PROJECT OF A PROTON RING ACCELERATOR FOR 7 BEV

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(presented by V. V. Vladimirski)

This report is based on the work on the design of the 7 Bev strong-focusing proton accelerator performed by the authors, and on the work of L. L. Goldin, D. G. Koshkarev, V. S. Kurishev, N. A. Monoszon, S. Ia. Nikitin, S. M. Rubchinski, A. M. Stolov and E. K. Tarasov.

The accelerator described is the first large strong-focusing accelerator under construction in the USSR. It is intended for research on the interaction of nucleons and mesons with nucleons and for investigating the production of anti-particles. It is also intended to serve in some measure as a model installation for the designing of an accelerator for about 50 Bev. The energy chosen provides for a sufficient margin over the threshold of anti-nucleon production and at the same time permits to build an installation of comparatively small size. The kinetic energy at the nucleon-nucleon collisions in c.m. system will amount to $2.2.10^9$ ev., thus permitting observation of the processes of multiple production of mesons with small multiplicity, the processes of hyperon generation and the production of anti-particles.

The energy chosen provides the possibility of designing an accelerator along the traditional lines proposed by Courant, Livingston and Snyder [1]) without going through the critical energy, since the critical energy with a suitable choice of parameters may be shifted beyond the working range of the particle energy. In our design we have chosen a system of orbit length compensation shifting the critical energy to infinity[2]). This choice permitted a substantial reduction in tolerance requirements in respect of the magnet system and accelerating field frequency control. The compensating magnets were convenient to use for placing the accelerating electrodes in position while the arrangement provided the opportunity of trying out on a model scale, the operation of a compensation system which might suitably be used for larger accelerators.

In choosing the parameters of the accelerator, we made no attempt to achieve a major economy in magnet weight and power feed, since it became clear, after the most tentative calculations, that these values would not be excessively large.

Of significant importance in choosing the parameters were the questions of injection. After considering possible variants, we reached the conclusion that injection into the accelerator should be accomplished during one revolution. There was no point in choosing a very high injection energy in this connection, for the greater the particle speed the smaller the injection time becomes and the greater become the difficulties of obtaining high currents. As injector we chose an electrostatic Van de Graaff generator. The nominal value adopted for the injection energy is 4 Mev.

Proton scattering on the residual gas in the chamber and the effect of the space charge at such a low injection energy become important and result in a marked broadening of the beam at the initial stage of acceleration. These phenomena have been analysed in detail in the paper by Berestetski, Goldin and Koshkarev[3]).

In determining the parameters of the magnet system, the principal question is that of angular aperture of the chamber.

The height of the chamber is determined by the vertical deflections of the particles. As stated, the scattering on the gas produces a marked broadening of the beam: due to the scattering the angular aperture of the beam at an injection energy of 4 Mev reaches $2.5.10^{-3}$ radian even with a residual pressure in the chamber of 2.10^{-6} mm.

The amplitude of the betatron oscillations of the particles also depends on the inaccuracies which are bound to occur in constructing the magnet system. An important factor is the non-constancy of the betatron oscillations frequency. Getting close to the resonance values produces an increase in the particle oscillations amplitude. The possible combination of the radial and vertical oscillations makes it imperative to increase the angular aperture by $\sqrt{2}$ times. In view of the above, the total vertical angular aperture of the chamber was chosen at 8.10^{-3} radian.

The linear dimensions of the chamber depend on the frequency of the betatron oscillations. An increase in this results in a reduction in the linear dimensions and a corresponding increase in the weight of the magnet involving an increase in the tolerance requirements for the magnet system. The selected value of 12.75 oscillations on the orbit length is a compromise and makes conveniently provision for compensating the dependence of the orbit length on momentum. The height of the chamber, under these conditions is 80 mm.

In determining the radial width of the chamber, account has to be taken of the fact that the synchrotron oscillations of the beam will directly lead to oscillations the amplitude of which depends on the amplitude momentum variations. Radial oscillations are intensified by the system adopted of compensating the changes in the orbit length. Therefore, to ensure the angular aperture agreed on for the chamber the width was increased slightly as compared with the height and set at 110 mm.

