VARIABLE MODE SOLID STATE MAGNET CYCLE TIMER*

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Summary. A solid state digital programmer of main ring magnet current at the Brookhaven Alternating Gradient Synchrotron.

At the Brookhaven Alternating Gradient Synchrotron (AGS) considerable effort is being devoted to the achievement of a higher intensity beam. Recently, due to multiturn injection and other improvements a significant increase in proton beam intensity has been obtained.

In order to fully utilize this advancement and at the same time provide maximum flexibility in the types and combinations of experiments which could be conducted simultaneously at the AGS, a variable mode magnet cycle timer was constructed. This device provides six distinct main magnet current waveforms such that the AGS Experimental Planning and Operations Group can schedule concurrent running of experiments requiring counter, spark or bubble chamber analysis. In general, the waveshape of our main magnet current may be thought of as combinations of the following line segments:

Rectify, a positive going current ramp
Flat-top, a nonchanging positive current amplitude
Invert, a negative going current ramp.

Thus the Operations Group may select:

Rectify - Invert
Rectify - Flat-top - Invert
Rectify - Flat-top - Rectify - Invert
Rectify - Invert - Flat-top - Invert
Rectify - Flat-top - Rectify - Flat-top - Invert
Rectify - Flat-top - Invert - Flat-top - Invert

The application and limitations of each current program are fairly complicated; however, typical usage might be Rectify - Invert for bubble chamber experiments, Rectify - Flat-top - Invert for both bubble chamber and counter experiments, and Rectify - Flat-top - Rectify - Flat-top - Invert for spark chambers at one energy, counter experiments at a higher energy, and bubble chamber runs at still higher proton energies (Fig. 1).

*Work carried out under contract with U.S. Atomic Energy Commission

The main magnet power supply is rated at a peak current of 7000 amps at 4800 volts. It consists of a 12 phase ignitron rectifier - inverter supplied by a motor generator set utilizing a 12 phase, 29,000 kVA synchronous generator.[1] The ignitron rectifier - inverters are divided into two banks of six interlaced phases. The firing point of each individual ignitron is controlled and phased to the rotation speed of the flywheel motor-generator by a set of electronic peakers.[2] The electronic peakers are in turn gated by the magnet cycle timer such that the ignitrons are fired under programmed control at approximately 30° (Rectify) and 165° (Flat-top). Invert is an internally controlled automatic function generated by the absence of Rectify or Flat-top, or by an external inhibit gate.

Prior to the introduction of electronic peakers, pulse trains generated via a group of saturable reactor biased transformers(connected so as to duplicate at signal level the 12 phase ac voltages applied to the ignitron banks) acted directly as phase controllers of ignitron firing. These pulse trains now are employed as input signals to the variable mode cycle timer and provide a method of synchronizing the cycle timer to machine cycles rather than real time. This synchronization is necessary as speed changes caused by magnet loading of the motor generator set result in magnetic field response following internal rather than actual time.

The magnet cycle timer itself consists of a binary repetition rate counter and four serial-two decade counters (Fig. 2). Basically, the repetition rate counter consists of a divide by six stage, a six bit binary counter, and a 12 position preset binary comparitor. This device serves to provide a reset and/or warning pulse (prepulse) and a start pulse (T_o) for all AGS timing operations. It operates with repetition rates of 0.4, 0.8, 1.2, 1.6, 2.0, 2.4, 2.8, 3.2, 3.6, 4.0, 4.8 and 5.6 machine seconds. Since it is clearly undesirable to ever generate a T_o pulse without previously sending a prepulse, the logic is so designed that a prepulse must have been generated before a T_o. In addition with the necessary independent control of the length of each current segment as well as of machine repetition rate, it was possible through operator error or magnet cycle timer failure to have a repetition period shorter than the Rectify/Flat-top time and consequently a machine malfunction. As a partial solution to this problem the unit was so designed that the entire set of time intervals must be completed prior to the introduction of a new cycle.

