MUON COLLIDER TEST FACILITY NEW PFN AND CONTROLS

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Abstract

A 3 Ohm PFN was designed with an SCR-based switch and charged to 20 KV with four parallel capacitor-charging power supplies. A 12 MW klystron mounted on a 1:20 pulse transformer powers a six cell, 805 MHz cavity inserted in a superconducting solenoid in the Muon Test Facility. Also a complete set of modulator-klystron interlocks and controls were designed to provide signal monitoring, timing, modulator voltage regulation, as well as interlocking all systems related to the modulator-klystron system. The controls use surface mount technology providing compactness and future technological compatibility. Communication of the system status and data is done through an MVME68040-based system acting as a local node and accepts analog and digital signals relaying them through an Ethernet connection to the main accelerator controls.

1. INTRODUCTIO N

Table 1

Modulator Parameters			
Pulse Length	50 µsec.	Pulse Energy	2.2 KJ
Pulse Rep. Rate	15 Hz	PFN Charge time	60 ms
Peak Primary Voltage	20 KV	Charge Average Power	37 KJ
Peak Primary Current	3.7 KA	Power Rating per supply	10 KJ/sec.
Peak Power	18 MW	# of Supplies	4
Capacitance total	11.0 µF		
Inductance total	99.0 µH		

Table 1 lists the parameters used in designing the modulator.

A PFN topology was chosen for the modulator using eleven inductor-capacitor cells, the inductor coil in each cell was split into two for purposes of tuning. The PFN is charged with four commercially available capacitor charging power supplies connected as masters. The PFN is discharged using an SCR-based switch through a 1:20 step ratio pulse transformer and 12 MW klystron on an on-demand basis.

The design cycle started with calculations for PFN impedance, pulse length, effects of mutual inductance, power supply energy requirements to name a few. Followed by computer modeling for design verification, ultimately leading to the implemented topology. The PFN was tested in stages, first the inductance of the coils was adjusted to obtain the required pulse flatness. Then the diode stack and SCR switch were high-potted for corona, polarity check, and conductance. Followed by the addition of the pulse transformer and a beam-stick as a load, allowing the PFN to operate at full repetition rate and pulse power. At each commissioning step the modulator-klystron controls were also tested using established procedures. The commissioning phase ended when the klystron was installed in the pulse transformer and the RF portion of the controls were tested with the modulator-klystron operating at full power.

2. PFN COMMISSIONING PROBLEMS

2.1 Shoot-through Condition

A shoot-through condition is when the PFN is charged while the SCR switch is still closed making the supplies see the klystron as its load. The primary mechanism used in commutating the SCR switch is by mismatching the PFN impedance and the impedance of the klystron as it's reflected on the primary of the transformer. In addition to this a diode stack of 96 diodes was connected at the anode of the SCR providing an additional 100 volt differential across the switch opening it before the next charge cycle begins. The diode stack has a reverse diode across it for protection but this diode failed, shorting out the diode stack, delaying the opening of the SCR switch and caused a shoot-through condition.

2.2 *Power Supply Power Factor*

The manufacturer of the power supplies claims to have a power factor greater than 0.85, it measured at 0.67 for each phase. This is a problem in a multiple-supply environment since much more power is used and harmonics are induced on the power line with potential damaging effects to elements on the line, like the A.C. power transformer.

3. MODULATOR-KLYSTRON CONTROLS

The controls were designed so they could be used with the FNAL LINAC modulators and the modulators used by TESLA test facility at DESY. Although the controls for the modulator and the klystron are integrated and quite compact, functionally they can be viewed as two sets of controls. One that controls everything on the primary of the pulse transformer and a second set controlling everything connected on the secondary of the pulse transformer.
A distributed approach was taken to implement the controls where no board relies heavily on other boards to operate. This facilitates testing and also reduces board interconnections.
The controls are implemented using six VME-style boards and using surface mount technology for compactness. Two boards are dedicated for the PFN controls and its charging supplies and four for the klystron and related systems. The boards are plugged into an RFI -VME crate providing good noise immunity from RF noise. All cabling is done through the rear of the RFI chassis to the top plate of an enclosed rack. Power to the RFI chassis is generated in an external chassis that has three linear power supplies. Communications to the external control system is done through a FNAL-designed system which digitizes all available analog signals as well as all of the latched status signals. It provides communications via Ethernet and provides remote control of the modulator-klystron by setting operating points and remote permits.

