertical and horizontal sizes of the injected positron beam differ insignificantly, the radial dispersion for the partieles with energy difference of $\pm$3% is small as compared to the betatron amplitude, therefore the radial injection appears to be more economical, because it saves the bending magnets gap.

The positron beam injection scheme for BEP is shown in fig.2. The septum magnet window transmission is 10^{-2}cm·rad in acceptance and $\pm$5% in ΔE/E, the septum thickness is 3 mm. The inflector kicker magnetic field bends the beam over the angle of 0.0214 rad. To reduce the stored beam oscillation amplitude the inflector kick is partly compensated by the deflection in the pre-inflector kicker of the same design, which is located 5 periods (or 1.5 betatron wavelength) before the inflector straight section. The amplitude ratio of inflector and pre-inflector is 2 : 1 at the positron accumulation energy of 125MeV. In the mode of high electron current accumulation at 250 MeV the equal kicks in inflector and pre-inflector are expedient to eliminate totally the excitation of the stored beam coherent oscillations.

The storage ring BEP will occupy the place of VEPP-2 (fig.3) and its median plane will be at the same level as that of the injector synchrotron B-3M. The transfer line from B-3M to BEP being 11.7° declined from the present direction, the synchrotron B-3M should be rotated over the same angle. To raise the accelerated beam intensity, the certain improvements will be made in the synchrotron construction.

Stacking electrons and positrons in BEP will alternate, and so will the guide field. The initial part of the BEP to VEPP-2M will be common for the electron and positron beams.

The main parameters of the storage ring BEP are summarized in table 1.

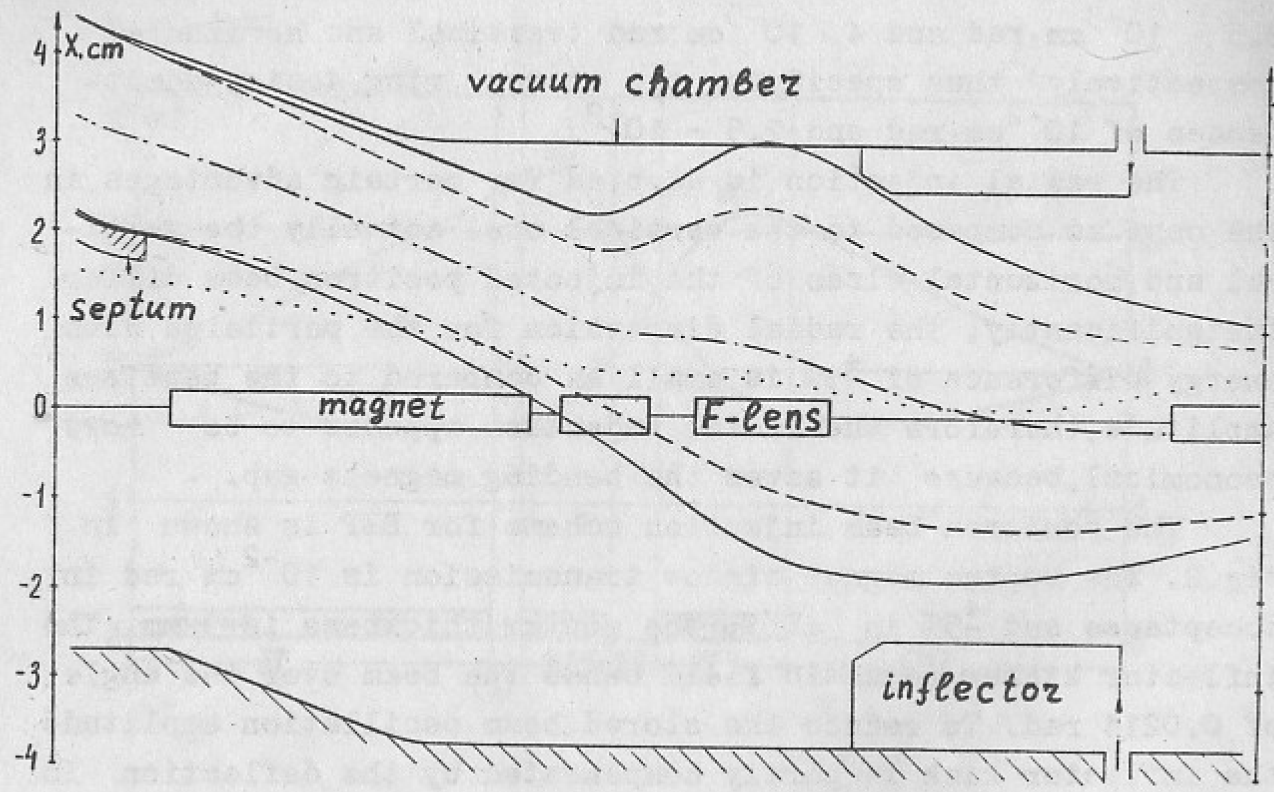


Fig.2. The positron beam injection scheme for BEP.

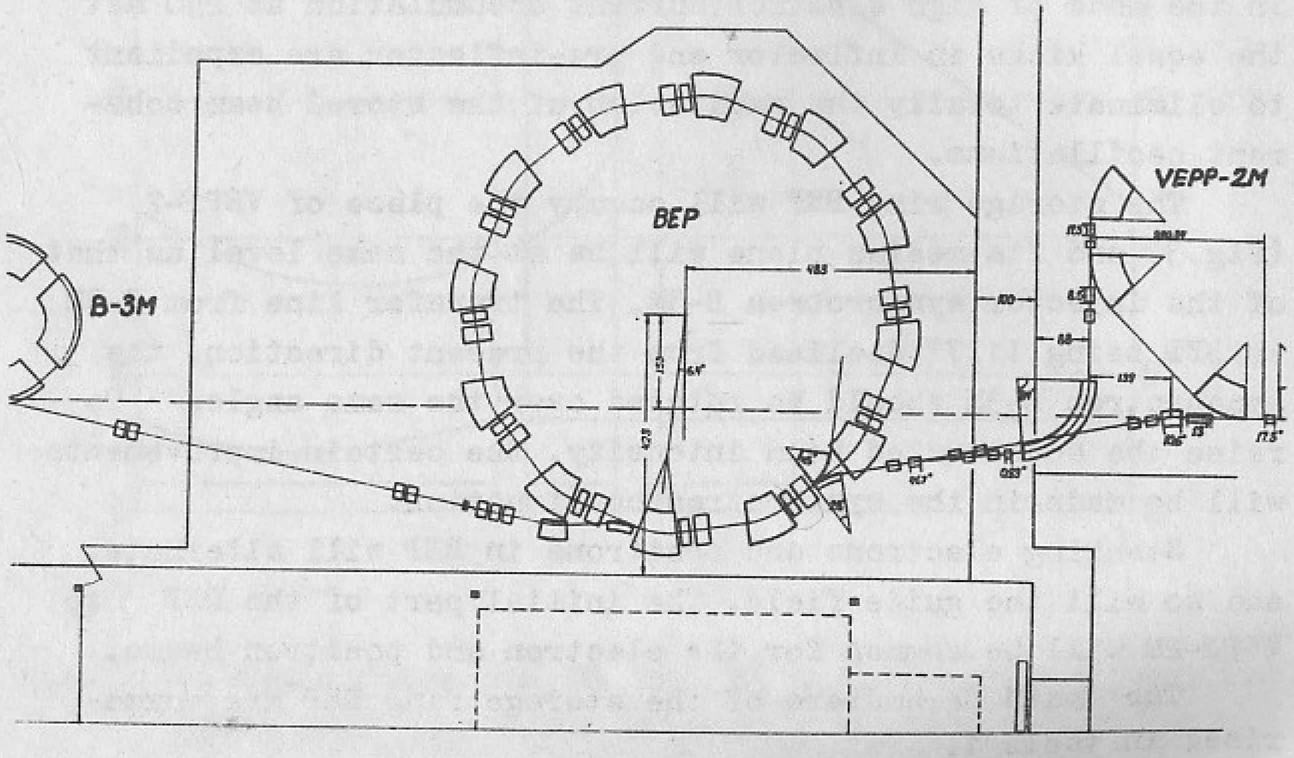


Fig.3. Layout of BEP.

