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The 6.3-Bev bevatron at the University of California Radiation Laboratory, in Berkeley, is a proton synchrotron accelerator using a programmed magnet field and rf system to maintain the accelerated particle in a uniform radius. The shell-type magnet is constructed in four quadrants and four 20-foot straight sections, making a total orbit length of 394 feet. Protons are injected at one of the straight sections and accelerated in one of the other straight sections by a 40 kw rf system using a drift tube. The two remaining straight sections are used for beam monitoring and target bombardments.

The bevatron actually consists of three separate accelerators and a 5.4-megawatt magnet power supply. A 480 kv ion gun injects into a 10 Mev linear accelerator, which in turn is the injector for the bevatron. How these four distinctive units are controlled, timed, and interlocked to give one unified operating unit is the subject of this report.

The designed energy of the bevatron was chosen sufficiently higher than existing accelerators so that a new era would be opened in physical research.

The bevatron construction project was first approved by the AEC in February 1948, and, after many delays and an expenditure of 9.5 million dollars, accelerated the first protons in February 1954.

At present the bevatron has accelerated 10^9 protons per pulse to an energy of 6.3×10^9 electron volts, and is able to do this 10 times per minute. The 10^9 protons pass a given spot in about 0.1×10^{-6} second. This is equivalent to 1.6 milliamperes per pulse, or a time average of 1.6 milliwatts output of this accelerator. From an energy standpoint this is not very efficient, considering a peak input of 100 megawatts into the magnet and 40 kw into the rf final amplifier; but from a physical standpoint the experimental results to be gained when mesons and other high-energy particles can be produced under controlled laboratory conditions are of inestimable value.

ION GUN

The protons actually begin their acceleration in an ion source that is biased at a positive voltage of 480 kv. The biased ion source is pulsed with a 500-microsecond pulse line and thyratron which strips the electrons from the hydrogen molecules. These ions are then accelerated through focusing and accelerating gaps until the ions have an energy of 480 kv. The 480 kv is furnished by a Cockcroft-Walton type of cascade rectifier using 16 kv rms (root mean square) at 800 cycles per second for input power. The direct-current voltage has a closed-loop regulator on it to hold the energy of the ions to ± 0.1%, which was the expected energy tolerance into the 10-Mev linear accelerator.

The biased ion source has several voltages and currents that should be telemetered into the main control room for monitoring. It requires only a single pulse to trigger the source and start a bunch of ions down the column.

LINEAR ACCELERATOR

The linear accelerator consists of a 20-foot-long tank resonant at approximately 200 megacycles, using 46 drift tubes. The rf energy is fed into the tank with 3 main oscillators using type 3W10,000A3 Eimac tubes and one pre-exciter using a 4W20,000A3. The pulsed 1.5-megawatt power into the oscillators is fed from two pulse lines at 26 kv. One of these lines is 120 microseconds long and feeds the cavity pre-exciter. The other, 700 microseconds long, excites the cavity to a voltage gradient of 500 kv per foot.

A beam buncher is used at the input of the linear accelerator; the rf for this buncher is fed directly out of a loop coupled into the linear accelerator cavity.

A beam deflector between the ion gun and linear accelerator keeps the quiescent beam from the ion gun out of the linear accelerator; it is gated off to allow the pulsed beam into the linear accelerator.

INFLECTOR

The output beam of the linear accelerator is passed through a set of strong focusing magnets, then through an electrostatic inflector that turns the ion beam through an angle of 35 degrees for the proper angle of injection into the bevatron ring magnet. The inflector voltage gradient is 35 kilovolts per centimeter and is powered at 80 kv d-c regulated to 0.01%; at the end of the inflector is a pneumatically operated cup on which the inflector output beam may be read with an oscilloscope. The cup is withdrawn about 0.6 second before the magnet is pulsed, and is back in place just after the beam has been injected into the bevatron.

The timing of the injected pulse into the bevatron must be within ± 50 microseconds; this is accomplished with either a peaking strip measuring flux in the main gap of the magnet or a peaking transformer that measures the magnet current. The pulse required to trigger the injector's 5-channel delay chassis comes from one of the two sources at the proper time for injection into the ring magnet and furnishes pulses in the order listed below.

1. linear accelerator pre-exciter
2. linear accelerator main pulse

3. beam deflector
4. ion gun trigger
5. spare and experimental use

Additional two-per-second test pulses are furnished the injector from the magnet pulser to keep the injector in a stable operating condition. These test pulses are synchronized with the magnet pulsing in such a way that the duty factor is not changed when the peaking transformer signal is used for injection.

MAGNET POWER

The magnet power supply was furnished by Westinghouse and consists of two 12-phase alternators; each coupled to a 65-ton flywheel and a 3600 hp. motor. Each alternator powers a 12-phase ignitron rectifier-inverter and are connected in series to feed a 100-megavolt amp pulse to the magnet every six seconds.

During standby and inversion the ignitrons are fired as inverters; when a magnet pulse is required the magnet pulser furnishes a bias that fires the ignitron as rectifiers. The bias is left on for about 1.75 seconds, which is time for the current to increase to 8,300 amps in the magnet and is the time that the machine is used for accelerating protons. When the bias is removed, the energy stored in the magnetic field--about 80 million joules--is inverted back into the flywheel of the motor generator sets. About 80% of the energy is thus recovered.

To maintain a minimum ripple voltage on the magnet during the rectification period, the two 12-phase generators are held in synchronism with an electronic regulator which operates on the generator fields and the ignitor phasing to affect the balance of power and synchronization between the two machines.

The magnet pulser that supplies the two-per-second test rate for the injector and the bias for the magnet pulsing also supplies pulses at minus 0.6 second and at minus 0.034 second as a prewarning that the magnet is going to pulse.

