# OPERATION OF A 3 GeV FAST CYCLING PROTON SYNCHROTRON

E. P. Tomlinson*
Princeton-Pennsylvania Accelerator
Princeton, New Jersey

## Summary

The Princeton-Pennsylvania Accelerator at the Forrestal Research Center in Princeton operates at approximately 19 pulses per second. It quite consistently achieves 1 to 2 x $10^{10}$ protons per pulse and has been tuned up, in ways which we do not yet know how to reproduce, to an intensity of 5 to 6 x $10^{10}$ protons per pulse. Since August 1963 it has been serving simultaneously one to four prime users, plus a similar number of parasites, with beams of $\pi$ and K mesons generated in an internal stationary target, usually platinum. Beam spill is achieved over a time of 2 to 4 msecs with some synchrotron oscillation structure and 100% RF structure. The latter has been used effectively in some experiments as a means for velocity selection in momentum analyzed beams. In addition to serving experiments, current major efforts of the staff are directed toward increasing stability and intensity, improving overall reliability in general and spill control in particular, preparing for an external proton beam, and accumulating equipment and experienced manpower for general support of experiments. Operating schedules and procedures will be described.

## Introduction

The Princeton-Pennsylvania Accelerator is a synchrotron which accelerates protons to 3 GeV with a pulse rate of approximately 19 cycles/sec. (The exact repetition rate depends upon the resonant frequency of the guide field magnets and associated capacitors, this frequency varying ± 0.5 cycle/sec, depending primarily upon the temperature of the capacitors which are mounted outdoors.) Acceleration to 3 GeV was first attained April 11, 1963. Since August, 1963 it has served, by use of internal targets, as a source of mesons for a score or so groups of experimenters. The highest intensities of fully accelerated beam achieved up to now are of the order of 6 x $10^{10}$ protons per pulse, i.e., 1.2 x $10^{12}$ protons per second or 0.2 microamperes, a beam power of about 600 watts. (It takes some two megawatts to run the machine.) Normal consistent operation has been at about half this intensity level.

## Operating Procedure

The machine is presently operating on a schedule of twenty-four hours a day, five days a week. Typically, within these 120 hours, 10 hours are scheduled for maintenance and tune up, 16 for "synchrotronics", and the remaining 94 for experimenters. Week ends remain as times for some maintenance and modifications. Only if and when these latter activities begin to dwindle can we contemplate adding more days to our operating schedule.

Laboratory shift crews consist of an operating engineer, three machine operators, three experimental floor operators, and two maintenance personnel for laboratory utilities. To these, of course, are added a continuously varying number of experimenters to complete the complement of personnel on hand during all shifts of operation.

## Experimental Support

As illustrated in Fig. 1 a given running period typically serves four or five prime experiments, several able to run concurrently, plus a number of parasite group activities.

This we do by bringing out from one internal target focussed meson beams at three or four different angles with respect to the primary proton beam, and magnetically splitting at least one of these into positive, neutral, and negative components. (The neutral component is, of course, not focussed.)

Beam configurations have so far been specified by the experimental groups. Apparatus for these is then assembled and set up by laboratory personnel, using the laboratory stock of dipole bending magnets and quadrupole focussing magnets, plus shielding blocks to control background and maintain safe radiation conditions. In addition to other standard support equipment, a 15" fast cycling liquid hydrogen bubble chamber, with full accessories including a 3 megawatt magnet, and built-in counter controlled logic for selecting events for photography, has been operated with a synchrotron

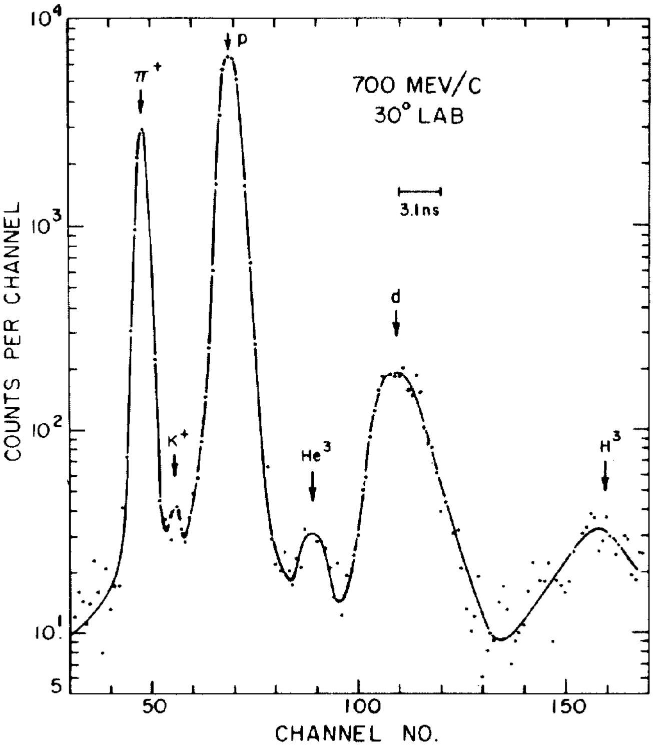

Fig. 1. PPA Experimental layout for 1st running period.

