MAIN CHARACTERISTICS OF A PROJECTED STRONG-FOCUSING 50–60 BEV PROTON ACCELERATOR

V. V. VLADIMIRSKI, E. G. KOMAR and A. L. MINTS

USSR Academy of Sciences, Moscow

(presented by V. V. Vladimirski)

This report is based on preliminary design work for a 50-60 Bev strong-focusing proton accelerator performed by the authors, and on the work of L. L. Goldin, D. G. Koshkarev, N. A. Monoszon, S. Ia. Nikitin, S. M. Rubchinski, S. V. Skachkov, N. S. Streltsov, E. K. Tarasov and others.

The limit proton energy was chosen according to the following: we needed energies known to be sufficient for the multiple production of mesons in nuclear cascade showers and for the production of anti-particles for all known types of elementary particles maximum energy of particles being 50-60 Bev, the kinetic energy in proton-nucleon collisions will amount to 9 nucleon masses in c.m. system. At the same time, it seemed expedient to employ the existing units designed for the 10 Bev accelerator already built and especially, its unique feeding system. The magnet peak power feeding the magnet amounts to approximately 100 MW, with a magnet weight of not more than 22,000 tons.

In a project of this kind, particular attention must be given to the problem of phase stability in the neighbourhood of the transition energy. A system of compensation of the particle orbit length oscillations was adopted which makes it possible to shift the critical energy to infinity[1]. The compensation principle is based on the utilization of forced oscillations of particles with momentum differing from the equilibrium one. The forced oscillations are obtained through periodical azimuthal alterations of the magnetic field intensity: every eighth magnet has the field of the opposite sign, its value being half the value of the ordinary magnets (fig. 1). The compensating magnets are set with an azimuthal period slightly smaller than that the free radial oscillations of the proton. The maximum amplitude of the orbit radial displacement is obtained in the compensating magnet, and the variation of its arc length is sufficient to compensate the mean change of the arc length in all the other magnets. The removal of the critical energy is effected by the 20% increase in the orbit length.

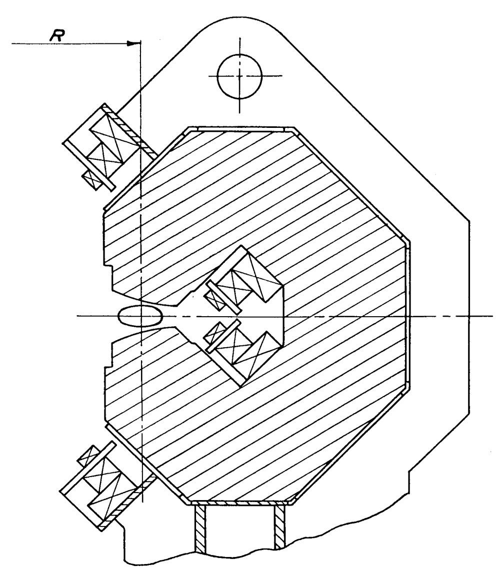

Fig. 1.

The adoption of the compensation system leads to the choice of comparatively high frequencies of the transverse oscillations of particles: 13.75 per revolution for radial oscillations and 12.75 for vertical oscillations. The mean angular aperture of the beam of 2.10^{-3} radian is a reasonable compromise between the tendency to decrease the weight and power level of the equipment and the necessity to achieve a wide enough range of tolerances for the magnetic field. The maximum field intensity on the orbit will lie between 10^4 and $1.2.10^4$Oe, the orbit length being 1,480 m. The main parameters of the orbit are given in Table 1.

TABLE 1

Total number of magnets	120
Number of compensating magnets	15
Number of radial oscillations per revolution	13.75
Number of vertical oscillations per revolution	12.74

Length of radially focusing magnets	mm.	10,990
Length of vertically focusing magnets	mm.	10,690
Length of gaps between magnets	mm.	1,515
Radius of curvature of ordinary magnets	m.	166.67
Radius of curvature of compensating magnets	m.	–297.6
Distance from the chamber axis to the asymptote of the hyperbolic poles in the ordinary magnets	mm.	404.0
Inside half-height of chamber	mm.	60
Inside half-width of chamber	mm.	100
Magnetic field utilization factor		0.8050
Logarithmic derivative of orbit length by momentum		$-8.2.10^{-4}$
Angular aperture of the beam		2.10^{-3}
Amplitude of radial oscillations due to compensation	mm.	40

The tolerances for the magnetic field are given in table 2.