Table 1

Energy		700 MeV
Number of periods		12
Circumference		22.35 m
Betatron tunes :	ν_z	3.18
	ν_x	3.61
Momentum compaction factor	α	0.05
Synchrotron radiation loss		17 keV/*turn*
Horizontal damping time		7.3 ms
Vertical damping time		6.28 ms
Dipole field		18.24 kGs
Max. quad. gradient		3.72kGs/cm
		2.48 kGs/cm
Dipole gap		40 mm
Aperture diameter in D and F lenses		56 mm
		84 mm
Max. accepted emittance		10^{-2}cm rad
Max. accepted energy spread at the injection energy 125 MeV		±3%
Harmonic number		2
Radiofrequency		26.83 MHz
Max. RF Voltage		60 kV
Synchrotron tune	ν_s	10^{-3}
SR quantum fluctuations beam sizes in max. of β-functions	σ_x	0.28 mm
	σ_z	0.012 mm
	σ_s	7.5 cm
	σ_{xs}	0.2 mm
	$\sigma_{\Delta E/E}$	0.51 10^{-3}
Beam sizes for the beam current $J = 2a(N = 10^{12})$	σ_x	0.4 mm
	σ_z	0.017 mm
	σ_s	10 cm
Beam emittances for $J = 2A$	ε_x	$6.4 \cdot 10^{-6}$cm.rad
	ε_z	10^{-8}cm.rad

II. Beam parameters

The principal mechanisms which determine the value of the equilibrium radial beam emittance ε_x are the quantum fluctuations of the synchrotron radiation (SR), and at high beam intensity also the effect of multiple intrabeam scattering(MIS).

The contribution of the SR quantum fluctuations is significantly reduced with growing ν_x [2]. For a FODO lattice the simple estimate is valid:

$$\varepsilon_x \approx \lambda \frac{R_0}{R} \cdot \frac{\gamma^2}{\nu_x^3} \qquad (1)$$

where λ stands for the Compton wavelength of the electron, R_0 is the orbit gross radius, R is the bend radius in the magnets and γ is the relativistic factor.

The MIS contribution to ε_x falls off much slower with the ν_x increase. At constant bunch length (σ_y = const) and with $\nu_x \approx \nu_z$ it is inversely proportional to the ν value and grows with the intensity as $N^{2/5}$. For the case of BEP ($N=10^{12}$, σ_y =10 cm, $\varkappa \equiv \sqrt{\varepsilon_z/\varepsilon_x} = 0.04$, $\varepsilon_x < 7 \cdot 10^{-6}$) the value of ν_x chosen is entirely determined by MIS. Below the main relations which govern this process are written down.

The energy diffusion rate is

$$\frac{d}{dt} \sigma^2_{\Delta E/E} = \frac{N r_e^2 c \Lambda}{2\pi \sigma_z \sigma_x \sigma_y \sigma_{x'} \gamma^3} \qquad (2)$$

where r_e is the classical electron radius, c is the light velocity, σ_z, σ_x and σ_y stand for the transverse and longitudinal r.m.s. particle displacements in the bunch, $\sigma_{\Delta E/E}$ is the r.m.s. energy deviation, $\sigma_{x'}$ is the local angular spread in the beam, and Λ is given by the equation:

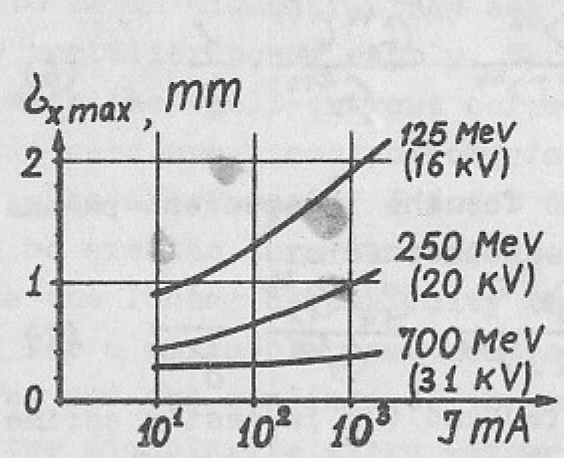
$$\Lambda \approx \left(\frac{E}{2} + \ln \varkappa^{-1}\right) \ln \sqrt{\frac{E}{2}}\, \gamma \sigma_{z'} \sqrt{\frac{\sigma_z}{r_e}} + \frac{1}{2}\left(\ln \varkappa^{-1}\right)^2 \qquad (3)$$

which is derived from the Coulomb scattering cross-section averaged over momenta. Using the relations

$$\varepsilon_x = \frac{G_s}{G_x} \langle I \rangle \sigma^2_{\Delta E/E} \qquad (4)$$

$$\sigma_y = \beta_y \cdot \sigma_{\Delta E/E} \qquad (5)$$

where G_s, G_x, G_z are the radiation damping rates of the synchrotron and betatron oscillations, $\langle I \rangle$ is the "emittance" of



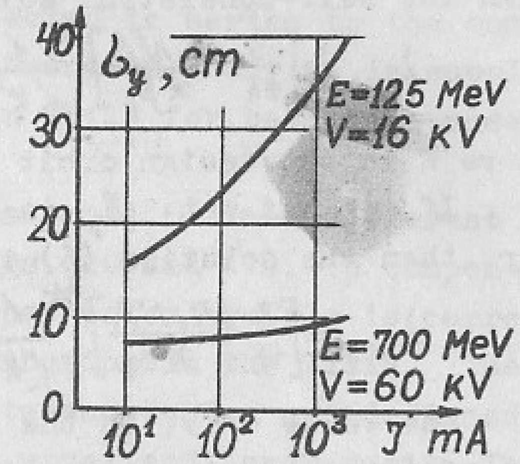
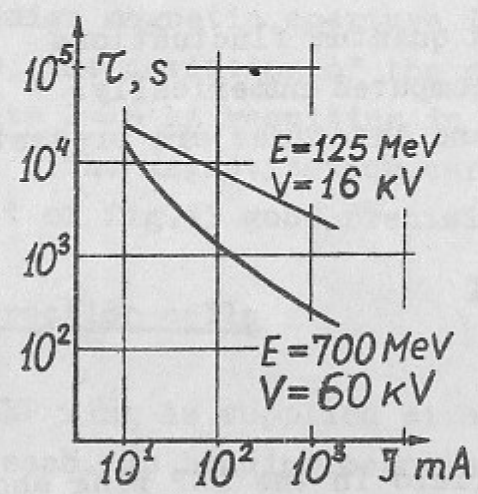


Fig.4; Fig.5. The computed radial σ_x and longitudinal σ_y beam sizes as functions of the beam current.



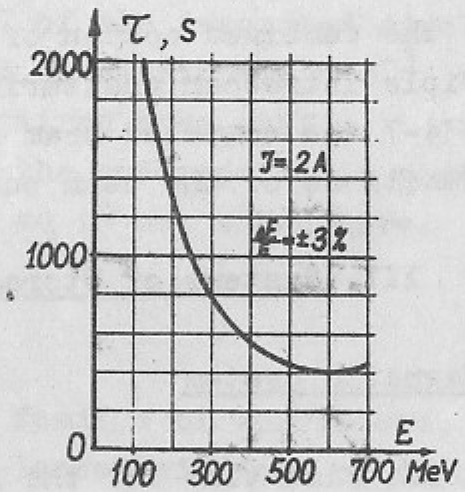


Fig.6; Fig.7. The computed beam lifetime which is determined by intrabeam scattering as a function of the beam current and of the beam energy.

the dispersion function η averaged over the orbit, and $\beta_y = R_0\sqrt{\frac{2\pi\alpha E}{qeV\sin\varphi_s}}$ is the longitudinal beta-function, we obtain the self-consistent solution:

$$\sigma_{\Delta E/E} = \left[\frac{3}{4\pi}\cdot\frac{r_e N\Lambda}{\varkappa\beta_y}\right]^{1/6}\frac{\langle\beta_z^{-1/2}\rangle^{1/6}}{\langle K^2\rangle^{1/6}\langle I\rangle^{1/4}}\cdot\frac{G_z^{1/6}G_x^{1/4}}{G_s^{5/12}}\cdot\frac{1}{\gamma} \qquad (6)$$

where K is the design orbit curvature.

If σ_y but not β_y is taken for the independent parameter then the solution (6) takes another form:

$$\sigma_{\Delta E/E} = \left[\frac{3}{4\pi}\cdot\frac{r_e N\Lambda}{\varkappa\sigma_y}\right]^{1/5}\frac{\langle\beta_z^{-1/2}\rangle^{1/5}}{\langle K^2\rangle^{1/5}\langle I\rangle^{3/10}}\cdot\frac{G_z^{1/5}G_x^{3/10}}{G_s^{1/2}}\cdot\frac{1}{\gamma^{6/5}} \qquad (7)$$

The value of Λ in the eqs. (6) and (7) is easily estimated after one or two iterations. For our case $\Lambda \approx 40$.

