THE PRINCETON-PENNSYLVANIA ACCELERATOR

Princeton University, Princeton, N.J.

(presented by F. C. Shoemaker)

SYNCHROTRON DATA

Person in charge . . . . M. G. White

Person supplying data . . . . M. G. White

History and Status

Design study	1955
Model tests	1955-56
Engineering design	1956
Construction started	1957
Completion date	1960
Scheduled operation	
Magnet cost	Still in construction
Total cost	Still in construction

Design Specifications

Magnet

Focusing, type	Weak focusing
Focusing, order	
Field index, n	0.58
Orbit radius	9.15 m, 30 ft
Mean radius	12.20 m, 40 ft
Sectors, number	16
Field, at inj.	270 G
Field, max	13 950 G
Power input, av.	a.c.+d.c., 1 200 kW
Storage system	Choke and capacitor
Rise time	Sine wave 1/40 s
Weight	Fe 350; Cu 27 tons (U.S.)

Aperture

Width (*)	17.8 cm, 7.0 in.
Height	7.0 cm, 2.75 in.

Shielding . . . . 15 ft of 240 lb/ft^3 concrete or 45 ft of earth.

Design Goals

Particle accelerated	Protons
Energy	3.0 GeV
Pulse rate	19/s
Output	10^{11} part/pulse 2×10^{12} part/s

Injector System

Type	Electrostatic generator
Energy	3.0 MeV
Injector output	8 mA
Injection period	7 turns
Inflector type	Electrostatic

Acceleration System

Frequency	2.5 to 30.0 MHz
Accel. cavities	four
Harmonic number	eight
Orbit freq. final	3.8 MHz
Gain, (Max.)	60 keV/turn
Input to RF, max	400 kW

Unusual Features of Installation

The principal feature of this machine is the high average current anticipated (0.1-0.5 microamperes) and the extensive shielding that totally surrounds the accelerator. Also unique for a machine of this energy is the high pulse rate of 19 per second.

Published Articles Describing Machine

1. White, M. G., Shoemaker, F. C. and O'Neill, G. K. A 3 BeV high intensity proton synchrotron. CERN Symp. 1956. *1*, p. 525-9.

(*) Aperture quoted is inside vacuum chamber and good "*n*" region at injection.

STATUS REPORT

Introduction

The chief objective of the Princeton-Pennsylvania Proton Synchrotron is a relatively high average beam current. Other major considerations are: a) the provision of complete and convenient shielding; b) reliability; c) structural provisions for future external proton beams. Many of the technical features of this machine are given in the Proceedings of the 1956 CERN Conference on High Energy Accelerators[1] and will not be repeated here. Basically the accelerator is a weak focusing, high pulse rate machine (19.0 ± 0.5 per second). The high pulse rate is achieved by resonating the magnet inductance with a capacitor bank, but in order to make multiturn injection possible and also to reduce the radio-frequency problem it is necessary to add a d.c. bias approximately equal to the a.c. amplitude. Many of the design peculiarities of this accelerator stem from the high pulse rate and the consequent high rate of change of field. Also the expected high level of radiation raises serious problems of radiation damage to organic materials commonly used in electrical insulation and vacuum chamber sealing.

Expected performance

Space charge calculations appear to limit the maximum average current to about 0.5 μA which, at 3 GeV, yields a maximum beam power of 1 500 W. The energy spread will depend on the duty-cycle employed and may vary from a fraction of a per cent up to 10% at a duty-cycle of 1/10.

Magnet

A full scale section of the magnet has been built and tested using 0.025 in. thick transformer silicon steel sheets drawn from the stockpile of 120 000 sheets intended for the final magnet. Performance has been satisfactory with respect to the maximum obtainable field of 13.8 kG, the field gradient and all mechanical and thermal properties. The magnet is composed of 16 semi-octants, each 11.6 ft long, built up of cemented laminated blocks of transformer iron. Separable pole tips 11.6 in. wide with a 3.0 in. gap are accurately spread by a non-magnetic steel front and back spacer and firmly clamped by two pneumatic tubes. Crenelated [2] pole tips have proven entirely satisfactory in yielding a region of good "n" of over 6 in. at 13.8 kG and 7 in. at injection field of 270 G. Hysteresis loss in the iron amounts to about 100 kW and total losses in the copper coils are 1 065 kW of which 287 kW is due to eddy currents. Magnet coils consist of 62 turns of water cooled copper bar 15/32 in.$\times$19/32 in. wrapped with mica and glass tape and embedded in epoxy resin.

