Operational results of an improved regulator and trigger system for the "Fast" Raster Scanning Power Supply System constructed at the Bevalac Biomedical Facility*

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Abstract

A new and improved regulator and trigger control system has been installed in the "Fast" Raster Scanning Power Supply [1]*. The beam scanning system was developed to achieve a more precise and efficient dose delivery method for radiotherapy treatments [2]. This article discusses design considerations, measured results, and provides further elaboration of subsystem feedback and control functions that had not been discussed in the previous paper [1,5].

I. INTRODUCTION

The Raster Scanner that is presently being commissioned at the Bevalac Biomedical Facility is an important new beam delivery technique for performing radiotherapy with charged particle beams. A tightly focused light ion beam is deflected in a raster scanning fashion with the purpose of conforming the dose distribution to the treatment volume [2,3,4,5]. This requires very well regulated power supplies for tightly controlling the beam spot movement and achieving the desired dose distribution.

Initial system testing of the power supply revealed several component and system reliability problems in the "Fast" scanner section. The following paper offers a condensed discussion of the nature of these problems and their subsequent resolution.

II. REVIEW OF "FAST" SYSTEM

As shown in fig. 1 the fast scanner system is powered by a single unipolar SCR controlled power supply that applies a bipolar forcing voltage to the magnet via a synchronized bridge network of silicon controlled rectifiers (SCR) switches and a single gate turn-on thyristor (GTO) power connecting switch [6]. A current-regulated feedback loop precisely controls the the magnet field during both the charging and discharging cycles. The power regulating actuator (426 amps @ 220 volts max) is a grounded source MOSFET transistor assembly (16 heat sinks with 25 devices per heat sink) that is mounted in the return leg of the SCR bridge network. During the discharge cycle a majority of the stored energy of the magnetic field is dissipated in the diode resistor (energy dump) network and the remainder in the actuator. High power back-to-back zener diodes connected across the magnet provide over voltage protection and act as a freewheeling voltage clamp to extinguish the residual magnet current. The latter process necessarily occurs at very low currents and is required before the bridge switches can reverse the magnet polarity. This transition is defined as the "zero current crossover region" of the scanning cycle.

III. PROBLEMS ENCOUNTERED AND SOLUTIONS DEVISED

A. Operational problems:

Throughout the construction of this project all the standard methods of noise suppression and decoupling were carefully employed to suppress extraneous cross talk and undesirable feedback paths. However, recurrent system and component failures during the power testing phases revealed valuable information for further system improvements.

Noise induced failures demonstrated several inherent weaknesses in the GTO commutation circuits and the need to expand and improve the fault detection and alarm circuitry. Unexpected delays in the switching confirmation circuitry (B dot trigger circuit) resulted in unnecessary perturbations in the zero current crossover region and suggested a need for better triggering alternatives. The current dependent transconductance of the FET actuators at very low currents contributed to feedback loop stability problems. The nature and scope and of these problems suggested a systematic improvement of the regulator/trigger control scheme.

B. The basic triggering philosophy:

The there are several underlining principles implemented in the regulator/trigger chassis that make control of the switching network unusually precise and immune to misfire. First, the sequence for the triggering of the SCR and GTO switches is divided into four logical "states". These are; the charging cycle (GTO is "on" with one set of SCRs conducting) and the magnet current polarity is forward (1) or reversed (2) and the discharging cycle (GTO is "off" with with one set of SCRs conducting) and the magnet is discharging (freewheeling) down from the forward (3) or reverse (4) polarity condition toward the zero current crossover region. Secondly, the process of switching between states is verified. Each "state" command that sets a desired firing sequence for the GTO and Bridge switches is quickly compared against selected magnet parameters that are continually monitored within the system.

