THE PRINCETON-PENNSYLVANIA RAPID CYCLING, 3 GeV PROTON SYNCHROTRON-RECENT IMPROVEMENTS AND FUTURE PLANS

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Introduction

The Princeton-Pennsylvania Accelerator is a 3 GeV weak focusing proton synchrotron, operating at a repetition rate of approximately 20 Hz. The machine was brought into operation in 1963 and has proven to be a valuable research instrument, especially in the areas of pion physics, K-meson physics, CP violation, and high energy nuclear reactions. By use of the slow extracted proton beam and the internal beam, it is customary to have as many as fourteen experiments set up at any one time. Beam current is shared between these experiments on an hour to hour, pulse to pulse, and simultaneous basis with an average of six to eight experiments receiving beam at the same time. Physicists from some twenty universities and laboratories have availed themselves of these facilities.

Present Operation

The synchrotron has been running for the past three years with an internal proton beam of 5×10^{10} per pulse at 20 Hz with an eight millisecond internal and external beam spill and a ten percent spill duty factor, exclusive of RF structure. A valuable feature has been the one nanosecond proton on internal target bunch structure which has made practical the use of time-of-flight techniques on neutral and charged particles. This feature is used for particle type differentiation and for energy determination. In order to increase the thirty nanosecond time separation between bunches, considerable machine time has been run with every other beam bucket empty. This is achieved by synchronously chopping the 3 MeV injected beam[1].

A slow extracted beam of 3×10^{10} protons per pulse was achieved in 1966.[2] This resonant extraction system produces a spot size of 4×4

millimeters, 30 meters from the synchrotron. The proton beam has been shared between internal and external targets on a cycle to cycle and intracycle basis as required. When full beam is extracted, an internal target is placed to shadow the extraction magnet septum and it produces low intensity secondary beams to the internal beam area for set up and testing of experiments.

Immediate Improvements

In order to improve the beam utilization duty factor the synchrotron magnet will be "flat topped" by late 1969. The flat topping method, which has peen described elsewhere,[3] will incorporate a solid state magnet drive source to replace the existing rotating machinery. All the switching associated with flat topping will also be performed with solid state devices. A functional schematic diagram of the flat topping circuit is shown in figure 1. The possible flat top duration will be zero to 50 milliseconds, constant to 0.01% and the resultant repetition rate will be from 20 to 10 Hz. During the flat top the beam may be either tightly bunched or unbunched with an energy spread of ± 100 keV.

At the present time, deuterons have been accelerated to 600 Mev[4] ($\approx 4 \times 10^{10}$/pulse) and alpha particles have been injected, captured and accelerated to 50 MeV ($\approx 2 \times 10^{9}$/pulse). Within a few weeks alphas should be available at 550 MeV as the only difficulty appears to be the readjustment of the RF frequency program. The method used for alpha acceleration consists of producing He^{+} in the Van de Graaff ion source and gas stripping to He^{++} between the Van de Graaff and the synchrotron.

In late 1969 a new acceleration tube for the Van de Graaff injector will be delivered which will permit operation at 4 MV rather than the present 3 MV. This improvement coupled with planned RF systems modifications will permit the acceleration of deuterons and alphas to a maximum energy of 1.2 Gev/nucleon.

An immediate program for improving the proton beam current by applying a non-sinusoidal RF accelerating voltage[5,6] is also underway. A system has been built which produces some additional accelerating voltage in the early part of the cycle at twice the normal RF frequency. Tests indicate that this system yields a factor of 2 in beam current and, coupled with the 4 MeV injection, calculations show that an intensity improvement of a factor of 3 should be realized. This system should be operating in late 1969.

Future Plans

For some time the intensity of PPA has been limited to 5×10^{10} per pulse by transverse space charge defocusing at injection. This limit will be raised slightly by virtue of 4 MeV injection and non-sinusoidal RF, but a larger increase is desired, especially since the average intensity will be reduced by any flat top on the maqnet cycle.

A fast cycling booster synchrotron has been designed and a proposal submitted.[7] This 20 Hz, strong focusing synchrotron would accelerate the beam from 3 MeV to 75 MeV before injection into PPA. The location of the booster (PPB) is shown in figure 2. The PPB magnet would consist of 6 FDF bending magnets, each 1.8 meters long, separated by 2 meter long straight sections with a small D quadrupole in the center of each. The plan is to construct the bending magnets from NAL booster "D„ laminations. The Q values of the PPB are approximately 1.75 and the expected intensity increase of PPA with the PPB is a factor of 20, or 10^{12} protons/pulse (2×10^{13} protons/sec). PPB design details have been investigated and reported elsewhere.[8]

Future plans include acceleration of useful beams of carbon and nitrogen nuclei. The realization of this goal requires the 4 MV Van de Graaff and RF system modifications.[9] As with α particles the plan would be to partially strip in the ion source and then fully strip in the injection line from a 2, 3, or 4 plus state.