Magnet power supply

Magnet peak energy of 1.4×10^6 joules is provided by a capacitor bank storing 0.74×10^6 joules and by the d.c. bias air core reactor. The capacitor bank, rated at 87 000 kVAr at 19Hz, is divided into sixteen sections which are placed between the sixteen magnet semi-octants. Such an arrangement greatly simplifies magnet coil construction by allowing multiturn coils, an important consideration in reducing eddy currents. Energy losses will be made up by a 1650 kVA 2-pole a.c. alternator and two 500 kW d.c. generators on a common shaft driven by a 3 500 h.p. synchronous motor through an eddy current clutch. The a.c. generator will be maintained in resonance with the magnet system by suitable servo-control of the slip of the eddy current clutch. Since the minimum magnetic field must be kept constant at $270 \pm 1/2$ G the d.c. and a.c. amplitudes must be controlled to a precision of 10^{-4}. This has been achieved in a small prototype of the final MG set. The air core reactor is unusual in that it consists of sixteen secondary coils uniformly coupled by their own mutual inductance plus the flux set up by sixteen equalizer windings connected in parallel. This extra coupling provided by the equalizer windings is necessary to split the frequencies of the many unwanted modes of the system from the operating frequency.

Vacuum chamber

An especially difficult vacuum chamber problem is presented by the high rate of change of flux, the need to waste as little vertical aperture as possible, and the ever present hazard of radiation damage. Full section models have been made of a possible solution consisting of many stainless steel U-shaped ribs supported by a front non-magnetic steel plate which, in turn, is supported by a front non-magnetic steel pole pieces pacer. Vacuum sealing will initially be made by a fibre-glass epoxy skin, but the possibility of radiation damage indicates the need for a more permanent solution. Use of enamel glass insulation of the ribs and possibly also as a vacuum coating is being explored. Evacuation will be accomplished by 22 well baffled oil diffusion pumps.

Injection system

A 3 MeV Van de Graaff accelerator yielding a total pulsed ion current of 8 mA has been purchased and tested. An inner electrostatic liner will be pulsed positive by about 40 kV during the 30 μs injection period in order to compensate for a 10 kV droop in the voltage and also in order to be able to inject at all times with zero radial betatron oscillations. The relatively high dB/dt of 58 kG/s will cause the beam to shrink 1.4 cm in one turn; an amount sufficient to miss the inflector plate. An injection of 9-10 turns is planned. Numerous electrostatic quadrupoles, deflectors and beam shifters have been included to steer the beam from the Van de Graaff to the synchrotron magnet with a final precision of ± 1 milliradians. All of these electrostatic devices will be servo controlled to a precision of 0.01 % and will be programmed to allow for the 30 kV modulation of the beam energy.

Radio-frequency

Radio-frequency acceleration will take place at four 6 ft straight sections located 90° apart around the magnet ring. Using the 8th harmonic the required frequency swing will be 2.5 to 30 MHz. The maximum energy gain per turn will be 60 kV or 15 kV per station. Two schemes to achieve these requirements have been tested at full power and both appear to be practicable. In one approach acceleration in the frequency range 2.5 to 6.5 MHz is performed by four drift tubes, each placed inside a ferrite-loaded cavity that can be tuned over the range 6.5-30.0 MHz. Tuning of the drift tubes is accomplished by magnetically biasing the 160 lb of ferrites used to load the drift-tube quarter-wave stub line. Tuning of each ferrite-loaded cavity is accomplished by a bias magnetic field produced by 15 000 A of current from a transformer driven by a 10 kW tetrode. Tests appear to show that no difficulties arise as the drift-tube frequency approaches the cavity frequency and we expect no loss of beam as the transition is made. Cavities and drift tubes are resonant plate loads of self-tracking amplifier stages which, in turn, are driven by a master-oscillator signal. The master-oscillator signal is first amplified by broad band distributed amplifiers delivering about 2 kW of average RF power. Frequency tracking of the protons to an accuracy of 0.01 % will be needed in order to avoid

