OPERATION OF THE COSMOTRON

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Although experiments at the Cosmotron are becoming increasingly complicated, several years of experience has led to rather routine operation for a large number of experimental setups. New arrangements such as K meson beams and the external proton beam become standardized somewhat as experience is gained. The machine is now run five days a week twenty-four hours a day, approximately two hours a day of which are used for routine scheduled machine inspection, minor maintenance (filling of liquid nitrogen traps, etc.) and for re-arrangement of experimental apparatus. Since there is a certain amount of time loss at machine start up and shutdown, twenty-four hour a day operation seems most efficient to us. Major experimental area changes involving moving analyzing magnets and large quantities of shielding are done, insofar as possible, on weekends and during operating time while another experiment is in progress. Approximately one week out of seven is devoted to major maintenance and installation of special facilities required by particular experiments. The operating crew consists of (a) two operators in the main control room whose duties include target changing, maintaining the proton energy and intensity at levels requested by the experimenter, start-up and shutdown for experimental access to the machine, and routine repairs (b), two operators in the motor generator room which houses the power supply and all incoming power to the Cosmotron who are responsible for proper operation of the main motor generator set, the ignition rectifier-inverters and the associated switch gear. In addition, when experiments require auxiliary magnets, an operator is on duty in the room which houses the D.C. generators available for powering these magnets and whose responsibility includes operation of this rotating machinery and making sure that the proper power, cooling water and interlock connections are made to the experimental magnets. The operating crew described is complemented as required because of complexity of set up or component failure by various staff members. These are (a) crew chief for the main control room, (b) crew chief for the motor generator room, (c) an electrical engineer with responsibility for overall machine operation and repair, (d) an electrical engineer doing control wiring and instrumentation, (e) an electrical engineer in charge of the motor generator room, (f) an electrical engineer in charge of experimental magnets, controls, etc., and (g) an electrical engineer doing electronic development and responsible for all electronic gear associated with the machine.

Aside from the basic equipment necessary to operate the machine, a number of facilities are available in the main control room for convenient experimental use. The circulating proton beam is monitored by continuously observing the signal from the induction electrodes placed in one straight section and this information may be sampled at any prescribed time, generally a few milliseconds before the beam strikes a target, converted into digital information and made available to experimental areas in various parts of the building via the coaxial cable system. The absolute calibration of this circulating beam monitor is known to about ten per cent and has a noise level equivalent to 10^7 protons; in addition, a dynamic beam attenuator is available which reduces the circulating beam to any determined value and maintains this intensity from pulse to pulse to within a few percent. An additional set of induction electrodes provides a difference signal which indicates the radial position of the beam in the vacuum chamber at any time. Timing signals are available for triggering of cloud chambers and gating of electronic apparatus and in some instances, certain functions of the machine such as the repetition rate, ultimate energy, and intensity are controlled by signals which originate in the experimental areas. A programming system has been installed which controls the repetition rate, peak magnetic field attained, the peak energy, the intensity of the circulating beam, auxiliary magnet powering and target position from pulse to pulse and allows automatic operation of as many as four simultaneous experiments requiring widely different machine conditions. In addition, the radio frequency accelerating voltage may be modulated so that on any one machine pulse a particular fraction of the circulating beam can be made to strike a target at a predetermined energy and the remaining beam continues to be accelerated and strikes a separate target at some higher energy.

The circulating proton beam is caused to strike a target by removing the radio-frequency accelerating voltage while the magnetic field continues to rise thus causing the protons to spiral inward. The rapidity with which the accelerating voltage is removed determines the length of the on target beam burst which can be varied from 0.001 sec.

