A FAST SEQUENCING BIPOLAR ENERGY DISCHARGE SYSTEM FOR THE BEAM BUMPER MAGNET IN THE ZERO GRADIENT SYNCHROTRON*

F. Hornstra, Jr. and H. J. Varga**
Argonne National Laboratory
Argonne, Illinois

Summary

An energy discharge system has been constructed which permits repetitive pulses spaced 30 ms apart or greater to the Zero Gradient Synchrotron (ZGS) beam bumper magnet. To allow beam bumping to either side of the equilibrium orbit, each pulse is independent in polarity and magnitude. Two pulses per machine cycle are provided, but the system is being expanded to five. The system consists of the beam bumper magnet time-sharing two independent energy storage subsystems each containing two series ignitrons, one for each polarity and two crowbar ignitrons, one for each polarity. A logic system automatically triggers the crowbar associated with a given subsystem. An early crowbar trigger can be used which shunts the coil well before peak current occurs reducing the peak current on a given pulse. Each subsystem contains a 2 A, 14 kV power supply and 450 μF of capacitance. The beam bumper magnet has a 4-turn coil which may be connected either in parallel or series. The inductance for one turn is 1.6 μH. The beam may be targeted or extracted in less than 20 μs or as long as several hundred μs, depending on the choice of C and L. If exceptionally long times are needed, the subsystems may be interconnected causing all capacitors to be in parallel.

Requirement of Beam Bumper System

The beam bumper magnet is used to produce fast spills or fast extraction in the ZGS by bumping the beam onto an appropriate target.[1,2] With this system, beam can be targeted or extracted in less than 20 μs or as long as several hundred μs. More than one bump per machine cycle is necessary to accommodate various uses, such as fast spills for a multiple pulsing bubble chamber together with a rapidly extracted beam for external use. In general, each bump will be on a different target located on either side of the equilibrium orbit; accordingly, each bump must be independent in polarity and in magnitude.

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**Presently at Iowa State University, Ames, Iowa

Unipolar Energy Discharge System

As a prelude to the system described in this paper, a conventional unipolar energy discharge system, illustrated in Fig. 1, will be discussed.

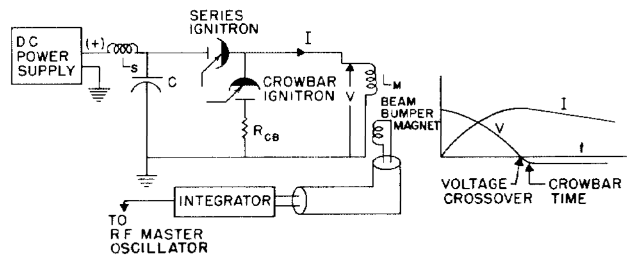

Fig. 1 Conventional Unipolar Energy Discharge System

The terms, zero crossing, peak current, and crowbar time are identified on the voltage and current curves in the figure. Peak current appears at voltage crossover; subsequent crowbarring changes the boundary conditions on the circuit, resulting in the current decaying at a rate determined by the time constant L_M/R_{CB}.

Because $\int B\,dl$ for the beam is changed when the bumper magnet is pulsed, an adjustment of the accelerating cavity frequency is necessary to keep the beam in the stable phase region. This adjustment is accomplished by feeding to the RF master oscillator a signal proportional to the current in the beam bumper coil. The signal is obtained by integrating the voltage induced on a 20-turn pickup coil.

Bipolar Energy Discharge System

Paralleling the series ignitron with one of opposite polarity and adding a parallel crowbar circuit also of opposite polarity together with a

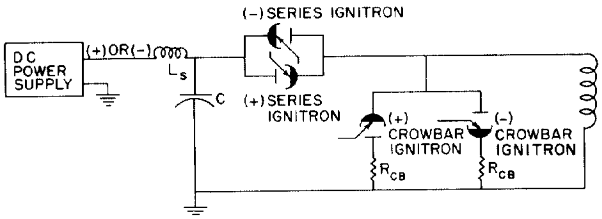

Fig. 2 Bipolar Energy Discharge System With Early Crowbar Capability.