The attempts were made to reduce $\sigma_{\Delta E/E}$ by inserting wiggler magnets in the lattice but the benefit was small as the increase of $\langle K^2\rangle$ is unfortimately accompanied with the growth of the dispersion emittance I. The estimates done with eqs.(4) and (7) show that the specified value of ε_x is obtained in the BEP lattice at the energy of 700 MeV and the contribution of the quantum fluctuations in $\sigma_{\Delta E/E}$ and ε_x is still small.

The combined action of the SR quantum fluctuations and multiple intrabeam scattering is computed numerically. In fig. 4-7 the computed beam sizes and lifetimes are presented as functions of the beam current.

III. Systems of Storage Ring

1. Magnetic System

The rise time for the guide field in the BEP ring should be greater than 5 sec, therefore the magnets and lenses have the laminated cores made of armco iron plates 20 mm thick.

The plan view of the magnet is shown in fig.8. The magnet pole is made as a flux concentrator with strongly chamfered edges shown in the elevation view (fig.9). Thus at 9 kA current the field strength of 23 kG is obtained with good uniformity that will give the possibility to raise the energy up to 900 MeV in the BEP ring if necessary. The energy of 700MeV

corresponds to the guide field of 18.24 kG.

The main windings of the BEP lenses and magnets are made of rectangle formed copper bus 16 x 36 mm^2 with the water duct of 10 mm in diameter, they are connected in series to the common rectifier power supply. Each element of the ring is supplied with the small-current correction coils for betatron tunes and closed orbit correction.

The apertures of F and D lenses are 1.5 times different and so are the turn numbers (see figs. 10 and 11). To compensate the linear chromaticity the lens poles profile is corrected for a sextupole component contribution in the field. The cores and the windings of the magnets and lenses are designed in two disjoinable mirror-symmetric upper and lower parts. The edge commutation of the turns in the quadropoles is designed in one layer with the quadrupole symmetry preserved (fig.12).

The technical specifications of the BEP ring bending magnets and quadrupole buses are listed in Table 2.

In figs. 13-15 the computed magnetic fields in the BEP magnets and lenses are shown as obtained from the computer code available on ODRA-1305. The code calculates the vector potential on a non-uniform two-dimensional rectangular mesh. In the design magnetic aperture i.e. 0.7 of the inscribed circle radius, the deviation of the gradient is within $1.5\cdot10^{-3}$ at currents $I = 6$ kA resulting in the betatron tune shift of $6\cdot10^{-3}$. The magnetization curve for the quadrupoles is similar to that of fig.13 good precision and so is not shown here.

2. Correction coils

BEP ring is supplied with seven familys of correctors, at 12 in each. In bending magnets and D-lenses windings of dipole correctors are situated, which pemit radial and vertical closed orbit management. D and F lenses have also small-current coils for field gradient correction. Two groups of sextupole lenses for fine tuning of chromaticity are foreseen and for betatron coupling variation a family of 12 Skew-quadrupoles also one.

Parameters of correctors are summarised in table 3.

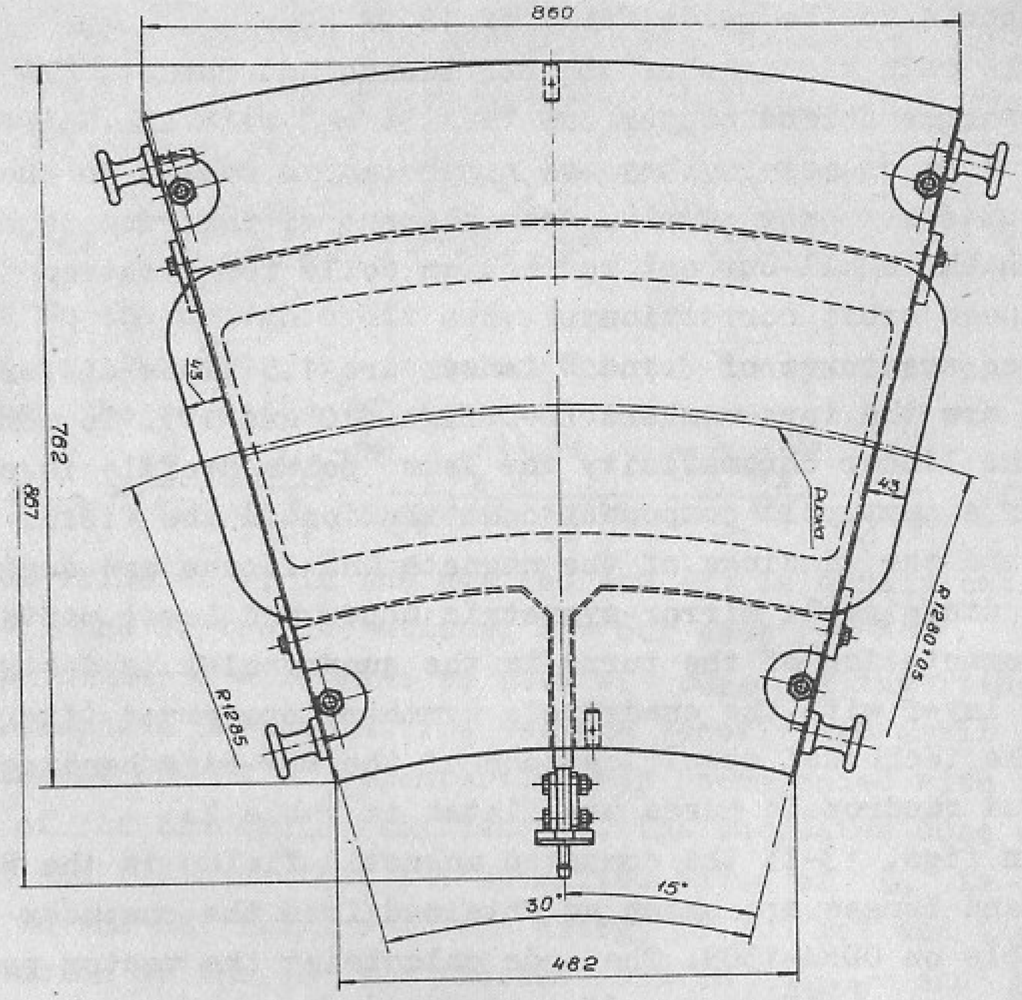


Fig.8. Plan view of the magnet.

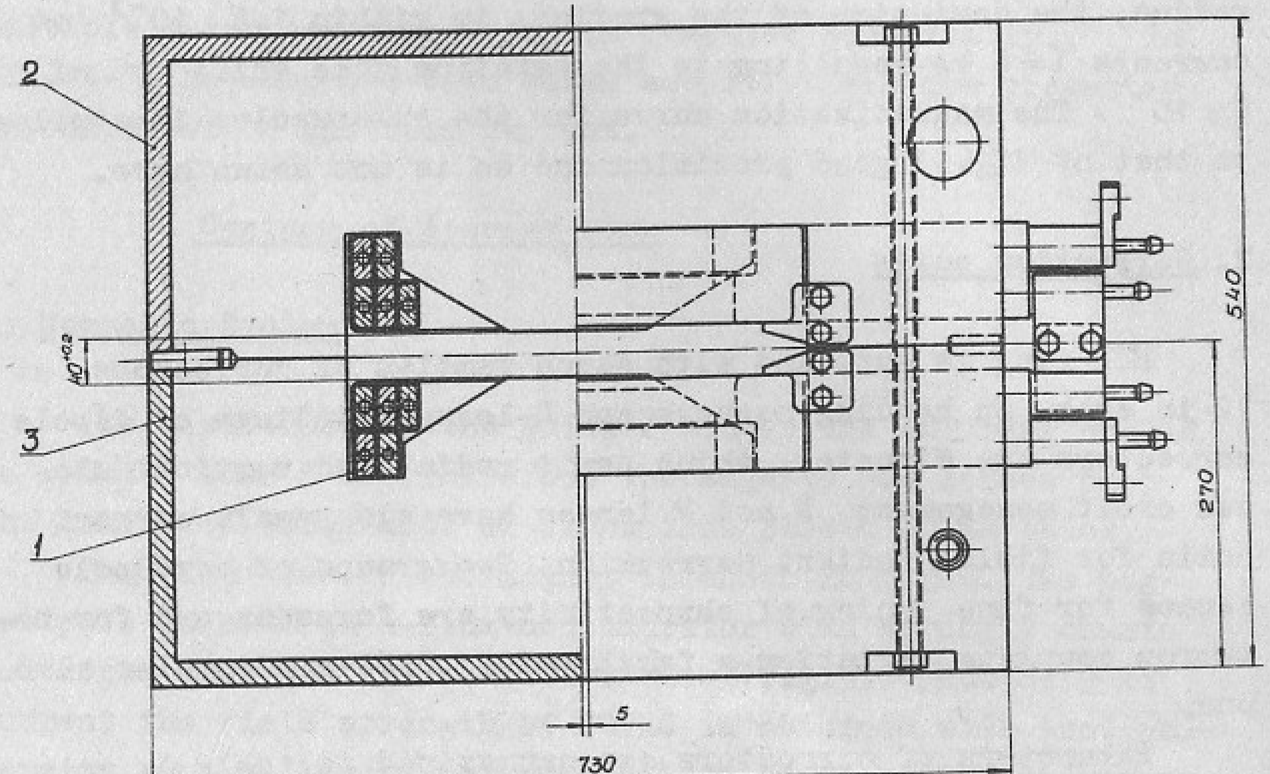


Fig.9. The magnet cross section.

