DESIGN STUDY ON 1000-GeV CYBERNETIC ACCELERATOR AND 1-GeV MODEL

A. A. Vasiliev

Radiotechnical Institute, Academy of Sciences, USSR
Moscow, USSR

There may be various approaches to the choice of the energy of a large alternating gradient accelerator designed to work in a range of several hundreds of GeV. The energy must be essentially higher than that of accelerators already built or under construction so that one may expect new opportunities for physical experiments in an energy range without any known characteristic energies.

The final choice should take into account both technological and economical feasibilities of the project.

For the accelerator considered here it is also important to know whether one can foresee construction of a still larger machine of this type. Of course, the later argument is hardly to be recognized stable; in fact, everybody knows that the ideas concerning the highest possible size of a proton synchrotron have been subject to perpetual changes during the two last decades. Yet, it seems quite possible for an accelerator in a 1000-GeV range to become the last representative of this class of proton synchrotrons.

Discussions of these as well as of some other considerations have led us to a value of 1000 GeV for the accelerator energy.

Another important question when determining the type of the accelerating system concerns the choice of linac-to-booster and booster-to-main ring transfer energies.

Minimization of the construction cost of the total system comes evidently as the first argument. However, one may also argue that the beam from both intermediate accelerators (the linac and the booster) could be used for experiments during time intervals when there is no injection into the following stages.

The later argument is very significant since the curve of cost as a function of energies of the intermediate stages is very flat in the vicinity of its minimum.

After careful study of different approaches we have come to the following scheme: an 800-MeV, 100-mA peak current linac, an 18-GeV booster, and a 1000-GeV, 3×10^{13}-protons per sec main ring, the linac and the booster running at 20 pulses per sec.

The accelerator cost depends greatly on the dimensions of the vacuum chamber aperture. An aperture decrease results in a reduction of the magnet weight and of its power supply and a reduction of power required for RF accelerating systems, correction system, etc.

Our calculations have led to a scheme with rather small dimensions of the vacuum chamber (40 × 66 mm). With such an aperture the beam would not perform the first turn due to errors in the magnet system.

If the number of betatron oscillations per turn, as well as the harmonic number of the accelerating field, are sufficiently large then coherent shifts of the orbit are much larger than the beam diameter determined by free betatron and synchrotron oscillations.

With an injection energy of 18 GeV the change in the accelerating frequency is rather small so that the accelerator is essentially a sequence of small linacs with magnet focusing systems as matching elements.

Automatic systems controlling the orbit shift include sensitive pick-up electrodes whose signals are fed to orbit-steering elements through amplifier and correction circuits. A number of papers treating design problems of these automatic systems have been published.[1,2,3,4,5,6]

In the 1000-GeV project, described in Table I, we use combined discrete and analog automatic control to steer the orbit at the first turn and during acceleration.

Although basic principles of automatic systems for orbit control are quite clear one may apprehend some unknown effects and difficulties. For experimental testing of control systems, a 1-GeV model of the cybernetic accelerator has been built and presently is in the start-up period at the Radiotechnical Institute, Academy of Sciences, USSR. The characteristics are listed in Table II.

The magnetic field follows an exponential law in time, the rate of change falling by a factor of 4 to the end. Energy gain per turn at the beginning of an acceleration cycle, ΔE is about 2 keV. The frequency of accelerating field shifts from 1.25 to 25 Mc/sec during acceleration, harmonic number (q) being equal to 5.

Brief Description of Accelerator Systems

Every magnet unit consists of seven blocks cemented by an epoxy resin. Windings of a magnet are also baked into the epoxy resin. Core laminations are punched out by high-precision hard-alloy punches. Laminations within a block and the blocks are cemented to form a curved magnet unit. Hence, outer units differ from those inside the orbit. Fabrication tolerances are better than 0.1 mm.

Each of the 20 support-beams carry 5 magnets. A magnet unit is supported by three small jacks. The total weight of the magnet is 16 tons (metric), each unit weighing 160 kg.

The vacuum chamber is pumped out through a collector by five titanium pumps to a pressure of about 7×10^{-7} torr. The chamber is made from a stainless steel pipe of an oval cross-section with a 0.4-mm wall.