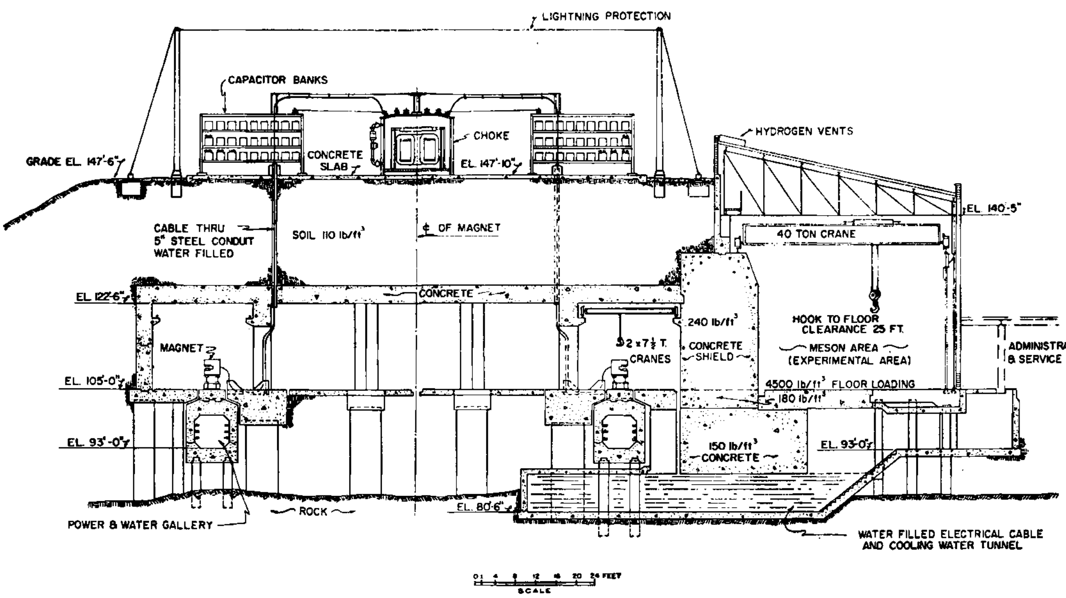

Fig. 2 Section through the synchrotron magnet room and meson experimental area.

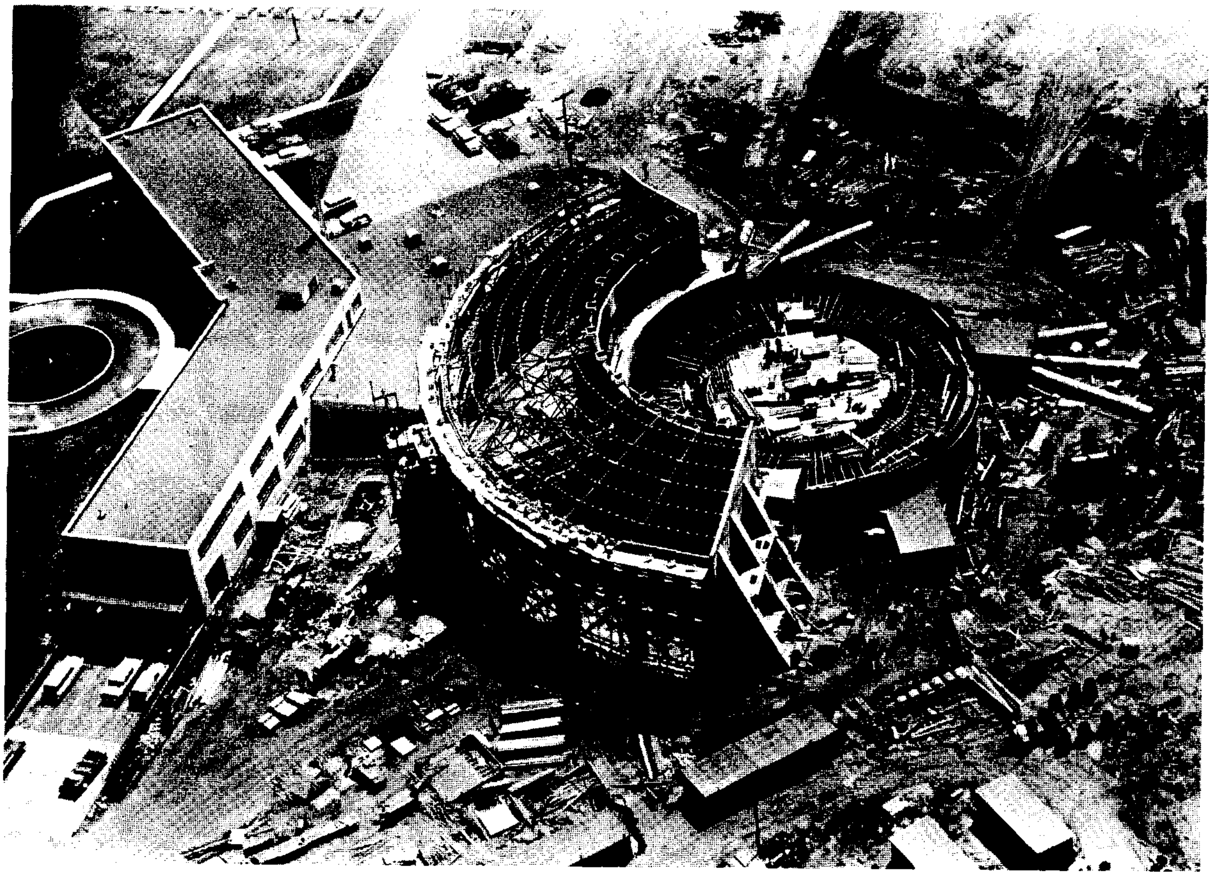

Fig. 1 Photograph of synchrotron building showing magnet room prior to pouring concrete roof. Meson experimental room partially surrounds magnet room. Laboratory and administration building is on the left.

beam loss. 40 kV has been obtained in a single cavity. Normal operation at 30 kV requires 20 kW of average input d.c. power to the final RF amplifier tubes. About half of this power is dissipated in the 1 600 lb of ferrites and is carried away by circulating silicone oil. A second approach to the large frequency swing problem is to place a large rotating condenser across the ferrite-loaded cavities and thereby increase the tuning range. This has been tested and found to be satisfactory.