An important consideration in the operation of a particle accelerator is the ability to select the exact energy at which targeting is to occur. As the cycle timer itself must count machine cycles, resolution of the duration of any given current time interval is limited to approximately 17 ms. However, this resolution is insufficient for many experiments. Consequently, the first time interval was designed to count any phase of the twelve motor generator phases thus creating a 720 cycle vernier (fine cut) as a direct function of the time between T_o referenced to a fixed phase and the preset count of the first time interval based upon a selection of any of the twelve phases.

Three of the four serial decade counters are essentially identical with preset N-1 counters while the final time interval reaches its compare at preset N. This was done so as to achieve a pulse one machine cycle prior to a Flat-top. Rotary switch binary comparitors were employed in the preset section so as to eliminate the need for binary to decimal decoding.

The decade counters may each be adjusted from 1 to 99 cycles (counts) of machine time.

The pulsing type of duty necessary to alternately store and withdraw energy from the main magnet ring causes torsional stress in the shaft of the MG set. The manufacturer's study of shaft oscillation indicated that the most effective method of reducing torsional oscillations is to invert one ignitron bank first: the second ignitron bank being inverted one-half cycle of natural shaft frequency later[3]. A solution to this control problem is obtained by gating each bank of ignitrons separately via gates shut off by any phase and a phase 270^{o} later.

The final output of the cycle timer consists of a group of NAND gates whose outputs are selected so that the desired magnet current waveshape is obtained (Fig. 3).

The cycle timer was constructed in two sections: logic and control, power and interlocks. Both units are slide mounted for easy maintenance. The power unit employs commercially available silicon current-limiting modular power supplies and several warning, alarm and interlock relays. The main assembly provides space for 56 commercial solid state logic cards in two holders. At present 36 cards are employed, hence there exists room for considerable logic expansion. All control and counter flip-flops are connected by lamp drivers to a service panel containing 56 lamps. As most of the magnet cycle timers operations occur at a 60 cps or lower rate, the service panel provides a convienient method of monitoring or trouble shooting the system. As the unit is to be employed in a darkened power room environment, nixie readout lamps were provided to indicate the cycle times of the repetition rate and time interval counters. A duplicate set of indicators is also located in the AGS Main Control Room. The control circuit provides for both external input and output interlocks as well as a warning horn and cycle chime.

Perhaps the most difficult problem was to construct an equipment failure protector which would protect the motor generator without severely limiting flexible operation. What was really desired was a device which would recognize an internal failure or control maladjustment and either shut itself off or operate in an entirely safe manner.

As a first step toward this ultimate goal the present magnet cycle timer employs an auxiliary counter which will discontinue magnet pulsing whenever the sum of the number of rectify cycles exceeds 62 (maximum safe operations level).

The present system has operated over two million machine pulses without a malfunction, and has expanded both the reliability and the versatility of the Brookhaven Alternating Gradient Synchrotron. Future plans may include magnetic field control of timing interval duration and more complete fault detection computer.

References

1. E.E. Shelton, "Electric Power for the Alternating Gradient Synchrotron", AIEE Conference Paper, 59-12 79, p. 1, October 1959.
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3. E.E. Shelton, "Electric Power for the Alternating Gradient Synchrotron", AIEE Conference Paper, 59-12 78, p. 20, October 1959.

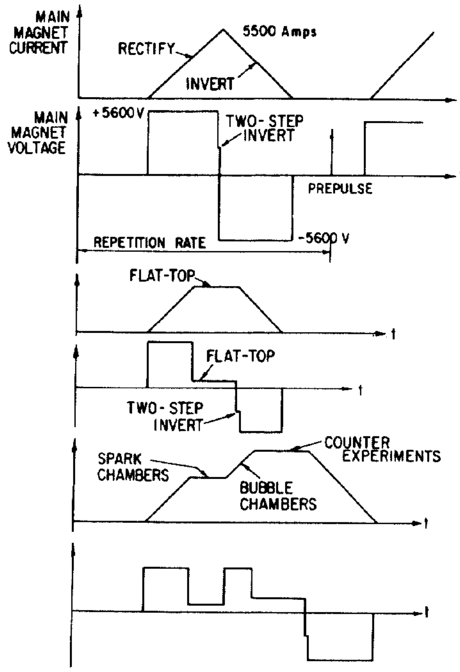

Fig. 1. Illustration of main magnet current and voltage waveforms for typical modes of machine operation.