Only metal gaskets are used. The vacuum collector can be baked-out by electrically heating a wire mounted inside it.

15 ferrite transformers driven by broadband amplifiers are used as accelerating elements.

The beam is injected from a 1-MeV Van de Graaff injector running at 150 pps through an

Table I. General Characteristics of the 1000-GeV Accelerator

	Parameter	Symbol	Unit	Value
1.	Maximum energy	E_{max}	GeV	1000
2.	Peak magnetic field at equilibrium orbit	B_{max}	kgauss	16
3.	Focusing structure	FOFDOD		
4.	Orbit length	L_p	meters	1.7×10^4
5.	Number of betatron oscillation per turn	Q		34.25
6.	Number of superperiods and number of long straight sections	N_{sup}		12
7.	Number of magnet periods	N		240
8.	Energy gain per turn	ΔE	MeV	56
9.	Acceleration time	T_a	sec	1
10.	Accelerating field frequency	f_a	Mc/sec	120
11.	Booster-to-main ring injection energy	E_b	GeV	18
12.	Linac energy	E_l	GeV	0.8
13.	Weight of magnet for main accelerator	P	tons(metric)	2×10^4
14.	Pressure in main accelerator chamber	p	torr	2×10^{-6}
15.	RF power	W_{RF}	MW	20
16.	Number of accelerated protons per pulse	N_p		3×10^{13}

Table II. Characteristics of 1-GeV Model of Cybernetic Accelerator

	Parameter	Symbol	Unit	Value
1.	Diameter	D	meters	17
2.	Ejection energy at 10^4 gauss	E_{max}	GeV	1.1
3.	Focusing structure	FODO		
4.	Number of betatron oscillations per turn	Q		6.25
5.	Number of magnet periods	N		50
6.	Number of magnets	M		100
7.	Injection energy	E_{inj}	MeV	1
8.	Vacuum chamber aperture		mm	16 × 21
9.	Acceleration time	T_a	sec	0.5
10.	Magnetic field index	n		191

ion-transport system including five triplets, a 90-degree deflecting magnet, correction magnets, and an energy stabilization system.

The orbit position control system includes 20 electrostatic electrodes and 20 lenses (for vertical and horizontal correction). By changing interconnections between the pick-ups and the lenses one can obtain various types of control.

The type to be tested first is a "local" system in which a feedback controls magnetic field in the correction lens positioned at the $\lambda_b/4$ point ahead of a pick-up electrode, to shift the orbit to a zero position at the pick-up point.

Presently, start-up works are under way. First turn and circulation of protons have been obtained.

Fig. 1 shows a photograph of a part of the 1-GeV accelerator.

Acknowledgment

Both the 1000-GeV cybernetic accelerator project and the 1-GeV model are being developed by the Radiotechnical Institute, Academy of Sciences, USSR, headed by academician A. L. Mints. Valuable participation of E. L. Burshtein, F. A. Vodop'yanov, I. Kh. Nevyazhskii, B. P. Murin, A. I. Dzergach, N. L. Sosenskii, Yu. N. Antonov, and others in the 1000-GeV project and of A. I. Dzergach, N. L. Sosenskii, G. I. Batskikh, V. V. Vladimirov and others in the 1-GeV model development is acknowledged.

References

1. Burshtein E. L., Vasiliev A. A., Mints A. L., Petukhov V. A., Rubchinskii S. M. Doklady Akad. Nauk (USSR), 141, No. 3, 590 (1961);
------- Atomnaya Energiya, 12, No. 2, 111 (1962).

2. Vasiliev A. A. Proc. Int. Conf. High-Energy Accel., Dubna (USSR), 1963; Atomizdat, Moscow, 1964, p. 871.

3. Dzergach A. I., Karpov V. A. Proc. Int. Conf. High-Energy Accel., Dubna (USSR), 1963, Atomizdat, Moscow, 1964, p. 867.

4. Baconnier Y. CERN 65-35 (1965).

5. Burshtein E. L., Vasiliev A. A., Dzergach A. I. Proc. Vth Int. Conf. High-Energy Accel., Frascati (Italy), 1965, CNEN, Rome, 1966, p. 34.