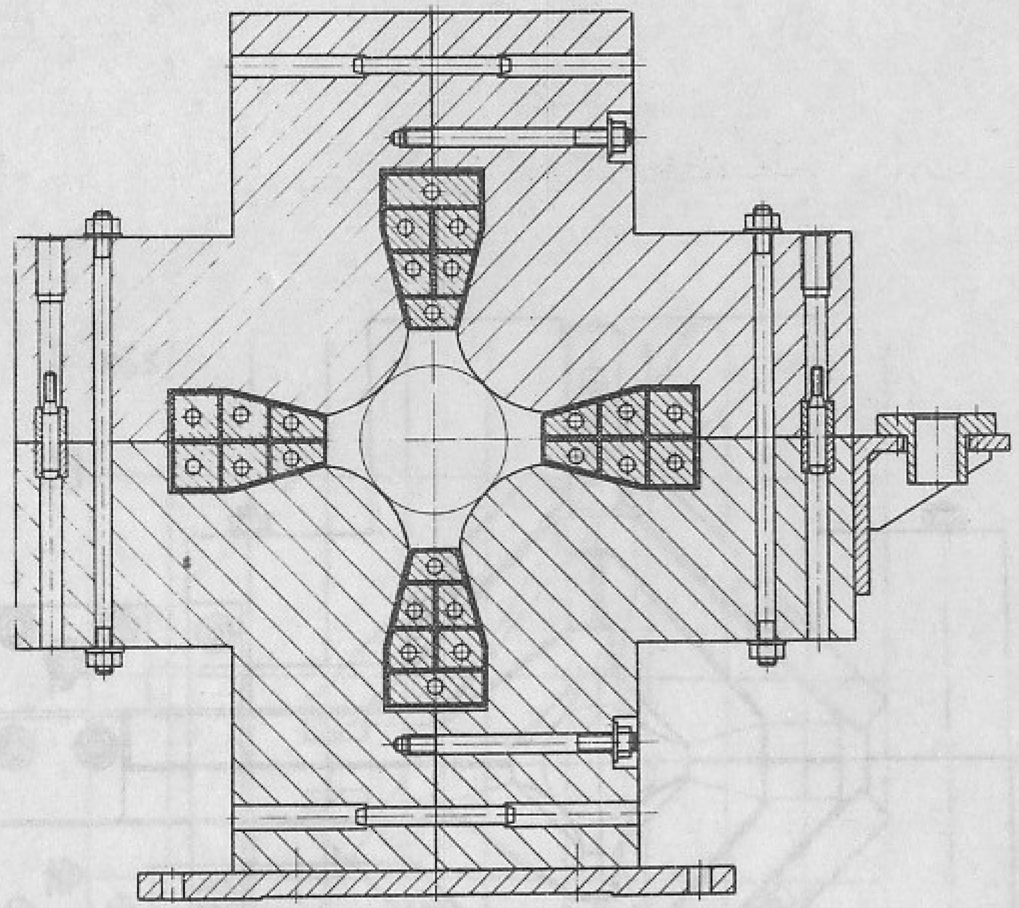


Fig.10. Cross section of the F-lens.

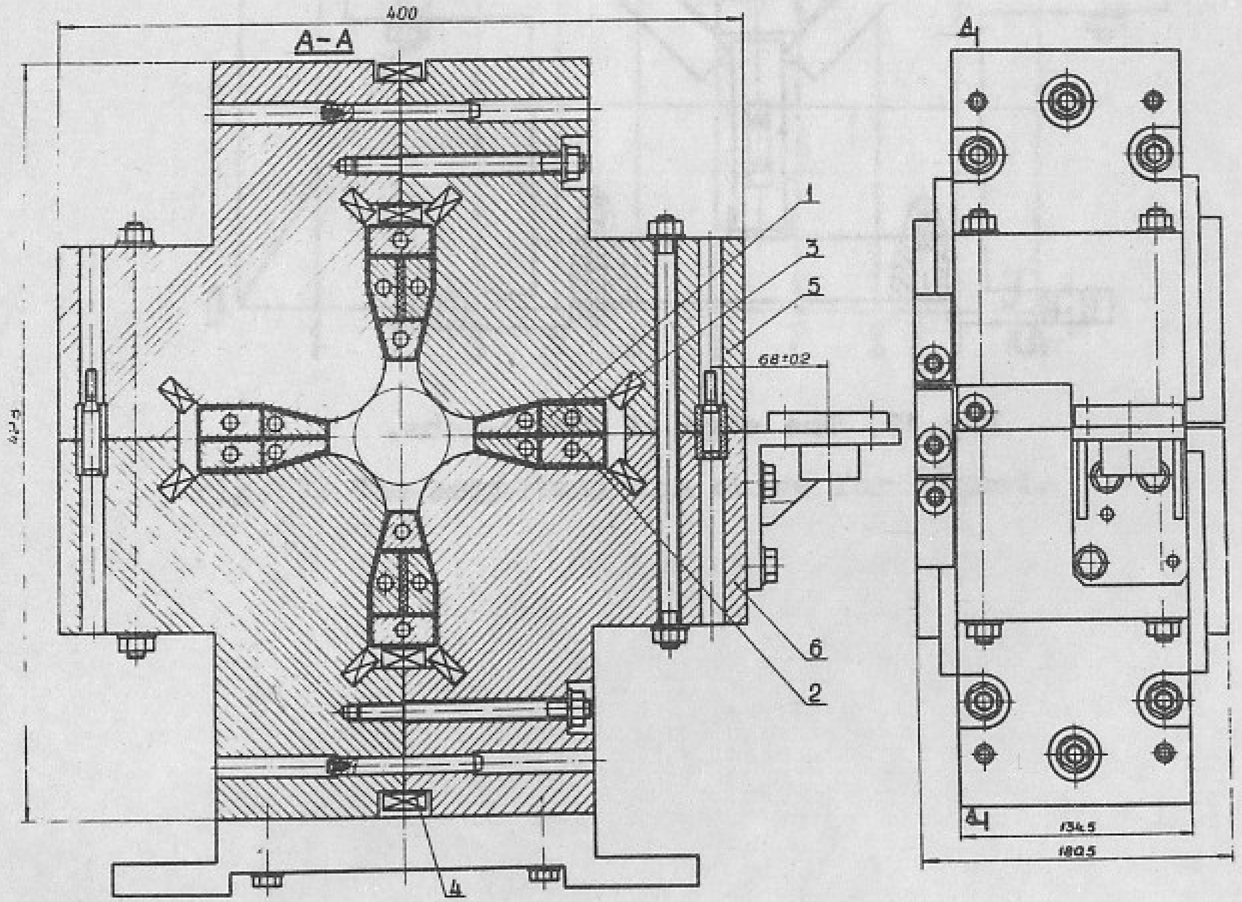


Fig.11. Cross section of the D-lens.