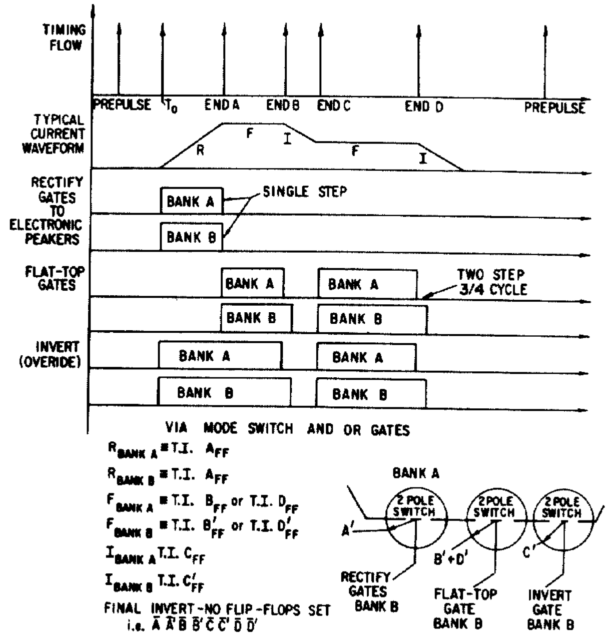

Fig. 3. Mode selection and timing chart.

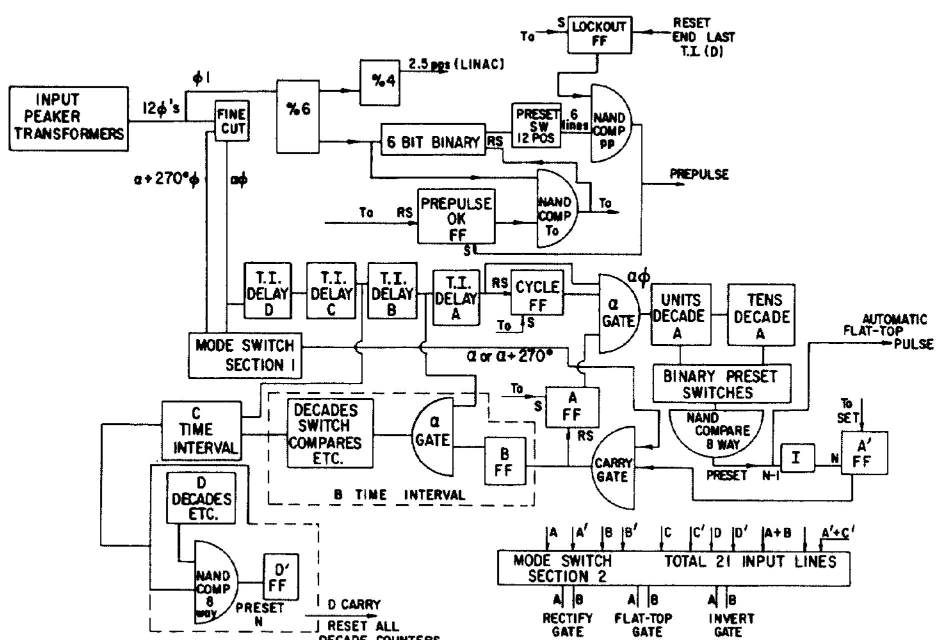

Fig. 2. Logical flow variable mode cycle timer.