A PROPOSED 12 GEV PROTON SYNCHROTRON

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The construction of a powerful multi-Gev accelerator which could contribute to high energy physics in Japan is a program desired for a long time. Since 1955 when The Institute for Nuclear Study was established in Tokyo, many types of discussions have been done on a future high energy project. One of the aims in constructing the 1 Gev electron AGS of the Institute was the technical studies in anticipation of a future proton machine such as the one now under our consideration. A high-repetition-rate synchrotron, a radial type FFAG, and a proton linac were considered in the course of discussions. The discussions became focused on a 12 Gev synchrotron in the fall of 1960, and the Special Committee of Nuclear Physics that is a subcommittee of The Science Council of Japan took up the proposal as a possible future plan. A study group for the synchrotron proposal was organized in February 1961 and the center of the group was located at the Department of Physics, Tohoku University, and a design study has begun. The following manuscript is based on preliminary studies worked out, since the end of 1959, with S. Yamaguchi, Y. Kobayashi, H. Saski, R. Yamada, T. Kamei, H. Kumagai, K. Fuke, H. Ishizuka (Tokyo University), Y. Torizuka, Y. Ohnuki, K. Abe, R. Kikuchi (Tohoku University), and T. Yanabu (Kyoto University).

I. HIGH INTENSITY SYNCHROTRON

The accelerator under our consideration is expected to be the first large accelerator in Japan and our purpose is to open a fruitful field of experimental high energy research as early as possible. Such a situation has led us to a rather conservative philosophy on technique. That is, the proposal should be well within the feasibility of our technique at present and any technical devices which may require long development and involve any risk in their realization should be avoided. As a result the discussion has converged to the synchrotron.

The maximum proton energy, 12 Gev, was chosen after careful consideration of the variety of particles concerned including antihyperons and of the production differential cross sections in the laboratory system. The beam intensity was considered to be at least 1 μa which might be the next step to be realized in the near future with multi-Gev accelerators. The intensity depends largely on the developments of the injector and the synchrotron is designed to obtain an intensity of 1–10 μa even with an injector similar to those of CERN, Brookhaven and Argonne. These intensity and energy parameters promise fruitful studies of particles including neutrinos. Technical studies and experiences on synchrotrons have piled up. In 1952, R.R. Wilson suggested the acceleration of protons to the 1 Gev region by their 30 cps electron synchrotron and it encouraged us to establish a 1 Gev electron AGS for the technical study of a future proton machine. The Southern Regional Accelerator Group also suggested the use of a 60 cps repetition rate. The door for high repetition rate proton synchrotrons was practically opened by the Princeton group in 1956. Other recent studies[1] also indicate the feasibility of the high repetition rate proton synchrotron, and it looks rather conservative, at least on paper, to aim at currents of the order of 1 μa by a synchrotron.

II. ECONOMICAL STUDY

After deciding to set the maximum energy at 12 Gev and the output intensity at a level of a few μa using a similar injector to those of CERN etc., the next problem is the choice of the maximum field on orbit, B, and the repetition frequency, f. The total cost was studied as a function of B and f. With the intensity set at a constant level, the following two factors are important in estimating the cost: the detailed type of injection, and the cost gradient of each component.

Assuming that the beam density injected in an aperture is proportional to the phase-space area available for horizontal oscillations, whether the phase space is perfectly filled or not, the condition of constant intensity of time-averaged output current is given by

$$(a-d)^2F^{-1}\nu f=\text{const.} \qquad (1)$$

where a is the total horizontal aperture and d the aperture loss due to misalignment and synchrotron oscillations; F is the form factor and ν the betatron oscillation number per turn.

Other assumptions are that the betatron frequency, ν, has the square root dependence on the change of radius of curvature, ρ, and the operating point is always kept at a similar point in the necktie diagram. From these assumptions dependences on ρ of other quantities such as the pair number N, the field index n, aperture loss d, necessary acceleration, etc. can be derived.

A magnet is designed as follows. The horizontal aperture, a, is adjusted to satisfy Eq. (1) when B and f vary. The vertical gap of the magnet is given by the sum of a constant concerning the geometry of the vacuum chamber, the betatron oscillation amplitude and a small amount for misalignment loss. The coil window is changed by the gap and the width of back leg is adjusted to have a constant flux density. Fig. 2 is an example of magnet cross section at $B=11$ kgauss and $f=16$ cps.