secondary beam and will become a standard laboratory facility. In general, however, secondary targets, detecting apparatus, etc., are designed to fit specific experiments and are, therefore, not provided by the laboratory.

## Technical Details

Of primary interest to experimenters, in addition to proton energy and intensity, is the nature of the spill of the accelerated proton beam onto a target. So far our target has been mounted inside the orbits used for injection and acceleration and the beam after acceleration has been steered into it by controlling the frequency of the RF accelerating system. Because the magnet cycle consists of a biased sine wave, somewhat flattened at the top by magnet saturation, there is available to us some 10 msecs of the 52 msecs machine period during which the circulating beam is within 10% of maximum energy. We have in practice been using 3 to 4 msecs of this time for spilling the beam, all on the rising portion of the magnet cycle. So far our control of the spill has failed to remove spikiness due to coherent synchrotron oscillations. From the point of view of statistics of counting, our spill, spread as it is over 4 msecs, is not better than a spill at a uniform rate of the same number of protons over some 0.5 msecs. Efforts to program the spill control with sufficient precision to improve the duty cycle have been only moderately successful, so we are now designing and building equipment for servo control.

The duty cycle figures above refer to spill characteristics superposed upon the RF structure of the beam. We have made no serious efforts to eliminate this RF structure up to now. Although we have made some speculations on ways to eliminate it, we have not pushed them, in part because experimenters have found ways to use the RF structure profitably. The PPA RF accelerating system operates on the eighth harmonic of the proton orbital frequency with a stable phase width at full acceleration of about 1/10 the RF period. Reduced to numbers at the time of maximum proton energy, targetting pulses have a time width of about two nanoseconds with a spacing of some 33 nanoseconds. These numbers turn out to make feasible the following techniques, first recognized by Piroué during survey of our machine and first exploited by Fitch during our first experimental running period. A conglomerate mess of electrons, mesons, protons and heavier particles in a secondary beam from the target is momentum selected by magnets

**Fig. 2. Typical experimental time distribution of particles in a momentum analyzed secondary beam.**

and slit configurations. The various mass components in the beam transmitted through such an analyzer separate time-wise, because of their different velocities, over a flight path of reasonable dimensions for our installation. Fig. 2 shows this time-wise spread.

Thus, interactions in experimental apparatus of, for example, K mesons can be singled out by their time of occurence with respect to the RF accelerating phase in spite of high contamination of the secondary beam by $\pi$ mesons and other particles. Maximum effective use of these techniques requires of course that the primary proton beam RF buckets remain reasonably fixed in phase with respect to the RF accelerating voltage, both over the extent of spill time and from pulse to pulse. Once this need was recognized it was relatively easy to satisfy it in synchrotron operation. Careful attention to maintain RF amplitude proportional to guide field time rate of change (dB/dt) over the spill time and reproducible from pulse to pulse achieves the required stability. These time of flight techniques provide, incidentally, the only presently known method for sorting out neutral particles generated in the synchrotron target.

## Future Developments

In our efforts to achieve operation of the PPA (a task which, due to our fast cycling, stretched to the limit some states of the art) and to maintain operation for experiments, many niceties in control convenience and some engineering precautions to insure reliability were by-passed. We are in the process of gradually correcting these defiencies insofar as time left from support of experiments allows. The major current development effort, however, is going into design and construction of equipment for extracting the primary beam of 3 GeV protons from the guide field and piping them to a new target location outside the shield around the synchrotron. We expect to see this extracted proton beam in use within a year. After attainment of the extracted beam we expect to be continuing efforts on increasing intensity, stability and reliability plus expansion of the external beam versatility by installing equipment to kick the beam into two more exit ports already available. We also foresee major efforts to increase spill duty cycle, perhaps by "flat-topping" the main accelerator magnet cycle. Beyond these, further developments will be dictated by the needs of experimenters in keeping up with the techniques of high energy physics.

*Speaking for the Staff of the Princeton-Pennsylvania Accelerator