A new all ceramic and metal vacuum chamber for PPA is at present being tested. This chamber should attain pressures of 10^{-8} torr. or better and when all sixteen sections have been installed in the magnet ring (hopefully by the end of 1970) PPA will be capable of accelerating partially stripped, very heavy nuclei.[10] For example, Xenon or Uranium would be stripped from 9 plus to 22 plus between the Van de Graaff and PPA and then accelerated to 40 Mev/nucleon.

When complete, the PPB will make possible the acceleration of very heavy ions to much higher energies with much higher beam currents.[7] In this case ions with $e/m \approx 0.05$ would be injected into the PPB from the Van de Graaff or a 750 KV Cockcroft-Walton. The PPB would accumulate charge, bunch the beam and then transfer into PPA for acceleration to ≈ 10 MeV per nucleon. If much hiqher energies are desired, the beam could be extracted from PPA, fully stripped, stored in the PPB, and then reinjected into PPA and accelerated to energies of the order of one GeV per nucleon. The currents expected in these more sophisticated modes are approximately 10^9 particles/pulse. Possible acceleration cycles are shown diagrammatically in figure **3**.

The PPB would also make possible the acceleration of polarized protons since the PPB would permit injection at 750 KeV from a Cockcroft-Walton. Such an arrangement would provide adequate ion source room as compared to the small space available in the terminal of the 3—4 MV Van de Graaff.

Long Range plans

It is recognized that in order to increase the usefulness of the PPA facility an eventual energy increase will be required. As it presently operates the PPA would be a satisfactory booster injector for a slow cycling, higher energy machine. Figure 2 shows how such a goal can be realized. The system would consist of the addition of a 10—15 GeV 45 kilogauss, superconducting or cryogenically cooled aluminum magnet ring around the present accelerator. This AG synchrotron might have a repetition rate of one/5 sec. and would be able to utilize the existing buildings, shielding and experimental areas. The project would be almost entirely one of magnet development.

Looking further into the future, once such magnets were built, a separate ring tunnel might be constructed as shown in figure 4. The ring pictured would have an energy of 75 GeV with a tunnel circumference identical to the NAL booster synchrotron[11].