TABLE 2

Permissible momentum errors, per cent	$\frac{\Delta p}{p}$	0.5
Tolerance for field intensity, per cent	$\frac{\Delta H}{H}$	0.25
Tolerance for magnetic field gradient per cent	$\frac{\Delta \text{grad}}{\text{grad}}$	0.3
Tolerance for radial displacement of magnets	mm.	1.0
Tolerance for vertical displacement (amplitude of 13th harmonic)	mm.	0.5

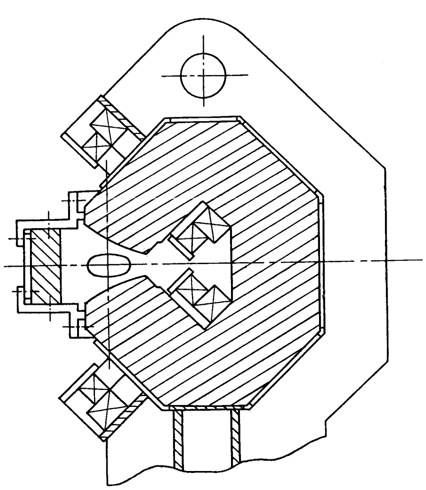

Fig. 2.

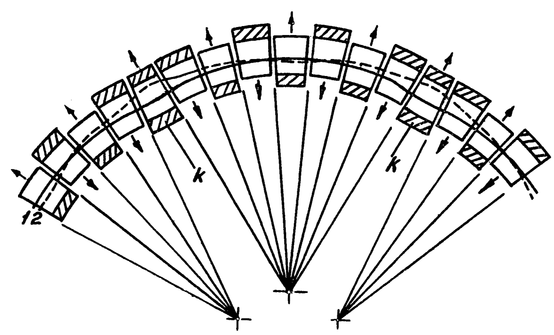

Fig. 3. Magnet setting for compensating α;
k — compensating magnets
⇅ — direction of rise of magnetic field
1 — equilibrium orbit
2. — displaced orbit where $\Delta p > 0$
(the amplitude of deflection from equilibrium orbit is greatly exaggerated)

The magnetic field gradient is comparatively low in the guiding magnets, so that they can be made without the neutral pole, but they have been introduced in the compensation magnet design. The profile of the poles is given in fig. 2. The yoke of the magnets is designed in a C-shape to provide easy access to the chamber. The magnets are too large to be constructed as single units. Each will consist of 5 sections weighting 38 tons each, with an over-all coil. The layout of the magnets is shown in fig. 3. The total weight of iron in the magnet system amounts to 17,000 tons. The total weight of magnets plus construction elements amounts to 22,000 tons.

Data on the magnet feeding system are given in Table 3.

TABLE 3

1.	Magnetic field use time	3.8 sec.
2.	Cycles per minute	6
3.	Maximum exciting current	12,000 A
4.	Maximum voltage	8,000 V
5.	Exciting coil resistance at 15° C	0,31 Ohm
6.	Maximum inductivity of the exciting coil	1.8 henry
7.	Peak power	96,000 kW

Generators with fly-wheels will be used to produce peak power of the order of 100 MW. The nominal power of each generator is 37 MW. A 12-phase inverter with ignitrons is designed. To bring down the ripple of the rectified voltage, a filter and a special suppression circuit with negative feedback are being designed.

A 100 Mev linear accelerator has been chosen as injector. The injection field intensity is 90 Oe.

The particle momentum deviation from the nominal value causes compensating radial oscillations and makes the free transverse oscillation frequency amount to one of the resonance values. This necessitates a tolerance of 5.10^{-3} for momentum errors.

The acceleration system is fed by a high frequency system with a frequency 30 times the revolution frequency. The main characteristics of the high-frequency system are given in table 4.