Shielding

To achieve complete shielding, and yet preserve flexibility, a combination of poured concrete walls, demountable block walls, and earth fill have been employed. The concrete walls and the block walls are 15 ft of density 4 concrete made from ilmenite iron ore, while the fill overhead consists of 22 ft of earth of density 1.8 on top of 3 ft of density 2.4 concrete. In the plane of the beam the earth fill is approximately 45 ft thick (see Figs. 1, 2 and 3).

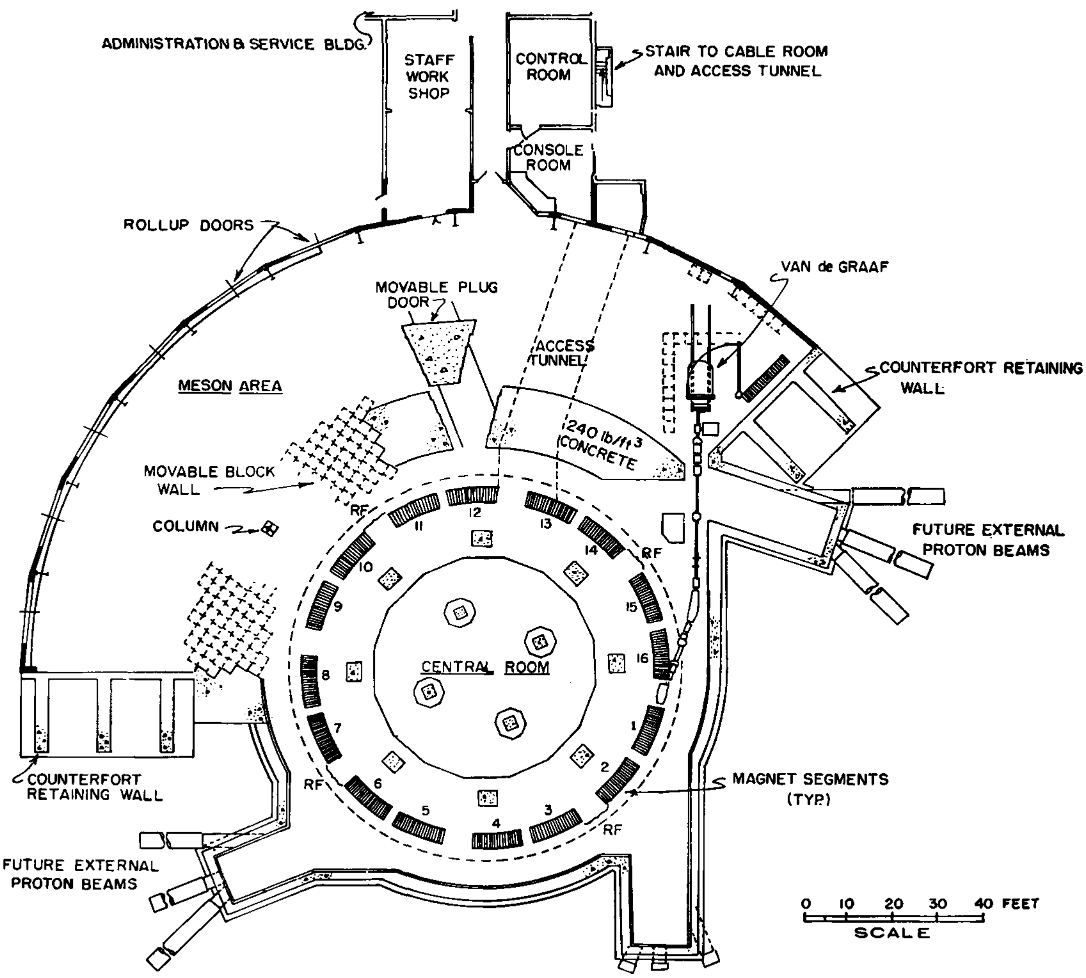

Fig. 3 Synchrotron plan view.

LIST OF REFERENCES

1. White, M. G., Shoemaker, F. C. and O'Neill, G. K. A 3-BeV high intensity proton synchrotron. CERN Symp. 1956. *1*, p. 525-9.
2. Bruck, H., Bronca, G., Hamelin, J., Neyret, G. et Parain, J. Correction du champ magnétique par entrefer d'amortissement ou par crénelage de la surface polaire. CERN Symp. 1956. *1*, p. 330-8.