to greater than 0.100 sec. The longer bursts are used for counter experiments in order to reduce instantaneous counting rates but because of the energy spread incurred in the above method of increasing the duty factor of the machine, it is unsatisfactory beyond a certain point for certain experiments. Minor modifications are being made in the magnet pulsing circuits to change the rate of rise of the magnetic field at any particular time to a value much smaller than normal. This "flat-topping" will make beam bursts available of essentially monokinetic protons for times considerably longer than 0.100 seconds and is limited essentially by heating of the magnet itself. In addition to extending the on target time, it is desirable for some bubble chamber operations and certain counter experiments to reduce it below 0.001 sec. A set of perturbing coils are being inserted in one straight section and when pulsed by a large condenser bank will allow an on target time of as short as a few microseconds to be achieved, which should also be applicable to a fast external beam. A large variety of target positions and arrangements are available routinely and are being continuously added to for particular experiments. Routine targeting is done through air locks, most of which are equipped with pneumatic rams for rapid insertion of targets if this is required because of background from early beam spill-out. Timing signals from these rams are available in the control room so that target positions can be monitored from pulse to pulse.

Complicated experiments and operation of two or more experiments in parallel requires a considerable variety of electromagnets, most of which are more or less for general purpose use and others which are quite specialized. Not counting the magnet required for extraction of the external beam there are in use seven bending magnets, the three largest of which have pole tips 18″ × 36″ with a nominal 6″ air gap. Four pairs of strong focusing quadrupole magnets are available, the largest of which has a 12″ aperture and is used in focusing the external proton beam and various pion beams. The smaller strong focusing magnets are of a design developed at Berkeley with a four inch aperture and are used mainly for K meson experiments. Eight DC generators are available for these magnets and range in size from 1200 kW to 50 kW with the total DC power available being close to two megawatts. Portable magnet current regulators for each generator are available in the experimental area and if required the magnets may be pulsed or turned off and on by the programming system so that a single magnet may serve different experiments on alternate machine pulses.

Between the various experimental areas and the several counting rooms there are runs of experimental coaxial cable for high voltage distribution and fast pulse transmission. Most signal cables are of 125 ohm and 197 ohm impedance. All of these experimental cable runs are to a central coaxial patchboard panel so that any counting room may patch into any one of the experimental areas. The present cables and fittings are suitable for resolving times as short as 3-4 $\times 10^{-9}$ seconds and any decrease in resolving time will require better cable and connectors or require fast circuits to be placed on the experimental floor. No central counting room is used although much of the slower circuitry is standardized and is used in various experiments.

In buildings adjacent to the Cosmotron are located shop and electronic construction facilities whose work is divided approximately equally between new facilities and repair of the machine and purely experimental devices. Four mechanical engineers and four designers and draftsmen spend full time designing modifications to the machine and assisting in the design of experimental apparatus. The advent of liquid hydrogen bubble chambers and increasing demands for liquid hydrogen targets has made a larger liquid hydrogen facility necessary and there is now under construction a liquid hydrogen plant which will be capable of producing in excess of 50 l/hr. In addition, venting of hydrogen gas from these devices and possible liquid dumping must be safely accomplished and a temporary system is now in use while a more satisfactory solution to the problem is being designed.

The intensity of the circulating beam is now routinely 1×10^{11} protons per pulse and as the beam intensity has slowly increased, the shielding problem has become more and more acute. Shielding around the Cosmotron is of two general categories, — (1) The main shield which protects the control room, laboratories and shielded experimental area and (2) Special shielding around particular pieces of experimental apparatus. The main shielding and auxiliary shielding near the machine have increased in the past few years to the extent that deformation of the glacial sand upon which the Cosmotron is built has transmitted to the magnet ring itself a tilt which has had the net result of a loss of $\frac{1}{2}$ inch of vertical aperture. Any appreciable additional shielding near the machine will require a mechanical releveling of the magnet or a correction of the median plane by pole face windings. The external beam is adding considerably to the shielding problem and, since an increase of internal beam to 10^{12} protons per pulse does not seem out of the question within a year or two experiments are underway to give more information on the exact nature of the radiation in order to design a completely new shielding structure.