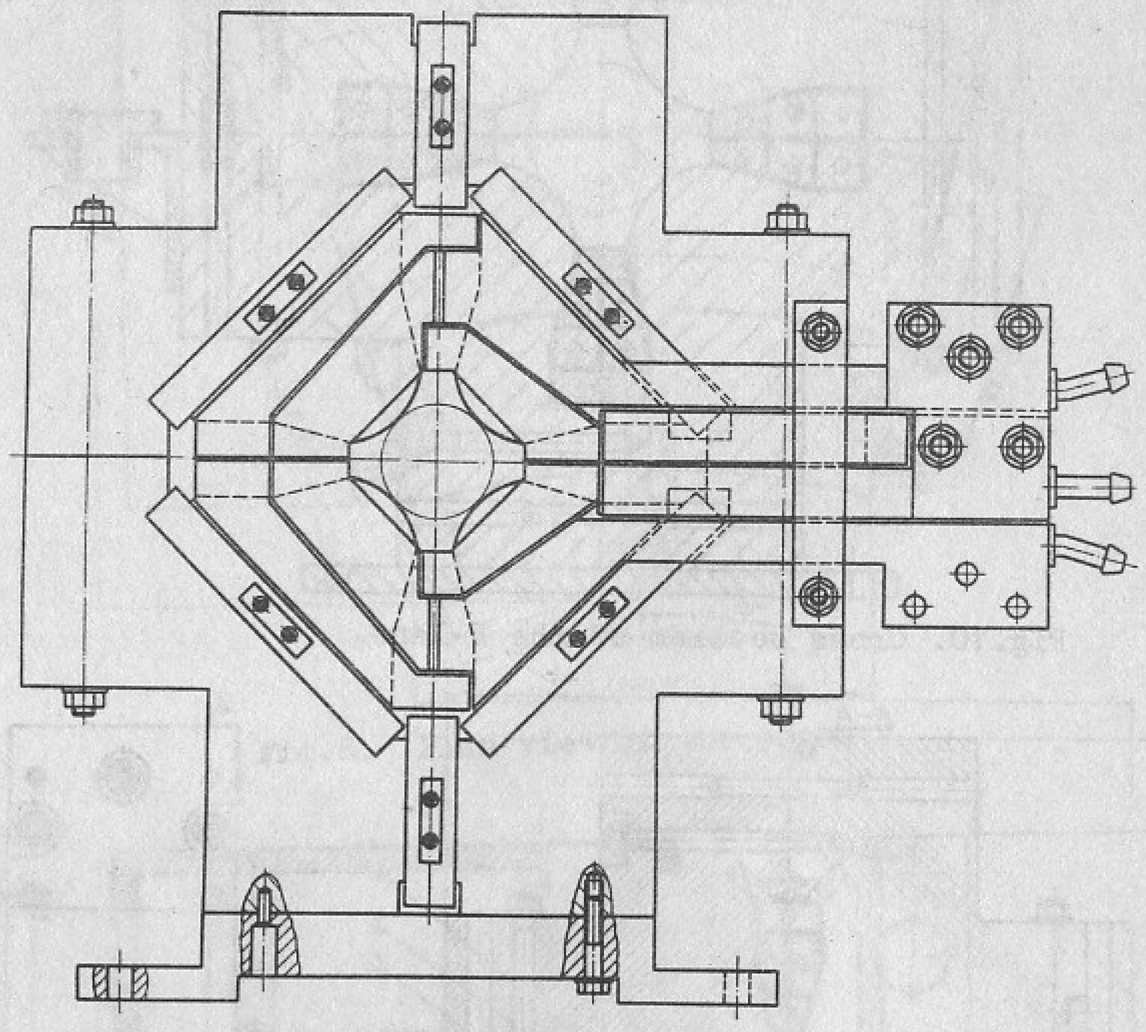


Fig.12. The edge of the D-lens.

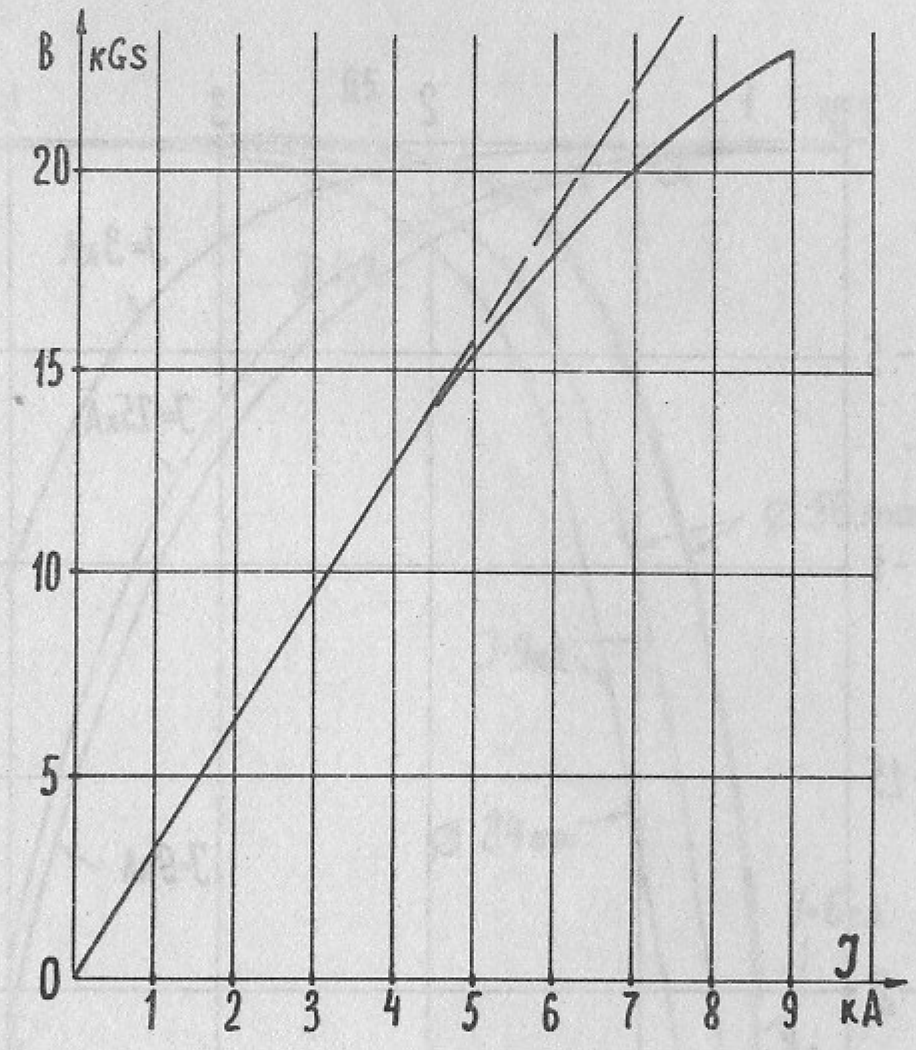


Fig.13. The magnetization curve for magnet.