3.1 Modulator Controls

The modulator controls provide:

- Personnel safety.
- Equipment protection and operation.
- Signal transmission, signal conditioning, and signal monitoring.
- Pulse amplitude regulation.
- Modulator timing.
- Charging Supply permits and operating reference level.

The first task of these controls is to transmit analog signals from the high voltage environment in the modulator with little or no signal degradation and with high noise immunity. In our system this is accomplished by using a current-driver based analog circuit capable of driving 50 milliamps into a 75 Ohm termination. This impedance is matching the twinax cables used.
A receiver board is used as the analog front end for signals originating at the modulator. The analog board supports sixteen inputs designed around a cluster consisting of a 75 Ohm current receiver using an instrumentation op-amp followed by a gain stage. The signal distributed from there for digitization, front-panel monitoring, and input to a discriminator circuit. A buffer also distributes the signal to on-board dedicated function circuits:

- SCR switch voltage balance.
- PFN pulse amplitude regulation.
- Transformer magnetization current monitoring.

A second board acts as system integrator, receiving digital signals from

- The analog board.
- Contacts from klixons in the modulator.
- Timing signals from the control system.
- Permits from the external safety system and other boards within the modulator-klystron controls.

All of these signals are processed in a programmable gate array (PLA) where transitions are latched and transmitted to the external control system for display on a parameter page. Also the transitions are buffered into memory within the PLA and are arranged according to the order in which they transitioned first. This information is useful when multiple signals are latched and one wants to determine which caused a trip first. The system control PLA also gates raw timing signals through to the timing PLA only when all the trips are cleared.

A second PLA processes timing for the modulator. It’s inputs are the raw charge and fire timing signals from the system control PLA:

- Sets windows inhibiting abnormal charge and fire pulse repetition rates.
- Sets the length of the PFN charging period.
- Sets the delay between end of charge cycle and the fire cycle.
- Limits when the fire cycle can occur within the 15 Hz cycle.
- Distributes the fire pulse to the PFN’s SCR trigger circuit and the charge pulse to the power supplies enable circuit.

3.2 Klystron Controls

The largest portion of the controls is mainly involved with systems related to the klystron. Four boards are used to implement this portion of the controls. Three of the boards have the same basic circuit topology. It is an analog front-end which receives the input and fans it out to a discriminator stage, a front panel monitoring point, and a buffer which drives the signal to be digitized externally. An on-board PLA consolidates all the discriminator outputs and then generates a status produced from the AND’ing of these levels. All of the local board statii are then integrated by one of the PLA’s to generate a modulator permit, RF enable permit, and a remote control permit.

The fourth board has only counters which indicate:

- Klystron filament run time.
- Klystron gun sparks.
- Klystron window sparks.
- Load window sparks.

Circuits were grouped in two of the boards whose functions will inhibit RF in the klystron and also stop the modulator from pulsing on the next cycle. These functions are:

- Pulse transformer, klystron collector, and solenoid temperature.
- Solenoid power supply controller.
- Currents of the six solenoid power supplies and their contactor controller status.
- Collector, Body, Solenoid, Pulse Transformer, Modulator water flows.
- Klystron filament power supply.
- Klystron ion pump power supply.
- Waveguide pressure.
- Klystron window and load window photo-multiplier dark current.

The third board is exclusively dedicated to circuits inhibiting only the RF source in less than a 1 μsecond of a trip but still allow the modulator to continue to operate.

- Klystron or load window spark is detected.
- RF level is picked up using an antenna and it is above a pre-set level.
- Klystron reflected energy or load reflected energy is above a normal level.
- Cavity spark is detected.

4. CONCLUSIONS

The control system works as expected. A revision will clean up board layout problems. Also re-designing of the board holding the RF circuits will make it easier to debug, and fix the problems seen with the FET switches used. The circuits supporting photo-multipliers should be modified to support *pin* diodes instead.

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