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THE TEVATRON EXTRACTION PULSER

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Abstract

The Tevatron QXR (Quadrupole Extraction Regulator) power supply is a linear current pulser combined with a dc transistor regulator. The pulser produces programmable current pulses of up to 250 amps with a maximum duration of 12 ms and a maximum voltage drive of +200/-250 volts. Its fastest repetition rate is 1 Hz. Between pulses a single power transistor regulator maintains 0 to 50 amps in the quadrupole magnet load. The pulser is an air-cooled 34 FET transistor bank operating in the linear region.

Introduction

During Tevatron flattop the four QXR supplies, located around the ring, drive current into quadrupole trim magnets in order to raise the machine tune towards resonance and extract part of the beam. Fermilab uses a combined slow and fast extraction mode, which means that while the QXR current is generally rising slowly from 0 to 50 amps and steadily extracting beam, it must occasionally pulse up towards 250 amps and extract a burst of beam. Pulses presently occur four times in the 23 second extraction period. The four pulses have different amplitudes and must be well regulated (0.1%) to take out precise amounts of beam. To do this, the QXR supply combines a linear FET pulser with a dc transistor regulator.

The System

A block diagram of the system is shown in Fig. 1. In operation, the pulser and the regulator compete for the load through diodes CR1 and CR2 respectively. Normally the regulator conducts, but when the pulser receives a program waveform higher than that of the regulator, it takes over the load and reverse biases the regulator's diode. Coil L1 prevents instantaneous reverse diode currents from loading the pulser. At the end of the pulse the GTO (Gate Turn-Off SCR) is turned off, forcing the load current to decay quickly through the 1 ohm resistor while isolating the -250 volt inductive voltage from the pulser and regulator. When the current drops below 50 amps the GTO is turned back on and the current decays slowly through CR3 until it reaches the level at which the regulator takes over. The fast fall time generated by the GTO is needed to cleanly terminate the fast extraction process.

The Pulser

The pulser is an air-cooled 34 FET transistor bank. Because the pulse waveform imposes simultaneous large voltages and currents on the transistors during the 12 ms pulse, the Safe Operating Area (SOA) curves of the transistors are the most critical parameters in determining the transistor bank size. Figure 2 shows the worst case waveform that the pulser is rated to