As regards the tolerances for the construction of the magnet system, the point to be noted is that errors in the magnetic field gradient from magnet to magnet result in the appearance of areas of unstable motion around the resonance values of the betatron oscillations number, of which 12.5 and 13 are important. Account must also be taken of the effect of the increase in oscillation amplitude when approaching external resonances due to fluctuations in magnetic field intensity. The particle oscillation frequency must be kept short of the limit resonance by not less than 0.1.

The frequency of betatron oscillations depends on the accelerated particle momentum ratio. We limited the possible change of the number of betatron oscillations due to the momentum errors to 0.1 and the overall width of the regions of non-stable motion to 0.05. The total range of the possible change in the oscillation number is 0.25, being the sum of the three values given.

The adopted values allow tolerances 0.7 % for the momentum error and 0.7 % for the mean square errors of the magnetic field gradient.

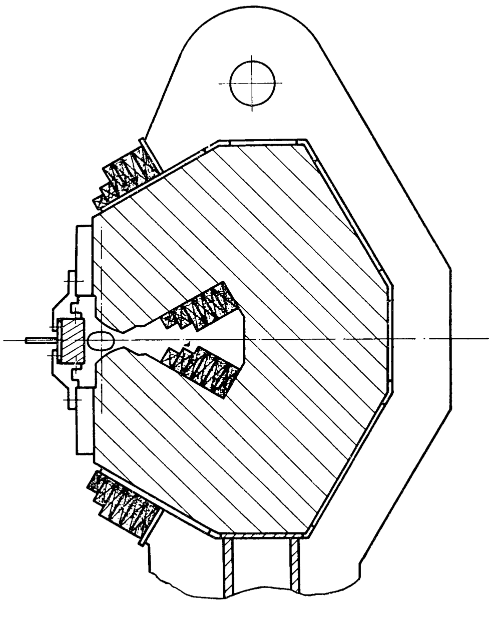


Fig. 1.

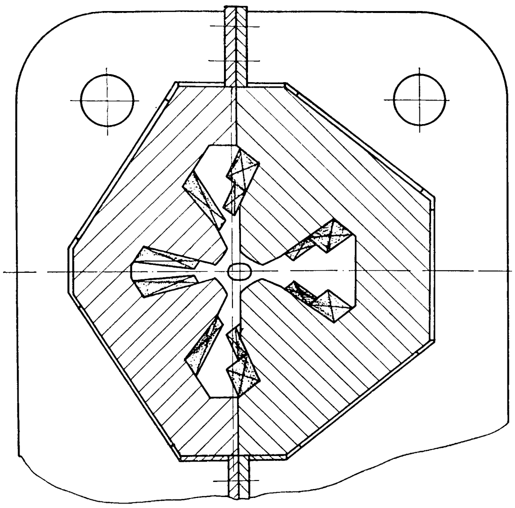


Fig. 2.

Limiting the mean square value of the magnetic field intensity errors by a tolerance of 0.2 %, we get a value of 2 cm. for maximum amplitude of forced oscillations which is permissible with our chamber width.

In calculating the tolerances, the non-linearity of the magnetic field is found to be significant. The quadratic non-linearity increases the dependence of the betatron oscillations frequency on the momentum. The cubic non-linearity changes the particle motion conditions in the vicinity of the resonances and worsens the tolerances. The final choice of tolerances was made in the light of non-linearity.

The magnet system of the accelerator comprises 56 periodic elements, i.e. 112 magnets. Of these, 98 are C-shaped with a neutral pole (fig. 1) while 14 are X-shaped magnets (fig. 2) and create the inverse field of half the value and serve to compensate the changes in orbit length.

Table 1 gives the principal parameters of the accelerator and the magnet system.

TABLE 1

Maximum energy of accelerated particles	eV	7.10^9
Cycles per minute		12
Maximum magnetic field intensity	Gauss	9,500
Magnetic field rise time	sec.	1.5
Orbit length	m.	251
Mean orbit radius	m.	40
Magnetic field energy	joules	10^7
Magnet system weight	tons	2,700
Total number of magnets		112
Number of compensating magnets		14
Number of radial and vertical oscillations per revolution		12.75

Angular aperture of the chamber	radians	8.10^{-3}
Chamber width	mm.	110
Chamber height	mm.	80
Logarithmic derivative of orbit length by momentum		0 ± 10^{-3}
Length of magnets	mm.	1,925
Distance between yokes of the magnets	mm.	290
Distance from chamber axis to Neutral pole	mm.	75
Radius of C-shaped magnets	m.	27.8
Radius of compensating magnets	m.	-53.5
Particle energy at injection	Mev	4
Minimum magnetic field	Gauss	90
Tolerance for random magnetic field errors	per cent	0.4
Height and radius accuracy of magnet setting	mm.	0.3
Tolerance for random deviations of magnetic field gradient	per cent	1.5
Tolerance for magnetic field non-linearity	per cent	1

In designing the magnet system, it is important to calculate correctly the limiting point of the hyperbolic poles. This problem has been studied in a paper by Vladimirski and Skachkov[4]. The measurements made by Grekov, Ryabov and Goldin [5] show the correctness of the calculations.