For other gating requirements, a differentiating circuit using the magnet voltage derives pulses at the beginning and end of rectification and at the end of inversion.

MAGNET

The air gap of the 9,500-ton magnet is 1 foot by 4 feet, and is pulses to 16,000 gauss. There are 21 copper tubes on the upper and on the lower face of the magnet that are used for small magnetic field corrections. At higher magnetic fields these relays are controlled by time-delay and variable-gate chassis triggered at some known value of magnet current. The magnet winding is air-cooled with two 250-hp fans.

One half of the magnet current passes through several peaking transformers that derive pulses at 30 calibrated points of current. These pulses are called current marks and are numbered 1 to 30.

There are two duplicate sets of current markers; one can serve as a spare for the other, but the primary reason is so that one set can be used for tracking the radio-frequency versus magnetic field, and the other for general triggering use.

RF POWER

A part of the magnet current passes through a ferroxcube core that is used in the inductance of a master oscillator. The resulting frequency of this oscillator is a first approximation to the correct frequency for proton acceleration. A thirty-point curve corrector is then used to trim this relationship to the precise requirements of the accelerator. This curve corrector is triggered by the 30 points of the current marker in order that the corrections be put in at precisely known currents. An electronic system is used to measure the frequency corresponding to each of the current marks, and to display this on an oscilloscope for monitoring the effectiveness of the curve corrector.

The output of the master oscillator is fed into a driver amplifier and then into a self-tracking type of final rf amplifier that delivers about 40 kw at 15 kv rms voltage to the drift tube.

The frequency range of this equipment is from 364 kilocycles to 2.46 megacycles, with a frequency tolerance ranging from ± 0.08% at injection, to ± 1.0% at final energy.

One special interlocking feature of the rf final amplifier, in addition to the standard personnel and equipment protection, is that the power for the self-tracking final amplifier must be turned off automatically when the magnet pulsing is stopped, and it can only be turned back on between magnet pulses after continuous pulsing is resumed. This is to protect some of the grid circuits of the final amplifier.

PROBES AND TARGETS

Various types of probes and targets are needed by the experimenters. To date air-operated mechanisms have been used because of the amount of linear motion required and the speed of response necessary. There are microswitches mounted at each end of travel so that the start and arrival times can be viewed on an oscilloscope. There is one mechanical flip-up device that uses a rotary Leedex switch to insert a small target in the middle of the beam; the target arrives in place 40 milliseconds after power is applied. A circuit consisting of a time delay and an electronic gate is used for timing the application of power to each of these controls. The delays are triggered by one of the 30 points of the current marker.

CLOUD CHAMBERS AND AUXILIARY PULSED MAGNETS

Several types of cloud chambers have been used: a large 4- by 8-foot continuously sensitive type diffusion chamber; standard expansion chambers; and a liquid-hydrogen bubble chamber.

Magnets for these chambers and for the film exposure program must be pulsed to their required fields in short times. The pulsing of the current is accomplished with an electronic current regulator, which regulates either at zero or at the maximum current. This electronic regulation eliminates contactors that would have to be opened and closed many times a day--and would require a great deal of maintenance work. So far the results have been good on a 360 kw motor-generator set. We hope to extend this same technique to a 1-megawatt pulsed analyzing magnet in the near future.

DEFLECTED BEAM

A program has been started to try to deflect the high-energy beam out of the ring magnet into a target area, so that inserting probes and targets into the beam will not involve vacuum problems, long probe travels, and working in restricted space. At present it seems as though a 6-ton pulsed magnet will have to be plunged, like some of the smaller probes, so that the right deflecting field is in at the right place at the correct time.

VACUUM SYSTEM

The volume of the vacuum system is 11,000 cubic feet and is held at 10^{-5} mm of mercury using a maximum of twenty-four 32-inch oil diffusion pumps. There is a maximum capacity of five 15 hp Kinney pumps to back the diffusion pumps. It takes about two days to get to operating pressures after the tank has been up to air.

It is necessary to let the tank up to air periodically so as to make adjustments or install new equipment in the vacuum chamber.

At present another very laborious job that requires opening to air is to clear short circuits between the insulated sections of the vacuum tank and others between the pole-face windings and ground. These parts do not have adequate insulation between them, and present quite a problem to maintain them clear. If four short circuits occurred at critical places at the same time, the several thousand amperes that would flow in the short circuit could burn a hole in the vacuum tank.

There is an automatic and continuous monitoring of these most critical joints, which will stop magnet pulsing if a short circuit occurs.

MASTER OPERATING CONTROL

As has been indicated above, there are many items that must be timed and operated for a given experiment. Some of these experiments do not require a beam every pulse--some require different energies, and some a different number of particles. This all leads to a problem when several experiments are carried on simultaneously. A master operating control is in the engineering stage that would allow several of these different modes of operation to be automatically selected, thus permitting the operator greater freedom in making the machine run effectively.

In order to facilitate testing of the various components there are several control areas used to put the equipment into operation. The Injector Control Room contains the controls needed to run the ion gun, linear accelerator, and inflector. The Motor Generator Control Room contains all the operating features needed to pulse the magnet and synchronize the generators. The Radiofrequency Control Room contains the master oscillator, 30-point current marker, and other auxiliary equipment. There is a remote-control point for the rf power on the tangent tank near the drift tubes and final amplifier. The vacuum system has its center of control for the heaters of the 24 diffusion pumps.

All the essential controls from each of the above areas have been remoted to a main control room where one operator can monitor all the vital signals to accelerate a beam. Each of the local areas has alarm panels for critical circuits. The Main Control Room has alarm panels that indicate trouble in given areas. All this control requires about 1,000,000 feet of control wiring, 200,000 feet of coaxial cable, and about 2500 vacuum tubes of over 100 different types.