The costs of the magnet, magnet power supply, rf system, tunnel (including air conditioning) which may depend on B and ρ, and the nearly constant terms such as the injector, and the main building etc., were summed up. The study showed that the cost surface in the B—f plane has a shallow bottom. If, however, we insist on making a magnet cross section by punching commercial silicon-steel sheets, there appears to be a practical limit in the choice of B and f due to the width of sheets, and the part of the cost-surface in which we are interested, is a slow slope with the limit on its downside. Fig. 1 is an example.

The slope of the surface near the limit is small and with slight changes in assumptions the minimum point may shift easily. The consideration of power costs in future years suggests that the lower frequency is preferable, and that of single turn injection expected at the first stage suggests the higher frequency. As a conclusion, the region of $B=11\pm2$ kgauss and $f=15\pm5$ cps could be used with a small variation of total cost. The cost appearing in Fig. 1 is the cost of the machine proper and buildings but not including the ground and other experimental facilities. We have chosen the parameters $B=11$ kgauss and $f=16$ cps.

III. PROPOSAL

Our design study has just begun and the full particulars of our proposal are yet to be discussed. However, the following is a tentative view of our proposal.

a. Injector

A 50 Mev linac which is slightly developed from existing ones is expected with 10 ma peak current and a 35 μs injection period. An adiabatic shift of orbit is provided for the

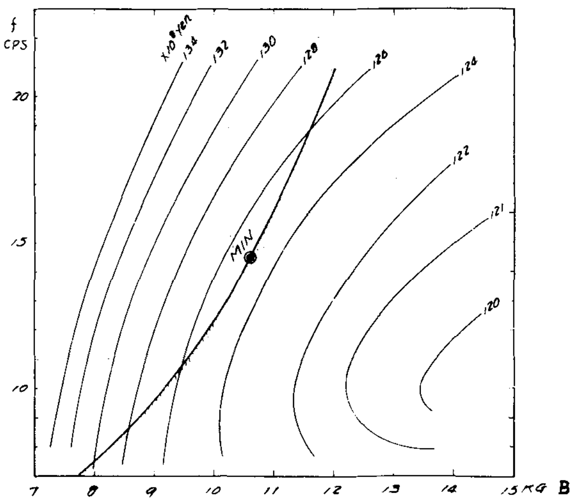

Fig. 1 Cost-surface of a 12 Gev synchrotron in B-f plane. The width of magnet cross section exceeds 98 cm on the right side of the hatched lines.

multiturn injection. Multiturn number is about 8 turns for 35 μs.

b. Magnet

Fig. 2 is a profile of the magnet. The gap is 8.8 cm at the center of the orbit and the horizontal aperture is 21 cm. The focusing order is FOFODODO, and one type of magnet profile is used with alternately back leg outside and back leg inside. One of the reasons for this arrangement is the ease of treating vacuum chambers, which would be especially important for a high-intensity, high-repetition-rate machine. The excitation system is the L–C resonance system first mentioned by Westendorp[2] and adopted by the Princeton group and others.

c. RF Acceleration

The high repetition rate demands a high acceleration, 900 Kev/turn at the maximum. With a phase angle of 60 degrees at the time of maximum acceleration, 24 rf stations with 43 kv peak per station are required. Each rf station consists of two ferrite-loaded cavities and is located in a 300 cm free space between magnets. The equilibrium phase of acceleration is intended to be shifted adiabatically from about 20 degrees to about 60 degrees during the course of acceleration. It reduces the rf power to one half and the voltage amplitude modulation to 2 and increases the capture efficiency.