The close tolerances for the magnetic field make it necessary to provide beforehand for the possibility of compensating the most important harmonics of the magnetic field intensity and magnetic field gradient fluctuations. With the selected number for the betatron oscillations, compensation should be in respect of the 13th harmonic of the fluctuations in magnetic field intensity and the 25th and the 26th harmonics of the gradient errors. Compensation can be effected by suitably connected additional exciting coil windings.

The acceleration of the particles is effected by electrodes in the form of drift tubes incorporated in the resonance output circuit of the high frequency generator. The inductivity of the circuit is automatically readjusted during the acceleration cycle.

The power of the radio frequency devices depends largely on the number of drift tubes. They are placed in the compensating magnets, where their stray capacity relative to the magnetic poles is minimal. This means that the number of tubes cannot exceed 14, and is in fact even less as there can be no electrodes in the region of beam deflection.

The tubes are fed by high frequency voltage, the frequency of which is a multiple of the revolution frequency. The choice of the 7th harmonic makes it possible to avoid phase splitting and operate within a suitable range of frequencies—0.65 to 8.5 Mc.

The tolerances determining the operation of the high frequency equipment follow from the analysis of synchrotron oscillations [6] and the accepted tolerance for momentum errors. In calculating the tolerances, account has been taken of the time constant of the electronic devices used for determining the law of frequency variations in respect of magnetic fields and the damping of synchrotron oscillations during acceleration. The linkage between the accelerating field frequency and the magnetic field intensity is effected by an induction coil, an integrator circuit and a functional transformer. The main characteristics of the high-frequency equipment are given in Table 2.

TABLE 2

Number of drift tubes		11
Harmonic of radio frequency		7
Initial frequency of accelerating field	Mc	0.65
Final frequency of accelerating field	Mc	8.5
Initial frequency of synchrotron oscillations	Kc	3.34
Final frequency of synchrotron oscillations	c	136
Energy gain per revolution	keV	4.35
Amplitude of voltage on drift tubes	kV	8.7
Power of the high frequency system	kW	500
Tolerance for slowly varying errors in frequency		
(*a*) at the beginning of acceleration		10^{-3}
(*b*) at the end of acceleration		10^{-4}
Tolerance for r.f. frequency modulation at frequency of synchrotron oscillations		
(*a*) at the beginning of acceleration		2.10^{-6}
(*b*) at the end of acceleration		4.10^{-8}
Tolerance for r.f. amplitude modulation with at frequency of synchrotron oscillations		
(*a*) at the beginning of acceleration		6.10^{-4}
(*b*) at the end of acceleration		5.10^{-3}
Tolerance for r.f. frequency noise modulation	cycles^2/ cycles	3.10^{-4}
Accuracy of measuring the magnetic field when determining the time of injection	Gauss	3.10^{-2}

The vacuum chamber of the accelerator is assembled from the same number of separate parts as there are magnets. The chamber is made of thin (0.2 mm.) stainless steel. Experience has shown that a chamber of this kind stands up well to atmospheric pressure provided it is corrugated. The corrugations should run interruptedly over the full length of the chamber with the channels spaced at 5 mm. Special experiments have shown [5] that the chamber pro-