6. Lambertson G. R., Jackson Laslet L. Proc. Vth Int. Conf. High-Energy Accel., Frascati (Italy), 1965, CNEN, Rome, 1966, p. 26.

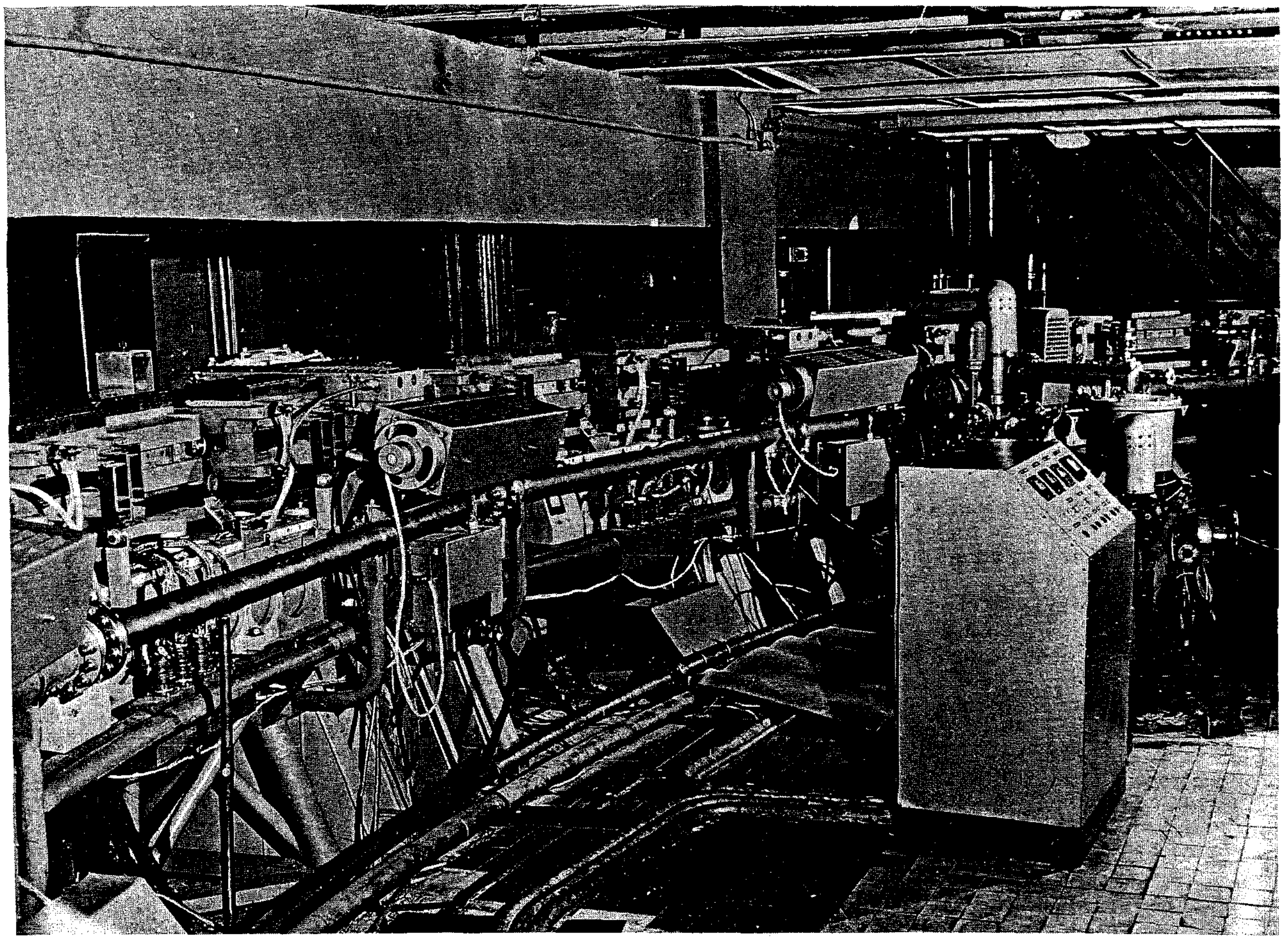

Fig. 1. View of a part of the I-GeV model.