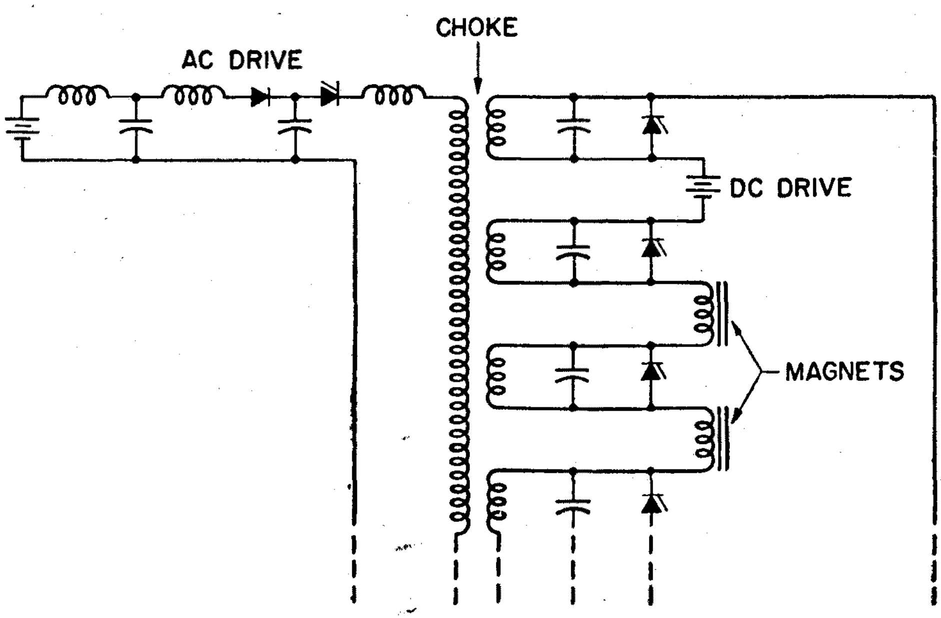

Fig 1. Simplified schematic diagram of PPA flat topping circuit

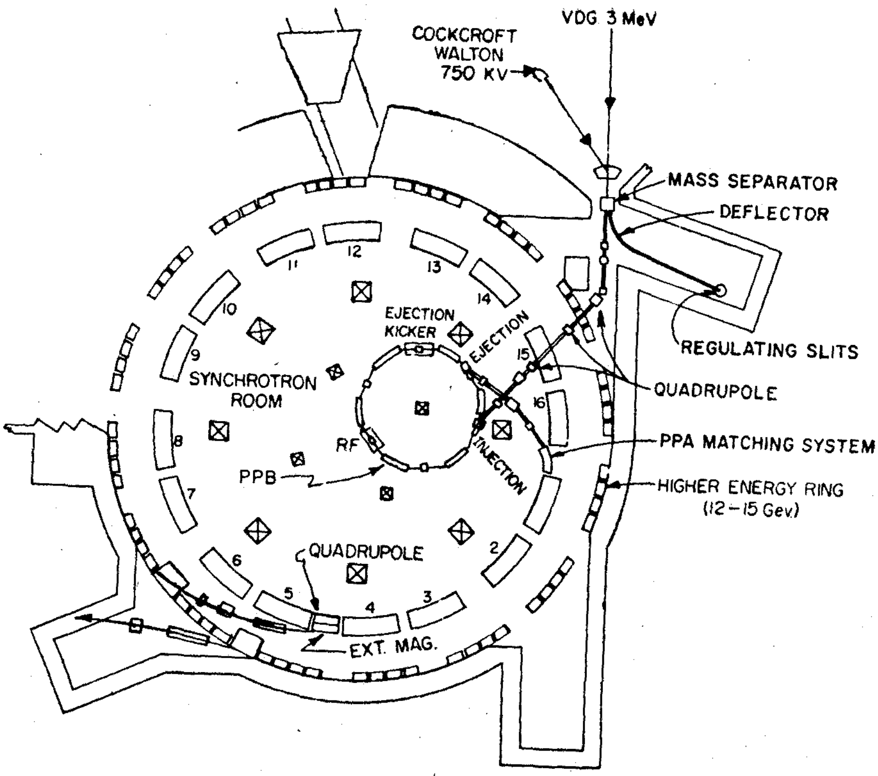

Fig 2. Plan view of PPA with proposed PPB and 15 GeV ring added

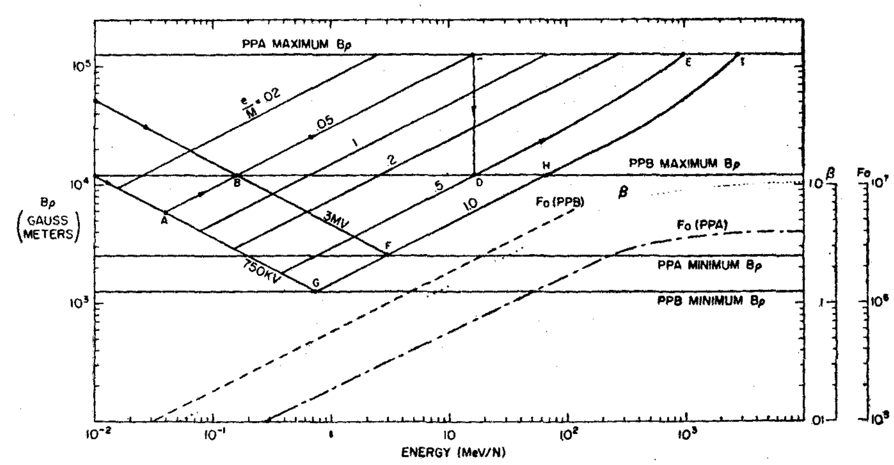

Fig 3. Diagram outlining heavy ion acceleration method

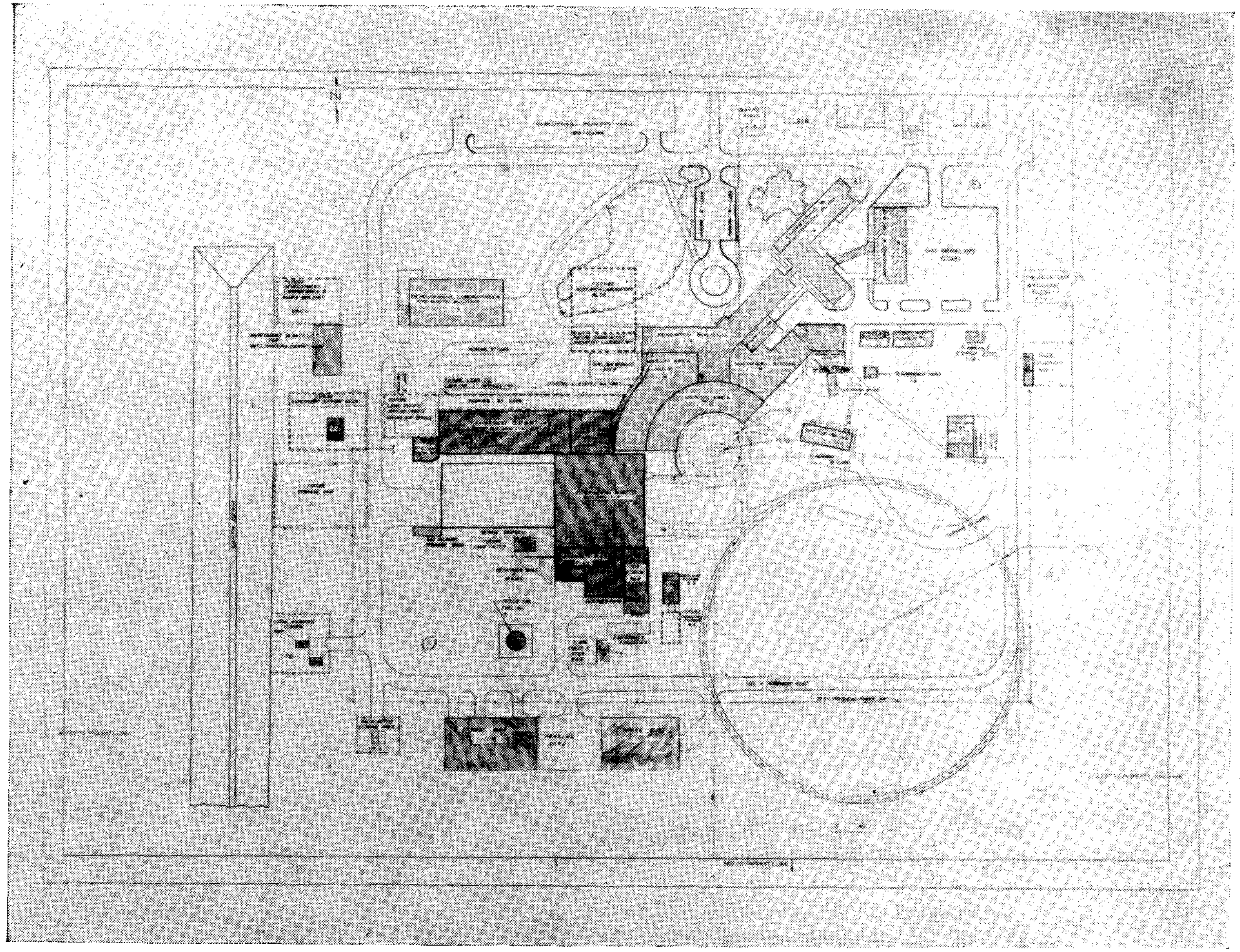

Fig 4. P an view of PPA site with proposed 75 GeV ring

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ДИСКУССИЯ

Столов: Каким образом осуществлена площадка магнитного поля и сравнивались ли способы получения площадки при помощи дросселей насыщения и управляемых вентилей?

Kirchgessner: The flat top switching is done with solid state, SCR's. We did consider saturating chokes but found that for a very long very flat top switching was much simpler.

Сивков: Когда предполагается сооружение первого и второго сверхпроводящих колец?

Kirchgessner: Someday, in a few years, when money is available.

Казанский: Какие потери дейтонов наблюдались при захвате в синхротронный режим и какой вакуум при этом был в камере ускорителя?

Kirchgessner: The losses are essentially the same as for protons, 90% loss in the capture process. 5×10^{10} protons/pulse as compared with 4×10^{10} deuterons/pulse. The vacuum whan we worked with deuterons was norma namely 2×10^{-6} torr.

Reich: Could you sketch the time law of the RF and say how you it obtain?

Kirchgessner: The nonsinusoidal RF is simply added 2nd harmonic in the early part of the machine cycle. This is done with one drift tube RF station which has been modified.