TABLE 4

	Parameters	Symbols and units	Parameters and requirements
1.	Accelerating field frequency at the beginning of acceleration	Mc	2.624
2.	Accelerating field frequency at the end of acceleration	Mc	6.068
3.	Tolerance for (slow) deviation of the frequency from the required value :	$\Delta f/f$	
	(*a*) at the beginning of the cycle		2×10^{-3}
	(*b*) at the end of the cycle		2.6×10^{-6}
4.	Corresponding precision of the magnetic field intensity measurement :		
	(*a*) at the beginning of the cycle	$\Delta H/H$	2.5×10^{-3}
	(*b*) at the end of the cycle		10^{-2}
5.	Frequency of small synchrotron oscillations :		
	(*a*) at the beginning of the cycle	Cycles	5.150
	(*b*) at the end of the cycle		24
6.	Tolerance for resonance harmonic :		
	(*a*) at the beginning of the cycle	$\delta f/f$	31×10^{-7}
	(*b*) at f = 50		4×10^{-8}
	(*c*) at the end of the cycle		12.5×10^{-9}
7.	Tolerance for r.f. noise frequency modulation	$\frac{(\text{cycles})^2}{\text{cycles}}$	4.8×10^{-3}

As can be seen from the table, the tolerances for frequency deviations are very narrow at the end of the acceleration cycle. However, the frequency variations are small at the end of the cycle, which makes the problem far less difficult. It is intended, as an alternative to design beam controlled frequency system. The system will be tested on the 7 Bev accelerator now under construction.

The energy gained by the protons in one revolution is approximately 100 Kev. The sum of the accelerating voltages is 200 Kev. Transformers with ferrite cores will be used as accelerating elements, the power level of the high-frequency generator will be about 500 kW.

LIST OF REFERENCES

1. Vladimirski, V. V. and Tarasov, E. K. On the possibility of removal of critical energy in a strong focusing accelerator. *In* Problems of cyclic accelerators. Moscow, USSR Academy of Sciences, 1955.

DISCUSSION

E. M. McMillan: What is the sensitivity to misalignment errors of both the compensated and the non-compensated machines?

V. V. Vladimirski: In strong focusing machines one can get quite narrow tolerances on n and we obtained on our models $\Delta n/n \simeq 0.03\%$ without much difficulty. In accelerators with weak focusing

$$\Delta n/n \simeq 10 - 20\%.$$

Errors in H are more serious. We have chosen Q as high as possible.

E. M. McMillan: Could one conclude from that that the tolerances on a compensated machine are about half of the tolerances on a non-compensated machine?

V. V. Vladimirski: Some tolerances are tighter, others can be slackened.

E. D. Courant: It appears that the radial displacement with respect to the equilibrium orbit for a given change in momentum is larger in a compensated than in a normal one. Therefore it seems possible to use multi-turn injection.

V. V. Vladimirski: This is true. But we have not yet worked out a design for multi-turn injection.

J. B. Adams: Have you calculated the 13th harmonic in the displacement of the magnet which gives a closed orbit deviation of 1 cm?

V. V. Vladimirski: Calculated and got 0.5 mm.

J. B. Adams: What amplitude of closed orbits does that displacement represent?

V. V. Vladimirski: Approximately 2 cm. no more.

L. Smith: What is the injection energy and the injection magnetic field?

V. V. Vladimirski: For the 50-60 Bev machine the injection energy is 100 Mev, and the injection field is 90 Oersted.

G. K. O'Neill: Is the power supply for the 50-60 Bev machine of the same type as the one of the Cosmotron or Bevatron?

V. V. Vladimirski: The power supply is similar to the one of the 10 Bev machine just finished. More accurate data will be given later by E.G. Komar.

E. D. Courant: What is the n value in the 50-60 Bev machine?

V. V. Vladimirski: It is $n = 167/0.4 = 410$

G. K. Green: Brookhaven took a low value of ν not because of the tolerances on the phase transition but because of misalignment. In fact the latter are ten times more serious then the former.

J. B. Adams: CERN figures are:

0.3 mm. at the 6th harmonic, given 1 cm. peak closed orbit displacement, which is very comparable with the Russian machine, which is surprising because of the difference in Q.