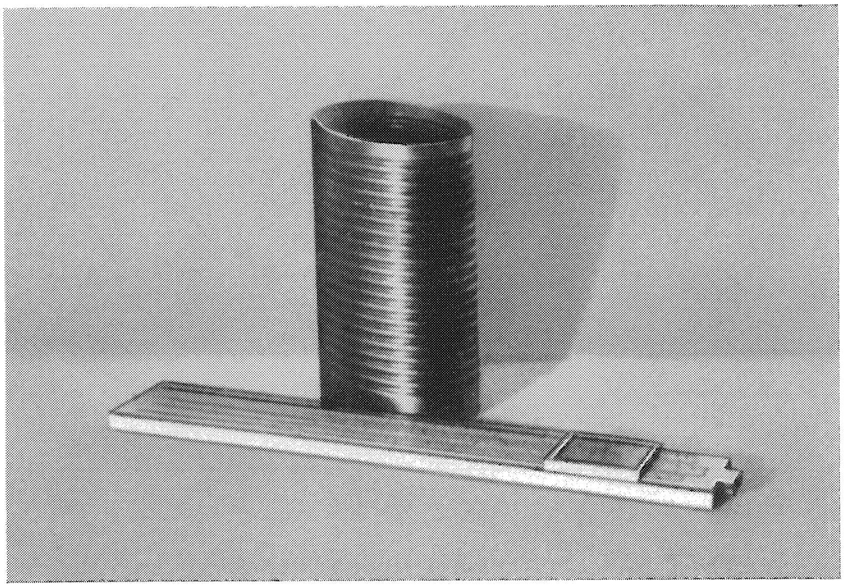


Fig. 3.

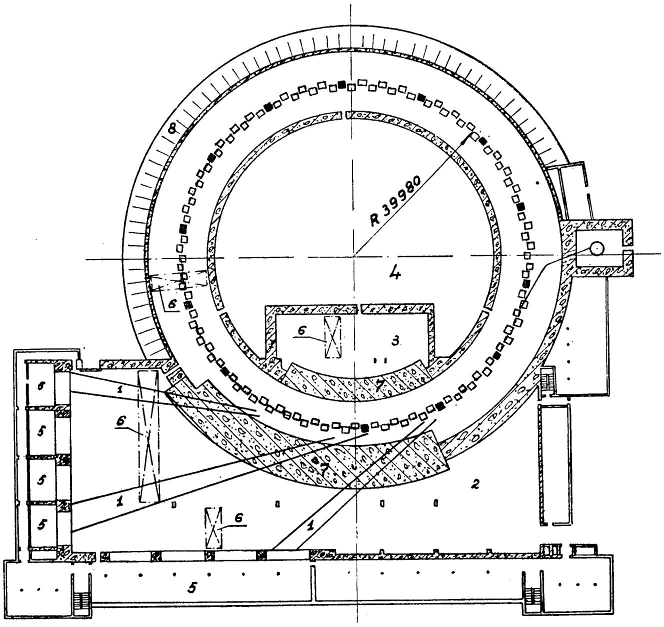
duces no distortion in practice in the magnetic field distribution. Figure 3 shows a picture of part of a chamber.

The small dimensions of the accelerator chamber allow the beam to be deflected at the end of the acceleration by pulsed magnetic fields. The average power necessary to obtain such fields works out at several tens of kilowatts. The deflection of the particles from the accelerator has been analyzed in a paper by Vladimirski, Goldin and others[7].

The close tolerances for the magnet setting makes it necessary to give careful thought to the design for the magnet foundation. For high energy accelerators the necessary rigidity can be ensured only by the ground on which it rests. For the 7 Bev accelerator, however, rigidity can be ensured by the foundation itself. When designing the foundation, therefore, the most dangerous harmonic (in our case the 13th—the closest to the frequency of betatron oscillations) has to be taken into account.

The calculations should be made on the basis of the least favourable premises as regards ground behaviour, i.e. that the ring foundation rests on the earth at 13 points and sags under its own weight. Calculations made by Vladimirski and Tarasov [8] have proved that a reinforced concrete ring with a cross-section of 4 × 5 m^2 possesses the necessary rigidity.

Fig. 4 shows the ground plan of the accelerator. The principal feeding aggregates are housed in a separate building and are not shown in this drawing. The principal auxiliary premises are within the ring formed by the magnet hall. Apart from the large outer experimental hall, there is a small inner hall for the deflection of positive particles. Deflection of particles into the outer experimental hall can be effected in three directions. The experimental halls are separated from the magnet hall by removable shielding walls.



☐ C-shaped magnet
■ X-shaped magnet
0 Injector (electrostatic generator)
1 Deflected beams
2 Large experimental hall
3 Small experimental hall
4 Central hall
5 Quarters for conducting work on the beams
6 50-ton cranes
7 Removable screen-walls
8 Earth bank

Fig. 4. Ground plan of the accelerator building

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