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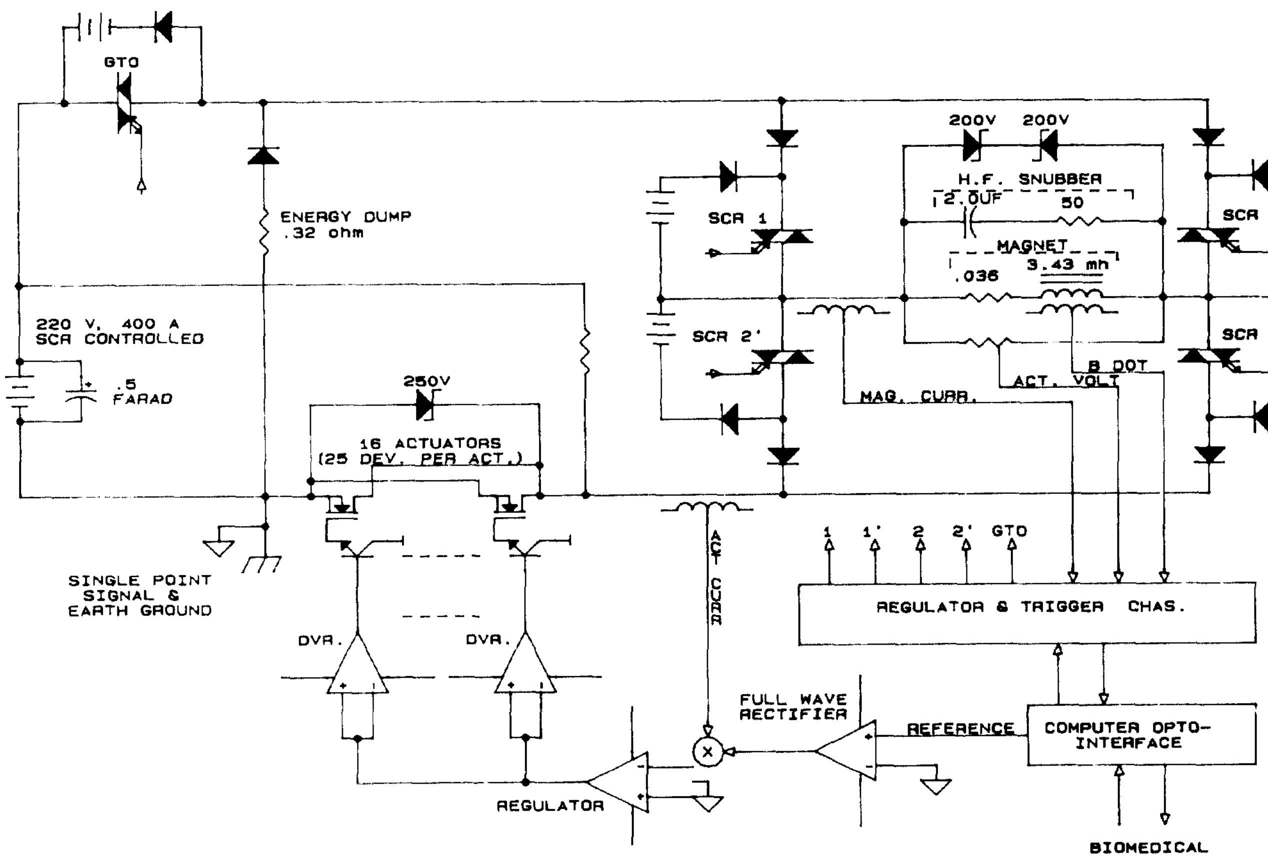

Fig. 1
"Fast" scan system

These four separate and unique "states" in conjunction with the verification function eliminate any possibility of the firing logic loosing track of the scanning process. A "short through" condition were two SCRs on the same side of the magnet fire simultaneously will also be avoided. If the chosen switch state is incorrect the system can shut down in a well defined and protected manner.

An example of the "state" and verify operation is illustrated during the zero current crossover region. As the magnet current (trace #1 of fig. 2) approaches its polarity switching region (< 4.0 amps.) the conducting SCRs are commutated off. To aid the SCR commutation the regulator feedback loop is also momentarily opened and the series actuators driven into the nonconduction. As seen in trace #2 the magnet bucking voltage rapidly rises to its zener clamp level (app. 325 volts) forcing the remaining magnet current to decay rapidly to zero. When the magnet voltage has collapsed to a preset threshold, the actuator is then driven to an optimal bias level to initiate a smooth transition to the next state. At the point where the locus of the controlling reference signals a polarity reversal the alternate SCRs are turned on and the feedback loop is closed. The resulting controller scheme is very flexible and provides full four quadrant scanning with triangular or any selection of variable slope waveforms.

C. New Regulator/trigger hardware layout:

The regulator/trigger system is divided into two chassis. All analog monitor, feedback, and control signals are fed to and from the regulator chassis. Reference control and feedback regulator circuits are contained within the chassis. The magnet parameters (zero cross region, B dot, reference locus, current and voltage) and the fast alarms are detected in the regulator chassis and digitally transmitted to the trigger chassis.

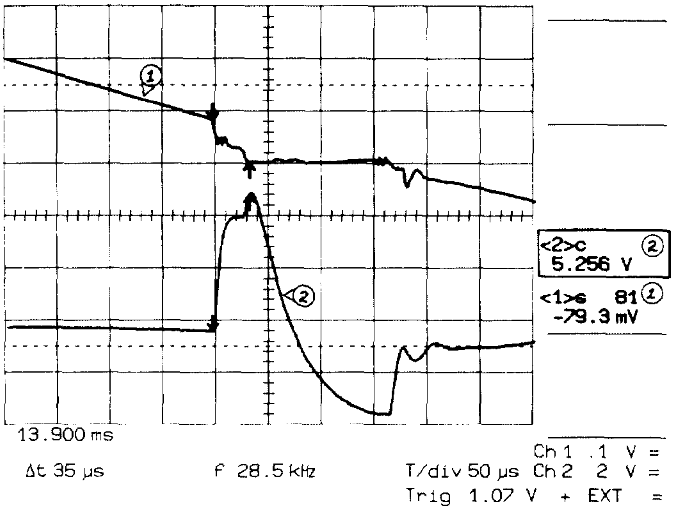

Fig. 2
Magnet current (#1- 5A/div.) vs Magnet voltage (#2 - 100 V/V)