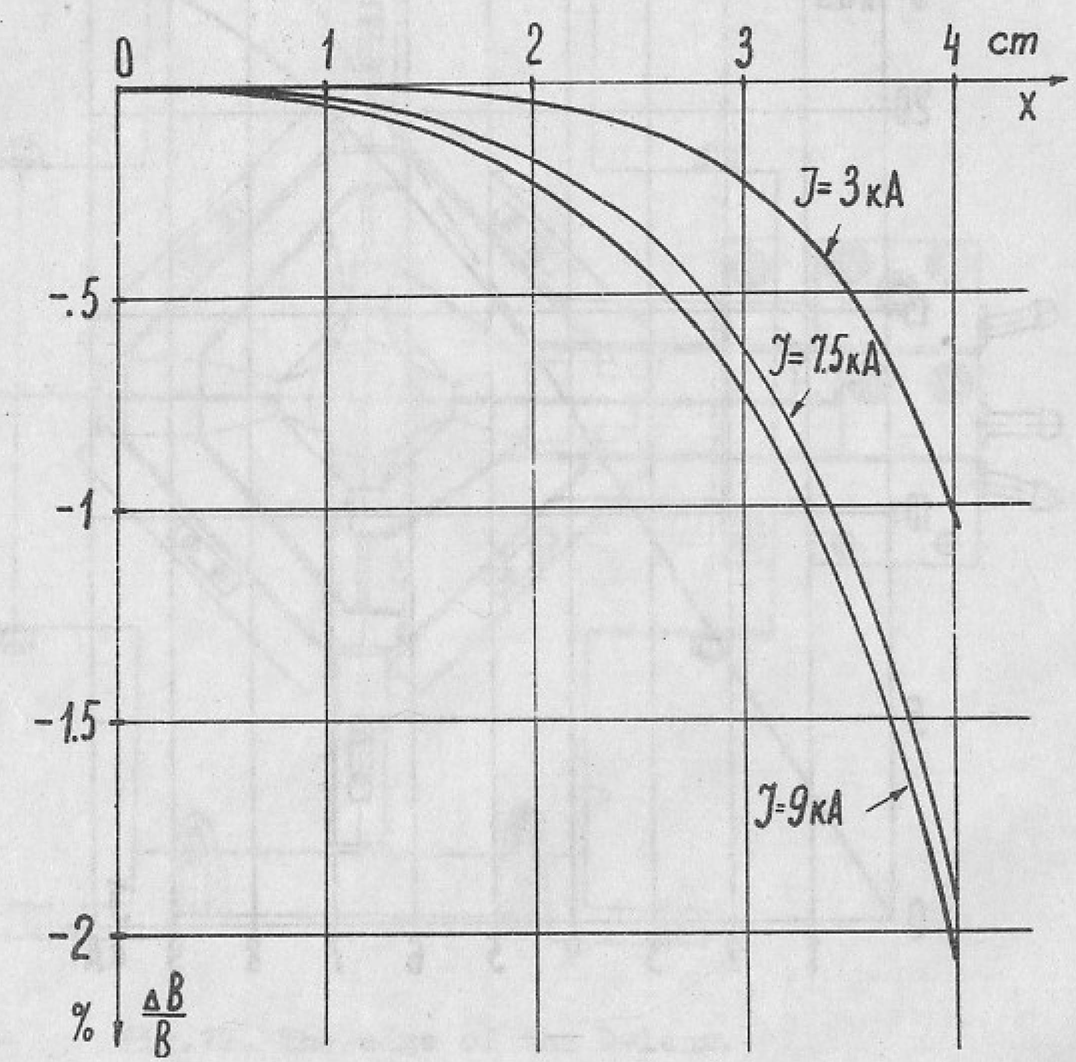


Fig.14. The computed field distribution in the magnet.

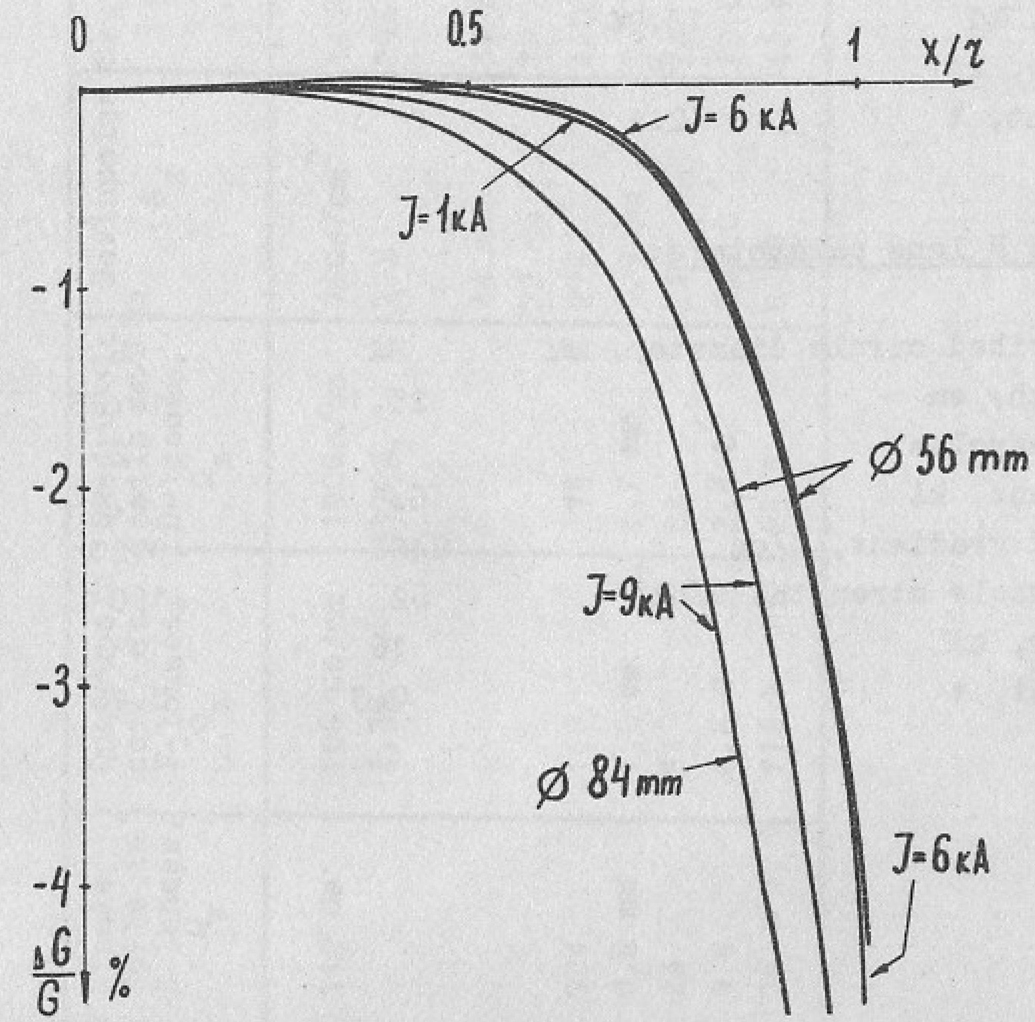


Fig.15. The computed field gradient distribution in lenses.

Table 2

The Magnet Parameters:

Gap, mm	40
Length, cm	67
Turns/pole	5
Current, kA	6.5
Field, kG	18.24
Power, kW	38
Weight, t	2.2

F and D lens parameters:

	F	D
Inscribed circle diameter, mm	84	56
Length, cm	25.1	16.25
Turns/poles	3	2
Current, kA	6.5	6.5
Field gradient, G/cm	2480	-3720
Sextupole strength, G/cm^2	62	-160
Power, kW	16	9
Weight, t	0.3	0.16

Table 3

corrector tipe / Parameters	Dipole coils in magnets, H_z	Dipole coils in D-lenses, H_x	Quadrupole coils in F-lenses, Q_x	Quadrupole coils in D-lenses, Q_z	Sextupoles S_x	Sextupoles S_z	Skew-quadrupoles S_q
Absolute value	60 Gs	112 Gs	106 Gs/cm	120Gs/cm	76Gs/cm^2	140Gs/cm^2	140Gs/cm
Relative value (for E=700MeV)	0.33%		4.3%	3.2%	22%	29%	
Effective length					44 mm	54 mm	70 mm
Bore Diameter					72 mm	72 mm	82 mm
Windings/coil	50	224	150	75	276	440	480
Wire diameter	0.8 mm	0.8 mm	1.2 mm	1.2 mm	0.9 mm	0.9 mm	0.9 mm
Current	2A	2A	5A	5A	2A	2A	2A
Resistance	6.4 Ω	9 Ω	6.8 Ω	3.4 Ω	2.1 Ω	10 Ω	8 Ω
Power	26 W	36 W	170 W	85 W	8.5W	40 W	32 W

3. Vacuum System

The BEP ring vacuum system comprises 12 water-cooled aluminium chambers (fig.16) that pass through the bending magnet and quadrupole doublet each, and 12 straight sections where the high vacuum magneto-discharge and titanium-evaporation pumps are housed. The latter provide for $4 \cdot 10^{-8}$ torr average vacuum in the ring with a 2A circulating current. The aluminium chambers are made by extrusion and exhibit a low desorption rate after the proper treatment.

In the seven standard straight sections (fig.17) made of stainless steel besides the pumps the following components are placed: the mirror-absorber for the synchrotron radiation, the electrode for Ar glow discharge treatment of the vacuum system surfaces and the perforated tube that has the same cross-section profile as that of the aluminium chambers. This tube continues the chamber smoothness thus minimizing the wakefields and shields the coherent radiation of the beam to the straight section volume.

The other five straight sections are occupied by the injection and/ejection septum-magnets, the inflector and pre-inflector Kickers and the RF cavity.

The aluminium chambers are terminated with the bi-metallic flanges (Al + stainless steel alloy) and joined to the straight sections by shielded Ar arc welding. The storage ring vacuum system is divided in sections by high-vacuum passage valves. In the open position the valve hole copies the vacuum chamber cross-section and the shut-off damper is tightened for electric contact to avoid the parasitic mode losses in the valve cavity.

4. RF system

The electron bunch length of 6m is available after acceleration in the synchrotron B-3M and beam ejection therefore the harmonic number of the BEP RF system is low: $q = 2$. The RF system parameters are presented in Table 4 and the cavity axial cross-section drawing is shown in fig.18.