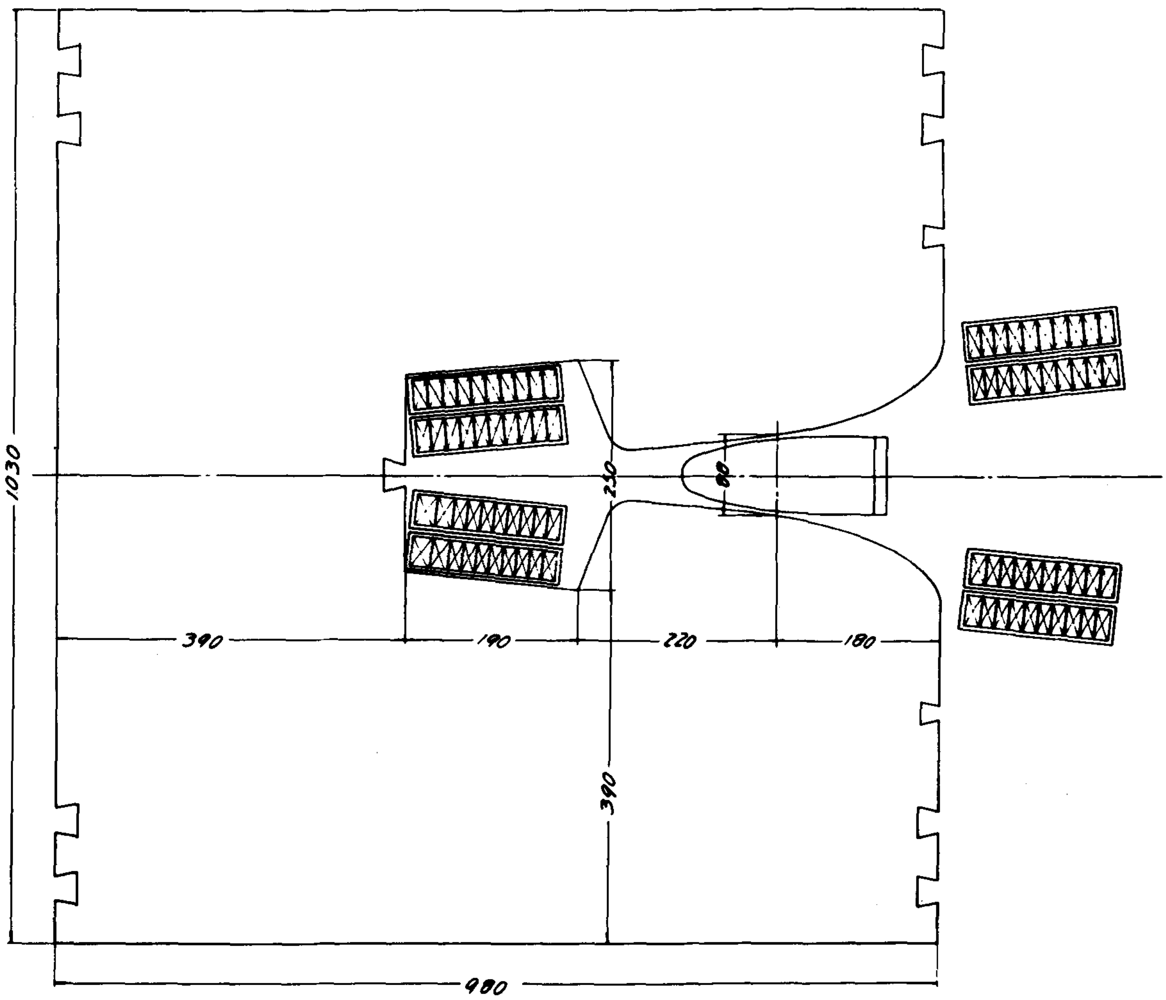

Fig. 2 Cross sectional view of the magnet.