Note: The (+) and (-) symbols indicate component use corresponding the respective polarity of the power supply.

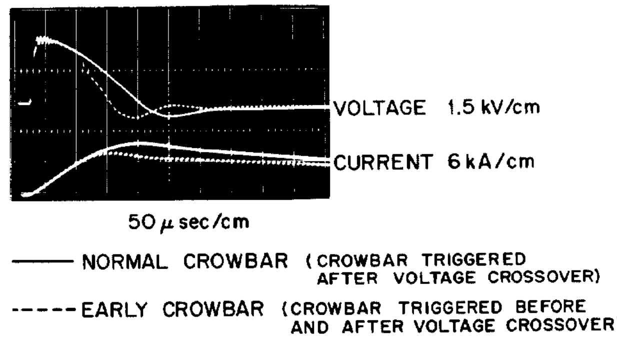

Fig. 3 Voltage and Current Comparisons for Normal Crowbar and for Early Crowbar

reversible power supply, as in Fig. 2, yields a system which is easily reversible. An additional property of such a system, however, is that a crowbar may be fired before voltage crossover, giving a lower peak current in the magnet for a given discharge. For example, if the capacitors are charged positive, the (+) series and the (+) crowbar ignitrons would normally be used, but the (-) crowbar is of the polarity to conduct before voltage crossover. Figure 3 is a photograph comparing voltage and current for normal and for early crowbar showing the reduced peak current when the early crowbar is used. Normal crowbarring follows voltage crossover in both cases. The value of the early crowbar feature is that an experimenter may count particles during the beam spill and at a time when his requirements are met, the spill may be terminated by the early crowbar. Some anticipation is needed to accommodate the fact that the current peaks shortly after the early crowbar fires.

Automatic Crowbar System

Automatic crowbar is provided by the logic illustrated in Fig. 4. The (+) and (-) symbols on