The copper cavity 1 high-vacuum design envisages the

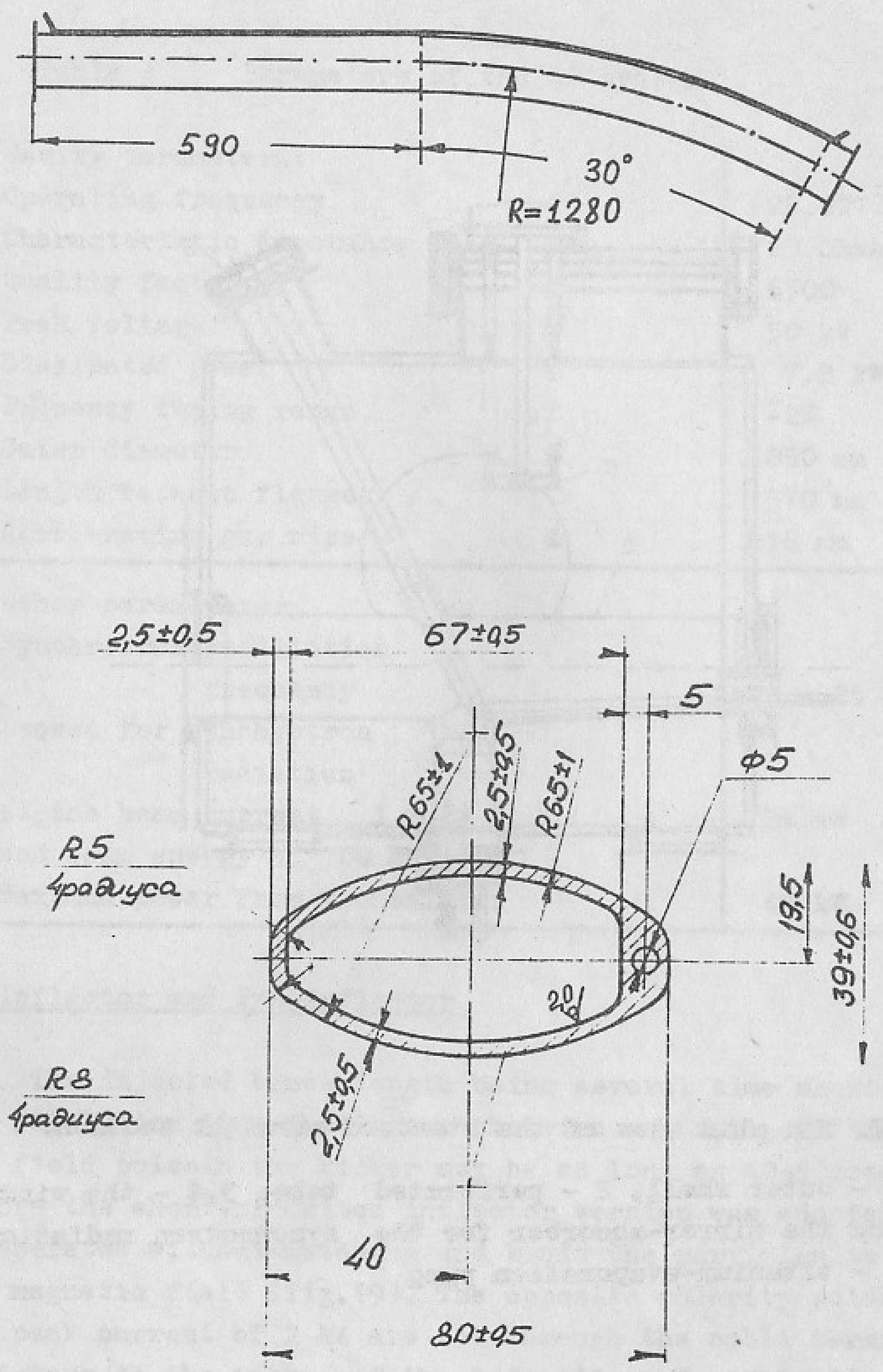


Fig.16. View and cross section of the aluminium vacuum chamber.

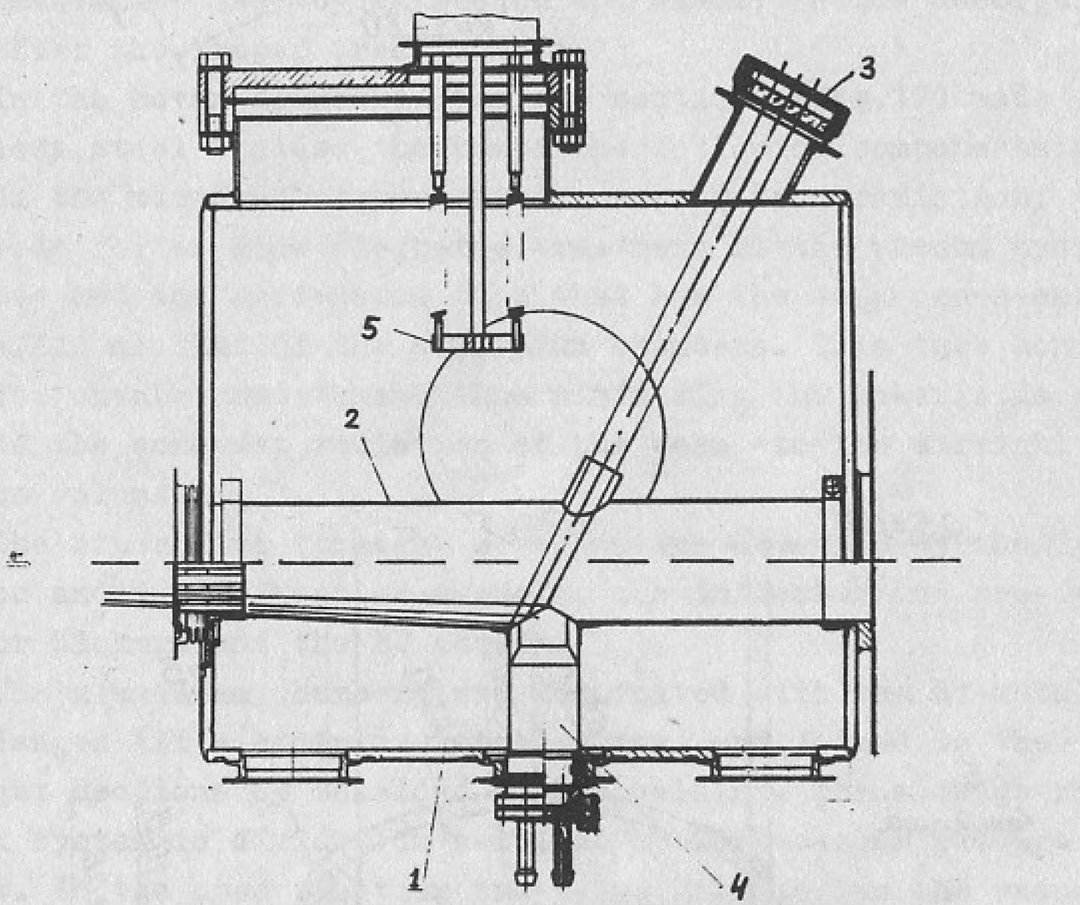


Fig.17. The plan view of the standard straight section.

1 - outer shell, 2 - perforated tube; 3,4 - the window and the mirror-absorber for the synchrotron radiation, 5 - titanium-evaporation pump

stainless steel outer shell 2. The operation frequency tuning in the cavity is effected by flexing of the side copper disks 3. The higher modes tuning mechanics 7 is also incorporated in the design.

Table 4 Parameters of the RF system

1. Cavity parameters:		
Operating frequency	f	26.827 MHz
Characteristic impetance		25 Ohms
Quality factor	Q	6500
Peak voltage	V	50 kV
Dissipated power	P	7.8 kW
Frquency tuning range	Δf	±2%
Outer diameter	Ø	850 mm
Length between flanges		570 mm
Accelerating gap size	d	16 mm
2. Other parameters:		
Synchrotron oscillation frequency		12 ÷ 25 kHz
Losses for synchrotron radiation at the beam current I_n = 2A and beam energy of 700 MeV		34 kW
Maximum power from transmitter		42 kW

5. Inflector and Pre-inflector

The injected bunch length being several time shorter than the revolution time T_o=43nsec, the rise and fall-off times of the field pulsein the kicker may be as long as 40-50nsec. Therefore the short-circuited inflector version was adopted which is operated without matching and bends the particles paths by its magnetic field (fig.19). The opposite polarity pulses with the peak current of 2 kA are fed through the cable terminating resistors to the inputs of the left side and right side plate electrodes. The characteristic impedance of the inflector kicker is 88 Ohms while that of the generator is about 6 Ohms.