The trigger chassis accepts commands from the beam delivery control system and provides the control logic for the state controller and the servo/fault detection circuitry the chassis generates the proper "states" that are translated into trigger signals for the bridge SCRs and GTO during the scanning cycle. At any zero current crossover region or during any serious fault condition the trigger chassis opens the regulator feedback loop and drives the actuator and magnet by a predefined current level.

To protect the system from catastrophic failures a more extensive set of fast alarms was installed in the regulator chassis. In conjunction with open loop control function of the trigger chassis the magnet can be ramped down in a very predictable manner at any power level. The fast alarms are supplemented by delayed alarms that allow the completion of a scan cycle if a few actuator transistors have failed during the cycle.

The noise layout for the regulator chassis needed to be very rigorous. To minimize cross talk all analog and digital signals were separately routed by the careful placement of the subsystem functions. All sensitive analog signals are interconnected via twisted pair wire and received by laser trimmed precision differential amplifiers [7].

Both chassis were designed to promote ease of testing and debugging. Among the number of available options is a simulation mode. All the necessary magnet parameters that are required for normal operation are simulated and fed back into the chassis to completely recreate the pulse sequence for the SCR and GTO switches.

D. Other Hardware modifications:

All the power switches in the original "fast" scanner system were Toshiba GTOs. During the power testing phase a number of gate drive units and GTOs failed. The expense (~$1000.00 per device) and long delivery time (>20 weeks) posed a serious bottleneck for efficient repair times. Consequently we decided to replace bridge GTOs with off-the-shelf SCRs. As shown in Fig. 1 isolated trigger, commutation, (effective at < 5.0 amps.), and bias current holding circuits were added to each SCR to make their operation compatible with the GTOs they replaced. The GTO power switch was retained for it's superior high current commutation ability(> 600 amps.).

To protect the actuators from the induced magnet voltage when the power GTO switches off, a power zener string of about 250 volts was connected across the actuator assembly. A bias resistor connected from the main power supply to the drain of the actuators provides a bias current to prevent the actuators from saturating during the zero current crossover region. Finally, in an attempt to eliminate the last of the obvious ground loops and adhere to the single point ground philosophy all control and monitor signals to and from the scanner system and the Biomedical control room were optically isolated.

IV. RESULTS

The oscilloscope photograph in Fig. 3 shows the transductor magnet current for both systems. The upper trace illustrates the zig-zag pattern of the fast system magnet current sweeping from a range of +/- 220 amps. The slope is approximately 34 amps./ ms. or 68 % of the maximum value. The lower waveform is the derivative of the magnetic field and is obtained from a B dot coil mounted in the "fast" magnet gap. Over most of the sweep the B dot variation is < +/- 2.0%. The large deviations observed during the zero crossing region can be tolerated in the clinical application since their excursions last less than 1.0 ms. Gross deviations in B dot occur for about 2 ms as the GTO switch is turned off and the magnet begins to freewheel down towards zero current. This problem will be corrected. The raster scanning beam delivery system is now being commissioned and its clinical use will start in the near future.

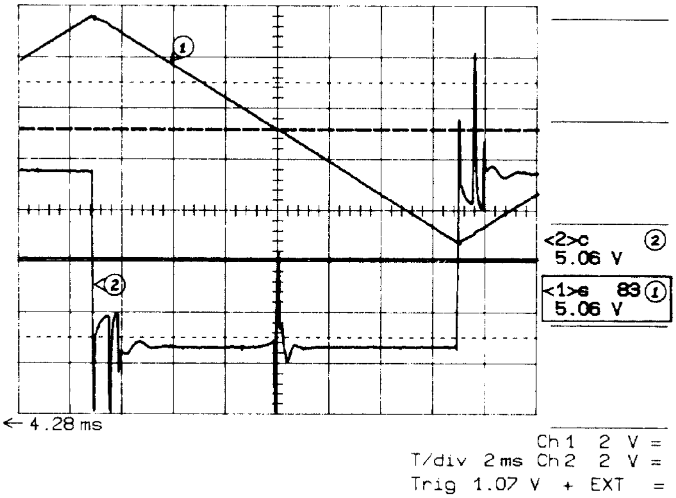

Fig. 3
Magnet current (#1- 100A/div.) vs B dot voltage (#2) full scan

V. REFERENCES

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[6 Manufactured by Toshiba semiconductor

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