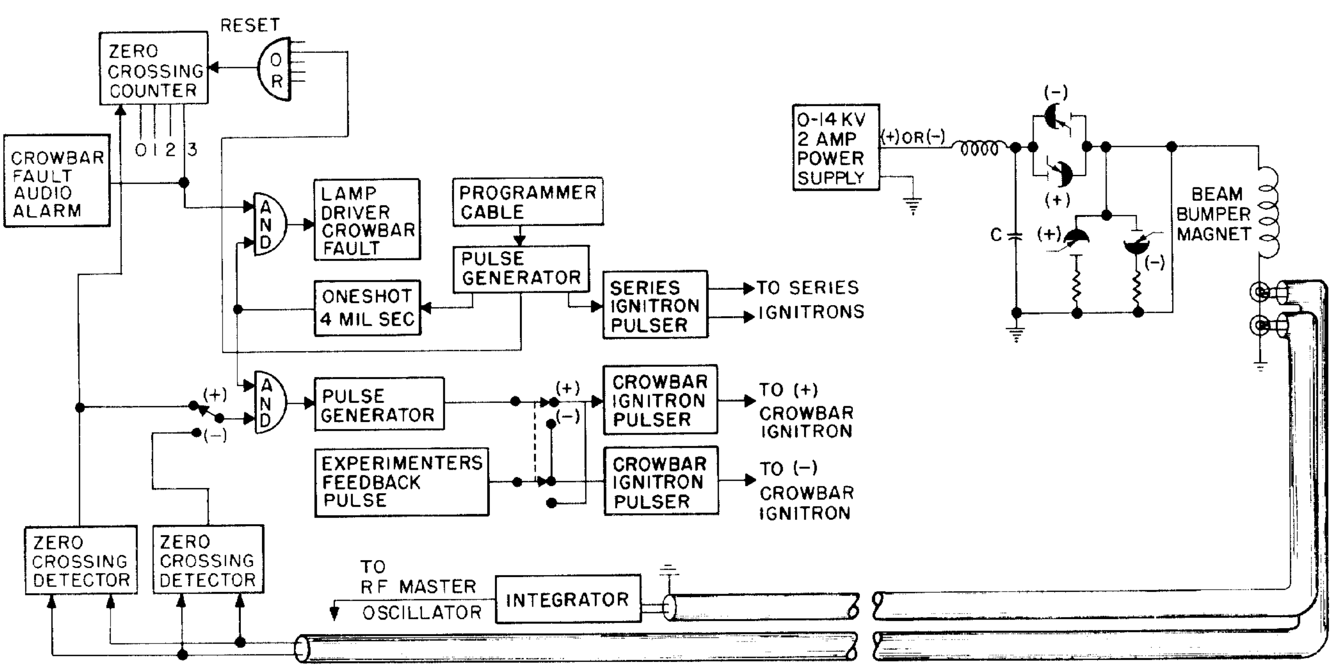

Fig. 4 Automatic Crowbar and Alarm Logic for Bipolar Energy Discharge System

Note: The (+) and (-) symbols on switches or components indicate switch position or component use corresponding to the respective polarity of the power supply.

switches or components in the figure indicate switch position or component use corresponding to the respective polarity of the power supply. All switches are automatically positioned at the time the power supply polarity is selected. The choice of polarity is determined by whether the beam is to be moved outward or inward when the magnet is pulsed.

Two zero-crossing detectors are available, one for each polarity. The proper one is selected as described above. In a like manner, the normal crowbar is connected for a chosen polarity and the crowbar for the alternate polarity is linked for early crowbar use. At zero crossing of the voltage, an output from the zero-crossing detector in coincidence with the one-shot pulse triggered by the series ignitron programmer pulse, activates the normal crowbar ignitron. This action occurs regardless of whether the early crowbar is used.

Also incorporated in the system is an alarm for crowbar malfunctions. Since the voltage will oscillate if the crowbar fails, a binary counter, which is reset on each series ignitron trigger command, counts the pulses from one of the zero-crossing detectors and activates an audio alarm if the number of crossings exceeds two. A lamp is also lighted to give a visual fault indication.

Multiple Pulsing System

Additional energy storage systems share the same magnet as depicted in Fig. 5 where one additional system is shown. Each system is completely independent; i.e., the amount of capacitance together with the polarity and magnitude of the voltage are arbitrary for any system. Systems are discharged in sequence as close as 30 ms apart, yielding fast independent movements of the beam in quick succession. If a comparatively long