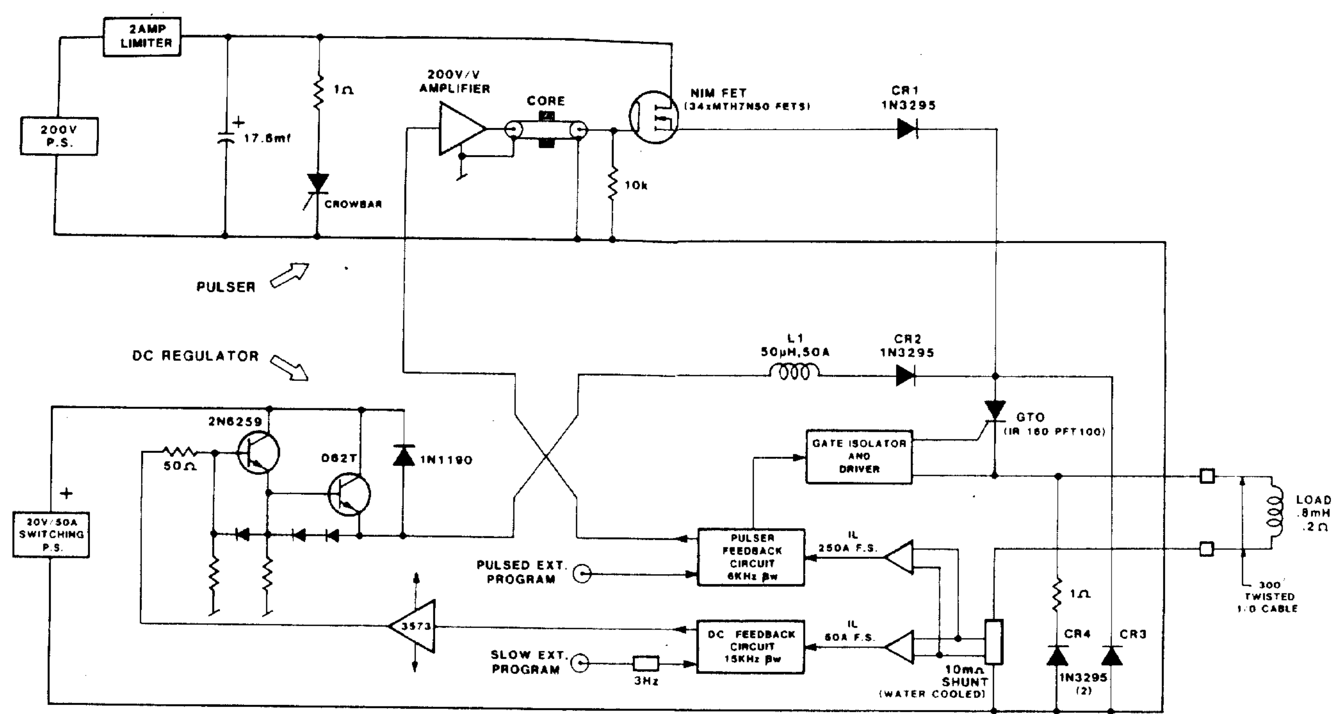

Figure 1. System block diagram.

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produce. The capacitor bank value of 17.6 mf was chosen to minimize transistor dissipation by discharging significantly during the pulse and reducing the drain voltage. For shorter pulses the cap bank scarcely discharges and is able to supply the higher voltages required to drive the load inductance. The fastest rise rate is 250A/2.5 ms. The transistor dissipation rate for the worst case pulse is 8.7 kW for 12 ms. Motorola's MTH7N50 FET in a T0218 case can dissipate 800 watts for 10 ms. We have paralleled 34 FETs to reduce the individual burden to 255 watts. The capacitor voltage was raised to 200 volts to compensate for the extra voltage drops contained in the sharing resistors, GTO and diode circuits, and circuit wiring.

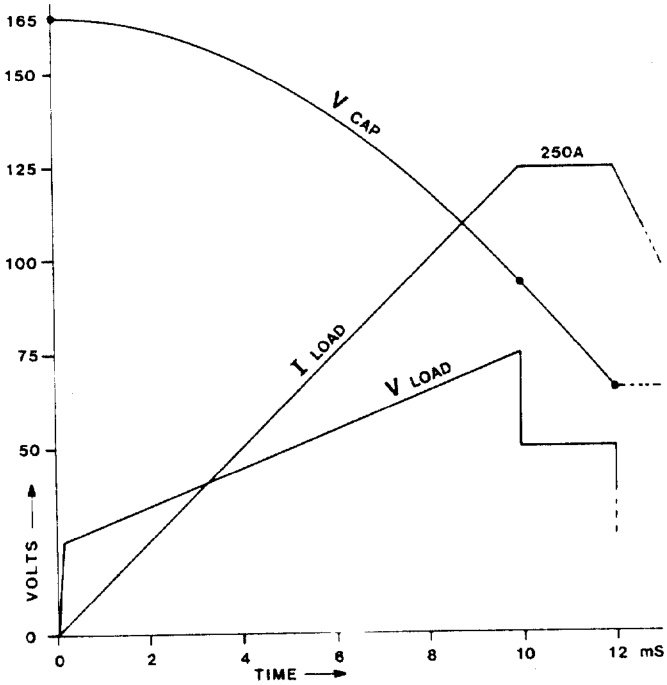

Figure 2. Worst-case pulser waveforms.

The FETs are housed in two NIM modules called NIM-FETs. A cooling fan keeps the FETs close to ambient temperature between pulses so that their full SOA is available. Figure 3 is a schematic of the NIM-FET module and Fig. 4 is a photograph. In the module, Q_0 drives the other 17 FETs. The CR1 diodes isolate the gates from each other so that a shorted FET does not turn on the other devices. The R_2 resistors supply a negative bias current using the 4-volt gate source offset voltage, so that the circuit can respond quickly in the negative direction in spite of the CR1 diodes. The R_1 resistors inhibit parasitic oscillations. R_3 is a sharing resistor and is also designed to be strong enough to outlast the fuse when a FET short-circuits. The CR2 diodes connect to an external blown-fuse detection circuit. Figure 5 shows a 250 amp pulse and the reference waveform. Note the change in the falling edge slope when the GTO turns on.

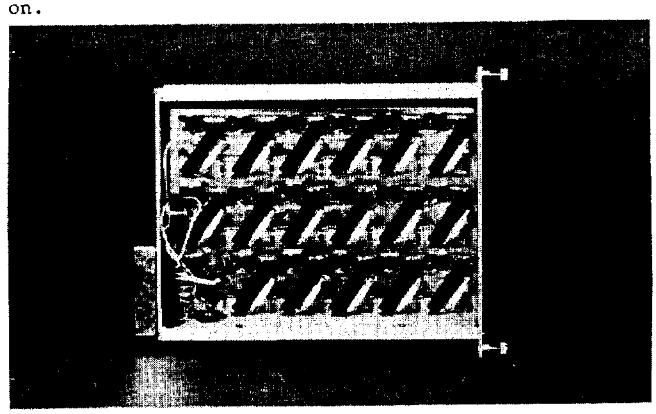

Figure 4. The NIM-FET module

Pulser Protection

To protect the FETs from waveforms that might damage them, such as too rapid pulsing or dc conduction, the system has two levels of protection. First, the reference waveform is gated to allow only one 14 ms pulse through every 800 ms. Secondly, a crowbar unit monitors the NIM-FET current and crowbars the cap bank if pulses longer than 14 ms or dc conduction are detected. The blown-fuse detector also triggers the crowbar and a comparator module will also grigger the crowbar if only one NIM-FET module is conducting.