Experiments on the Cosmotron are done both by groups within Brookhaven National Laboratory and by groups and individuals from a number of other institutions. Since a certain amount of direct collaboration takes place, the fraction of inside and outside work done is difficult to assay exactly but approximately 40 per cent of Cosmotron time is devoted to experiments conceived and carried out by persons not on the laboratory staff. Requests for machine time, which are considerably in excess of the time available, are screened on the basis of feasibility and physical interest. Assignment of time is then made and an operating schedule arrived at. This "scheduling" involves a complicated sorting in time of the various experiments in progress taking into account magnet and shielding moving, liquid hydrogen and generator availability and interference with preceeding following and parallel experiments so that a maximum amount of machine time is utilized.

Plans for the immediate future include an addition to the building through which the external beam will pass, possibly arranged so that while one experiment is in progress in one half of the building, another, shielded from the current one by a concrete wall, is in the process of being set up. At the conclusion of one experiment the proton beam, by means of a steering magnet, will be pointed into the other experimental arrangement. This building will be equipped with at least a thirty-ton crane. The present building cranes with a capacity of ten tons are not adequate for the large pieces of experimental equipment now in use. Recent experiments on the injection system indicate that substantial increases in captured beam may be obtained by correcting the effects of a drooping Van de Graaff energy during a pulse. These effects are due to two causes, — (1) improper entrance angle and position into the inflector during the injection pulse and (2) displacement of the equilibrium orbit from the injected protons. Modulation of the Van de Graaff energy by means of a liner which is presently being designed and independent control of entrance angle and position will actually allow protons to be injected at an increasing energy. Also ion source development should increase the present pulsed injection current of 3 ma of protons. In addition, a feedback radio-frequency system which will damp phase oscillation has been tried with success. We have found it valuable to devote from five to ten per cent of operating time to improvements and studies of the operation of the machine itself some features of which are still incompletely understood.

The major difficulties encountered in several years of operating the Cosmotron have proved to be few. The water leak and consequent layer to layer short which caused a major shutdown and complete removal of the coil from one quadrant last year was due to a crack in the copper tube carrying cooling water silver soldered to the magnet bus bar. An improved device for more rapidly detecting water leaks is in operation on one quadrant and will be duplicated on the other three. The only major trouble which has developed in the magnet power supply has been the recent necessity for rewedging of the windings in the alternator stator and some settling of the generator foundation. This is due in part, at least, to the repeated transient forces due to torque reversal in the motor generator shaft on each pulse and can easily be remedied on future machines of this kind. Shortly after installation, the Myvaseal rubber blankets on the vacuum chamber were partly contaminated with organic solvent which caused some vacuum leaks. Now, however, that all of these blankets have been replaced, the pressure in the vacuum chamber is approximately 2×10^{-6} mm. of Hg. A study of gas scattering in the machine indicates that the average pressure in the machine is substantially the same as that indicated by ion gauges in the straight sections.

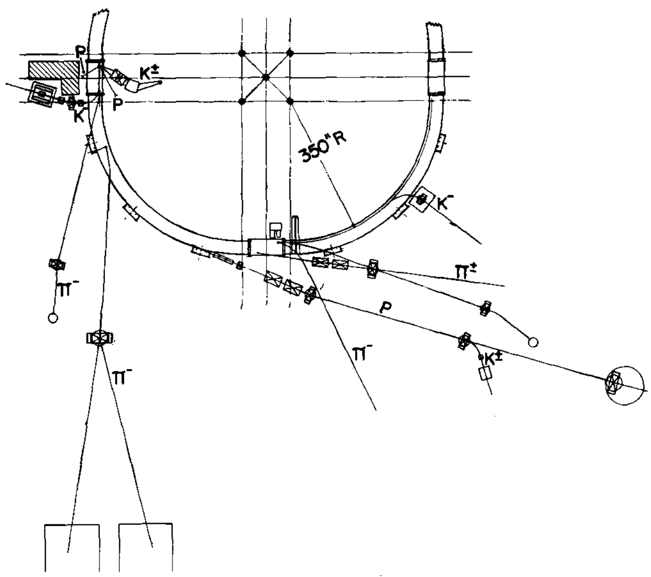

Fig. 1.