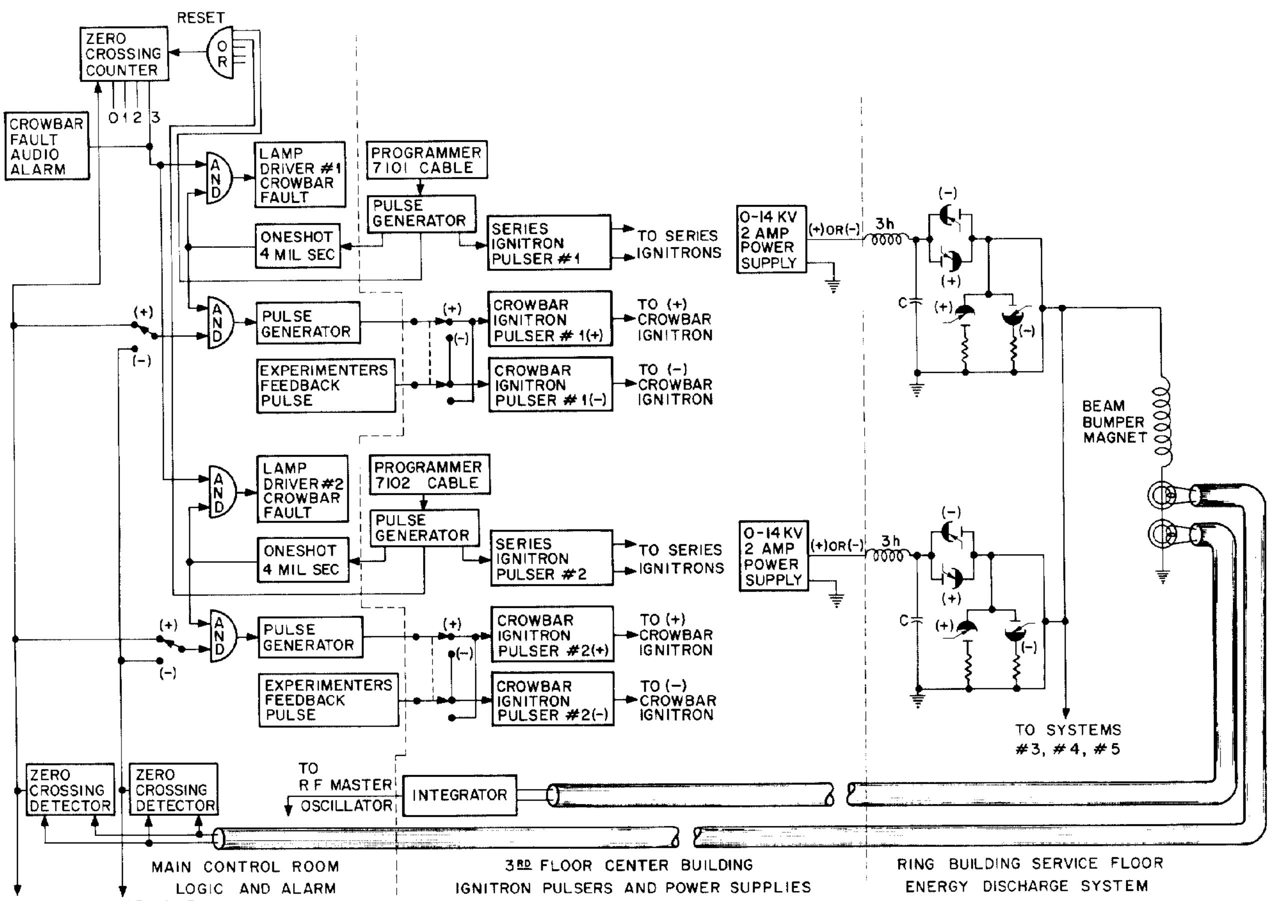

Fig. 5 Fast Sequencing Bipolar Energy Discharge System

spill is desired which requires more capacitance than contained in a system, two or more systems are charged to the same voltage and discharged simultaneously effectively paralleling the capacitors.

The logic presented in the preceding section can now more fully be appreciated. The automatic crowbar scheme provides a trigger exclusively to the crowbar associated with a given system. The correlation of a crowbar with a system is an essential requirement, particularly when the systems operate with different polarities, a situation which occurs when both an outward and an inward excursion of the beam are required during a machine cycle.

The audio alarm will sound on all crowbar malfunctions, but the visual alarm indentifies the offending system by sensing the audio alarm signal in coincidence with the one-shot pulse initiated by the corresponding series ignitron programmer pulse. Both the audio and the visual alarm respond for only one second each time they are activated eliminating a reset for the alarms; but, in addition, sporadic or persistent trouble can readily be differentiated.

All logic is achieved with Fairchild micrologic. The zero-crossing detectors are μL 710 Differential Comparators, while the coincidence circuits and one-shots are derived from μL 914 NAND/NOR elements.

Each system contains a 2 A, 14 kV power supply and 450 μF of capacitance. The beam bumper magnet has a 4-turn coil which may be connected in parallel or in series. The inductance for one turn is 1.6 μH.

Conclusion

The device described here has been used extensively in providing single and multiple pulses to the beam bumper magnet for a variety of experiments. The most recent application has been in supplying two beam spills 580 ms apart to the 30-in double pulsing hydrogen bubble chamber. In this application, the first pulse is acquired from 350 μF of capacitance in system one charged to 3 kV, and the second pulse is obtained from 350 μF of capacitance in system two charged to approximately 4.5 kV.

The automatic crowbar circuitry has proved reliable and the crowbar fault alarm feature allows the system to function with a minimum of operator attention.

As a test, pulses separated by as little as 20 ms have been attained with no difficulty.

Acknowledgement

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References

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