The DC Regulator

The dc regulator is a standard emitter follower but it uses a single large power transistor rather than a bank of smaller transistors. We use the Westinghouse

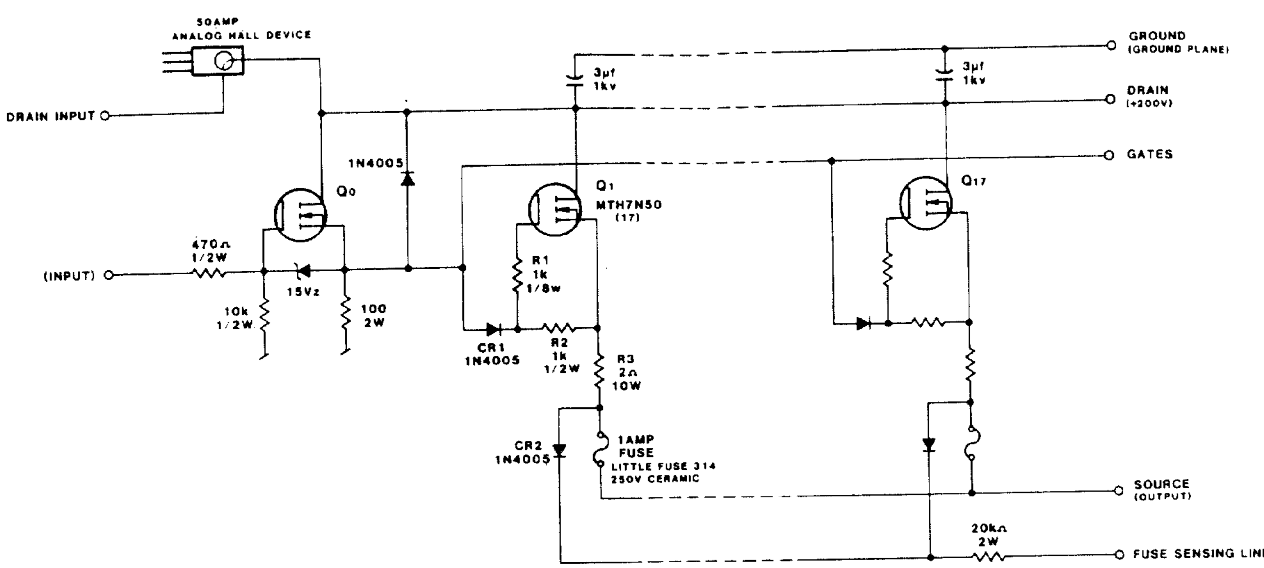

Figure 3. NIM-FET module schematic.

D62T transistor, which is rated at 1.1 kW dissipation with its case at 75°C and which has a Beta of 10 at 75 amps. It is Darlingtoned with a 2N6259 and driven by a Burr Brown 3573 power op-amp. A 50 ohm base resistor inhibits negative base-impedance oscillations. The program input to the regulator is rolled-off at 3 Hz so that the supply does not follow LSB-type fluctuations from the D/A reference. Its function is to change the current only slowly.

Conclusions

The QXR power supplies have been operating successfully since August 1983 and have played their part in the complex process of extracting the Tevatron beam. Their design takes advantage of some of the interesting power devices that are now available to engineers.

Acknowledgements

I would like to acknowledge the very capable help of Phil Paul, who built the electronics with fine contributions from Mark Koenig and Rose Callaghan.

V load 55V/div.

I load 50A/div.

I reference

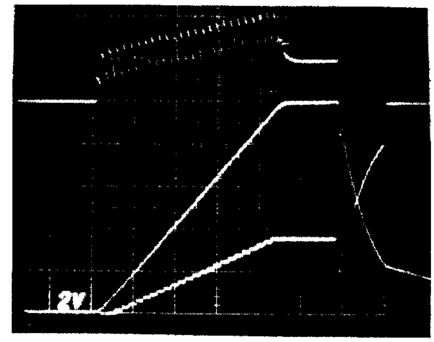

Figure 5. Pulser waveform.