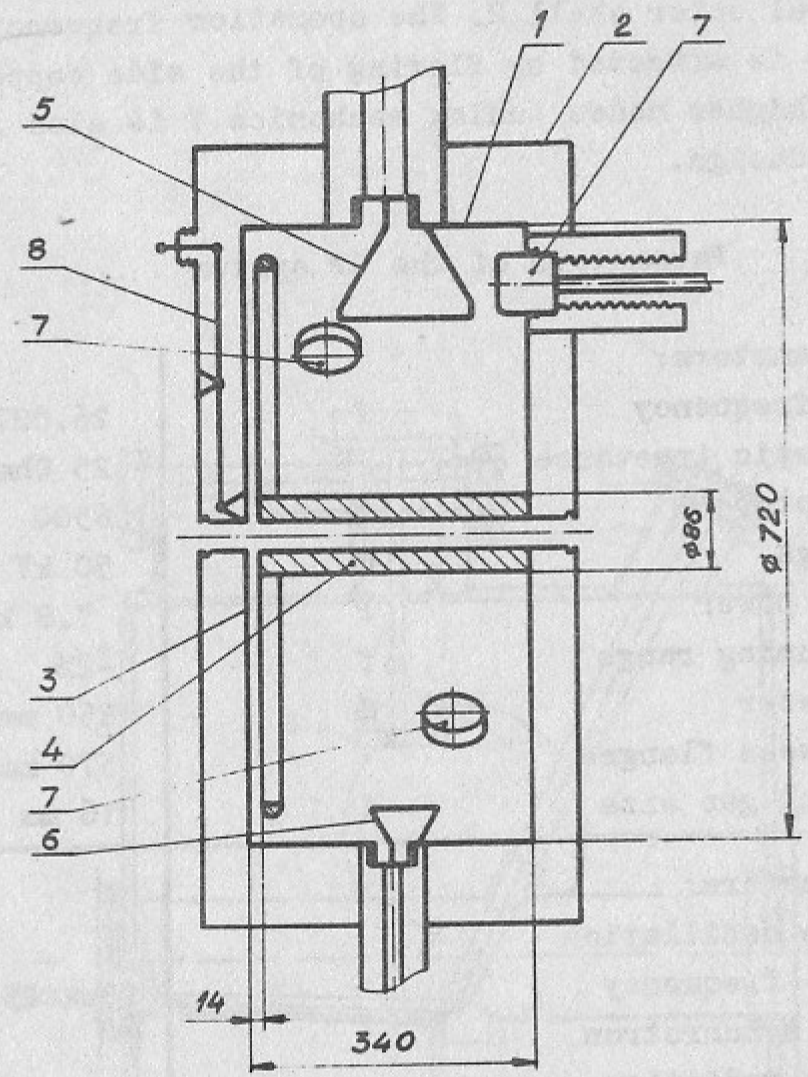


Fig.18. The RF cavity axial cross section.

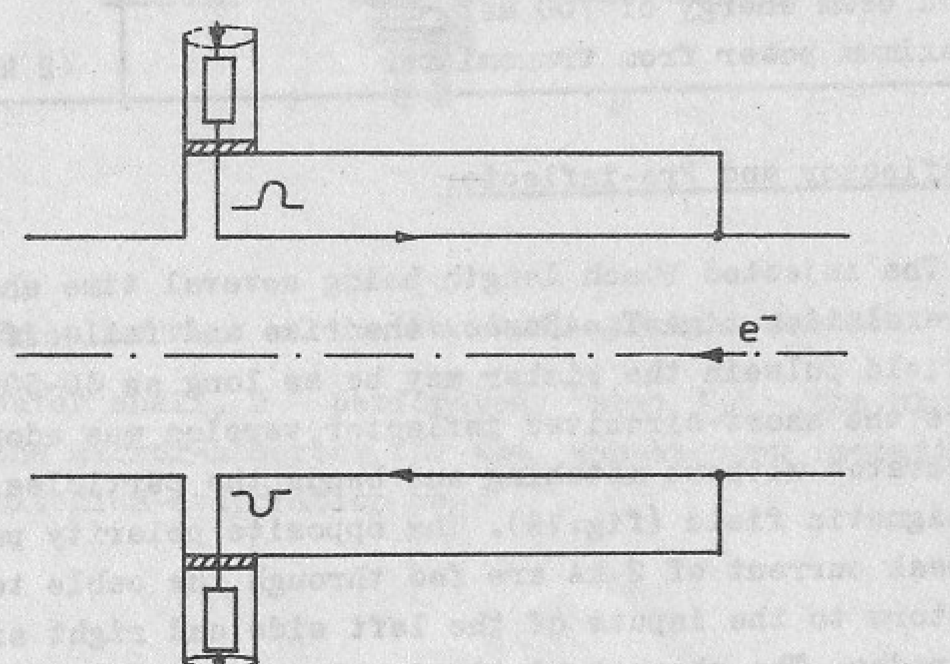


Fig.19. The scheme of magnetic inflector.

The generator yields the artificial shaper line discharge pulses through the thyratron. The charging voltage of the line is 25 kV. The thyratron is connected to the kicker input by 8 cables of 50 Ohms wave impedance connected in parallel.

For escape of the synchrotron radiation the kicker plate is cut with slot 5 mm wide. There is a mechanic drive in the inflector straight section which provides for the plates grounding and mutual connection over total length after the accumulation cycle is finished thus forming a singly connected domain in the chamber cross-section.

The inflector and the pre-inflector straight sections are identical and will be operated both in beam injection and ejection.

IV. Cures of the Coherent Instabilities

The experience with the beams approaching the intensities of 10^{12} on VEPP-3 shows that the beam emittances and energy spread are greater than those specified for the VLEPP project due to excitation of non-stationary collective oscillations which blow up the effective emittances and energy spread. For the ultra-relativistic beams the main cause of coherent excitations is the wakefield of the beam traversing the vacuum chamber discontinuities, injection-ejection kicker electrodes, RF cavities and other components which disturb the beam environment smoothness. The wakefields determine the intensity thresholds and growth rates and ultimately put the limit on the attainable intensity for the beams with specified parameters.

Apparently a realistic storage ring design should include these discontinuities of essential (e.g. RF cavities, injection-ejection kickers) and constructive (valves, belows, joints) nature, besides the beam diagnostic systems also have to break the vacuum pipe smoothness for SR ports, pick-up electrodes etc. The BEP ring is designed so as to minimize the beam coupling with the environmental structures to the reasonable limit.

In the vacuum chamber design the cross-section of the aluminium pipe in the bends and quadrupoles is continued in the 7 standard straight sections with perforated pipes (fig.17), the belows are covered from inside of the chamber, the flange joints are supplied with contacting washers etc. Such an approach results in localizing the essential discontinuities in 5 non-standard straight sections. The inflector and pre-inflector assemblies provide for the kicker plates grounding along their full length after injection pulse. The step discontinuities in two septum magnet straight sections will be covered by a wire grid. The RF cavity of the second harmonic placed in the non-standard straight is seen by the beam as a small gap radial line.

The electrodynamical studies of the beam environment components are under way, the impedance bench measurements are beginning, the preliminary estimates for the instabilities seem to be optimistic. However the coupled-modes head-tail instability being favoured now by a low value of synchrotron tune may force in the future another version of the accelerating RF with higher harmonic numbers and peak voltages.

Plans

In 1985 manufacturing of all components of BEP is planned to be finished and storage ring will be assembled. In the end of 1984 is planned to complete electrodynamical studies of the beam environment and magnetic field measurements.

On the basis of these measurements the needed improvements of magnetic and vacuum systems will be done.

References

1. V.E.Balakin, G.I. Budker, A.N. Skrinsky "On possibility of installation with colliding electron and positron beams at superhigh energies". In "Problems of high energy physics and controlled nuclear fusion research", p.11, Moscow, 1981.
2. A.A. Kolomensky, A.N. Lebedev "Theory of cyclic accelerators", F.M., Moscow , 1962.

В.В.Анашин, И.Б.Вассерман, В.Г.Вещеревич,
Б.И.Гришанов, А.В.Евстигнеев, И.А.Кооп,
В.И.Купчик, В.М.Меджидзаде, А.А.Михайличенко,
Е.А.Переведенцев, В.М.Петров, И.К.Седляров,
А.Н.Скринский, Э.М.Трахтенберг, Ю.М.Шатунов

ЭЛЕКТРОН-ПОЗИТРОННЫЙ НАКОПИТЕЛЬ-ОХЛАДИТЕЛЬ БЭП

Препринт
№ 84-114

Работа поступила - 31 августа 1984 г.

Ответственный за выпуск - С.Г.Попов
Подписано к печати 19.09-1984 г. МН 04552
Формат бумаги 60x90 1/16 Усл.2,0печ.л., 1,6 учетно-изд.л.
Тираж 290 экз. Бесплатно. Заказ № 114.

Ротапринт ИЯФ СО АН СССР, г.Новосибирск, 90