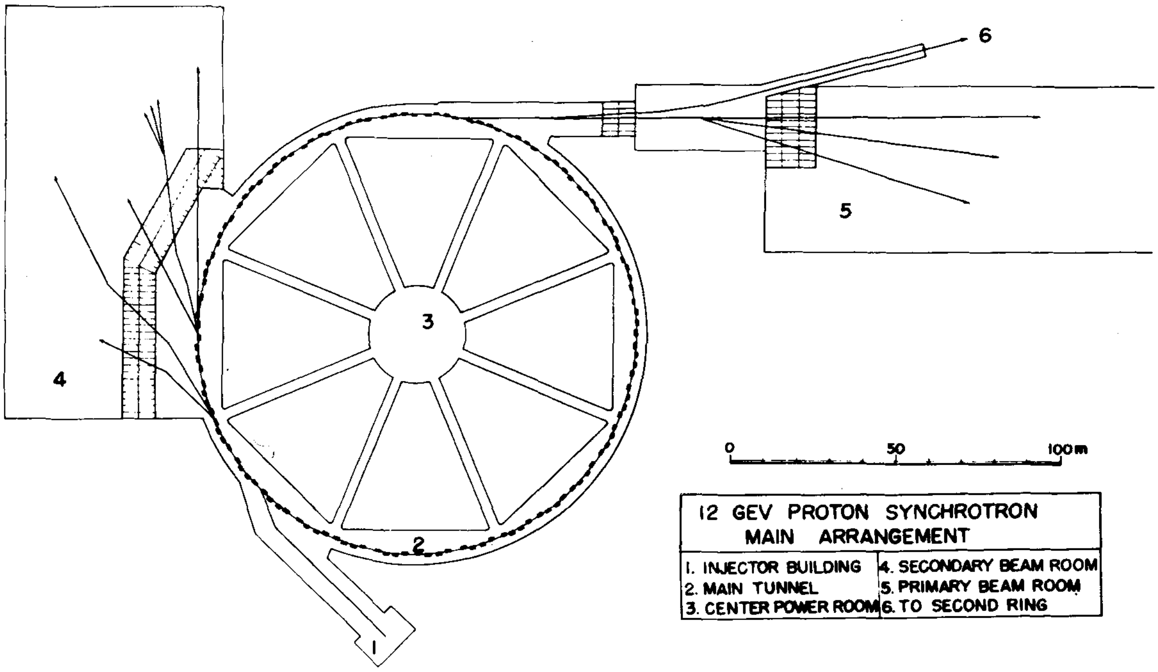

Fig. 3 12 Gev synchrotron and building layout.

d. Experimental Rooms

Fig. 3 shows the main arrangement of experimental rooms. The secondary beam room with relatively low radiation level and the primary beam room with a high radiation level are separated. The main research building, control room and counting rooms are located near the secondary beam room.

e. Second Ring

The second ring for further acceleration is expected as a future development. The most promising one is the 250–300 Gev ring such as M. Sands[3] has suggested. A magnet of 1,000 m radius and 5,000 tons is estimated. The beam of the first ring can intermittently be led into the second ring.

IV. PARAMETERS

General Features:	
Energy	12 Gev
Pulse rate	16 cps
Output	2 μa
Injector:	
Type	Proton linac
Injection energy	50 Mev
Injector output	10 ma peak
Injector period	35 μs
Orbit:	
Focusing type	Alternating gradient
Focusing order	FOFODODO
Field index	$n=142$
Betatron frequency	$\nu=6.2$
Orbit radius	$\rho=39.13$ m
Mean radius	$R=66.11$ m
Circumference factor	$C=1.69$
Period number	$N=32$
Aperture:	
Width	21 cm
Height	6 cm
Magnet:	
Sector number	128
Sector length	192 cm eff.
Straight section	290 cm eff.
	140 cm eff.
	50 cm eff.
Field at injection	265 gauss
Field at maximum	11.0 kgauss
Storage system	Choke and condenser
Frequency	16 cps
Rise time	31 ms
Magnetic energy	6 Megajoules
Magnet power	5Mw

Weight:	
Each sector	15.5 ton
Total	2,000 ton
RF ACCELERATION:	
Rotational frequency	0.227 to 0.722 Mc/s
Harmonic number	32
RF frequency	7.26 to 23.11 Mc/s
Number of RF stations	24
Energy gain maximum	900 kev/turn
RF peak voltage	43 kv/station ($\phi = 60°$)
RF power to cavity	840 kw
Ferrite weight	1 ton/station

REFERENCES

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2. W. F. WESTENDORP, *J. Appl. Phys.*, *16*, 657, 1945.
3. M. SANDS, MURA 465, June 10, 1959.

DISCUSSION

L. C. TENG: What is the total cost?

T. KITAGAKI: The total cost is about 2 x 10^{10} yen or about 60 million dollars including the main part of the experimental facilities but not including the ground and the second ring.

H. D. BRUCK: The machines with a resonant power supply have a very short duty cycle because the field is at its maximum value only a very short time. So the intensity cannot be really used for counter experiments where one likes to use the output for a long time. We are considering similar machines but for this reason have thought it necessary to add a storage ring, one single storage ring, to accommodate the duty cycle. We would propose to inject one pulse and to use it on the target in the storage ring during the time between one pulse and the following pulse; or, to accumulate during one second all 16 pulses and to send them all together once a second into a bubble chamber. But without the storage ring, or a device that maintains the magnet for some time at its maximum value, the machine seems not very flexible for use.

T. KITAGAKI: Of course, I agree with the usefulness of the storage ring . But, we have not considered the storage ring up to this time.

R. WIDEROE: I would like to know when the machine will be finished.

T. KITAGAKI: This is a very difficult question for me and I would like to know it too.