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TOWARDS THE AUTOMATED OPERATION OF Z20: A TW PULSED POWER MODULE*

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Abstract

The Refurbished Z machine, ZR, will have 3 distinct missions. The first is to increase the capability for the user community by providing higher peak currents. The second is to increase the pulse repeatability and pulse shape flexibility. The third is to increase the shot capacity by providing operational turn-around time consistent with conducting a shot per shift. The success of the third mission relies heavily on the reliability of the components and well defined maintenance cycles. A system assessment module called Z20 has been built which conforms to the ZR Program design requirements.

Z20 is currently being used to test the reliability of the components comprising the ZR pulsed power modules. To assess the project requirements of one failure in fifty ZR shots, we plan to perform 7200 shots of the system assessment module. At a typical shot rate, this task would take approximately three years. To minimize the impact on the facility while obtaining the required reliability data, the system will be configured to fire and reset automatically with the ultimate goal of un-manned operation.

A systems approach was developed using National Instruments LabVIEW® software and Field Point® I/O hardware. All communications between subsystems are provided via Ethernet using fiber optic media converters. The major subsystems for operating the module which will be described are the gas pressure and purge, high voltage power supplies, oil-section late-time energy diverter (oil diverter), triggering, precision monitoring of Marx charging system, personnel access control and remote operation of the laser trigger system.

I. INTRODUCTION

Sandia's Z accelerator completed original construction in 1985 as PBFA II. The center portion was modified in 1996, converting from a high voltage to a high current configuration to drive z-pinch loads. The environments created have enabled critical experiments that address many Stockpile Stewardship and High Energy Density Physics Program needs. Z has since grown into a multifaceted facility. At more than 1000 shots after what was supposed to be a provisional modification to assess scaling of z-pinch current, users are asking that Z be a stable, precision platform for a large number and variety of reliable, reproducible experiments. Much of Z was not optimized for z-pinch applications nor designed for the rigors of daily use at today's 18MA output level.

Z has become a workhorse for weapons physics and weapons effects programs as well as a more recent role in critical material properties and equation of state research. ZR is committed to be a stable, precision platform for reliable, reproducible experiments. This objective is reflected in the requirements for ZR: component and system reliability such that no more than one in fifty shots leads to a loss of experimental results or to a slip in shot schedule due to accelerator failure. One challenge is the verification of this reliability specification on a single module. It was determined that approximately 7200 shots on a single module would demonstrate the "no more than 1 in 50 shot loss" project requirements for the full 36 module ZR.

II. THE Z20 MODULE

The pulsed power for ZR is based on technology previously developed at Sandia of Marx generators, water insulated intermediate storage capacitors (ISC), pulse forming lines (PFLs), output transmission lines (OTLs), vacuum magnetically insulated transmission lines (MITLs), and post-hole convolutes. Z20 is the oil and water sections of one module of the full 36 module ZR. Previously, the circuit modeling was successfully validated during the System Assessment Test Program (SATPro). The goal of the Z20 automation task is to

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assess the reliability specification of the components in Z20.

The Z20 module is comprised of a 60-stage, 100-kV, 43-nF Marx generator charging a 26-nF, 100-ns intermediate storage capacitor to a peak voltage of approximately 5.5 MV in about 1.2 µs. See Figure 1. Figure 2 shows a view of the pulse forming and switching components. A Laser Triggered Rimfire Gas Switch (LTS) switches the ISC into a 2.6-Ω, 45-ns long coaxial PFL in approximately 200 ns. The negatively charged PFL is switched via water switches into a 4.2-Ω, 35-ns tri-plate transmission line (OTL1). Pre-pulse/peaking switches are located between the output of OTL1 and a 6.4-Ω, 50-ns transmission line (OTL2). For the purpose of assessing the system, OTL2 is terminated in eight parallel liquid resistors made of a Sodium Thiosulfate water solution.

To correctly and efficiently assess the system, extensive diagnostics are featured. Current and voltage monitors are co-located in the input and output positions on the Marx, ISC and PFL, as well as numerous positions on the output transmission lines. Current viewing resistors (CVRs) measure the current through each of the eight liquid resistors constituting the resistive dummy load for the system, allowing for an assessment of current uniformity along the output transmission line.

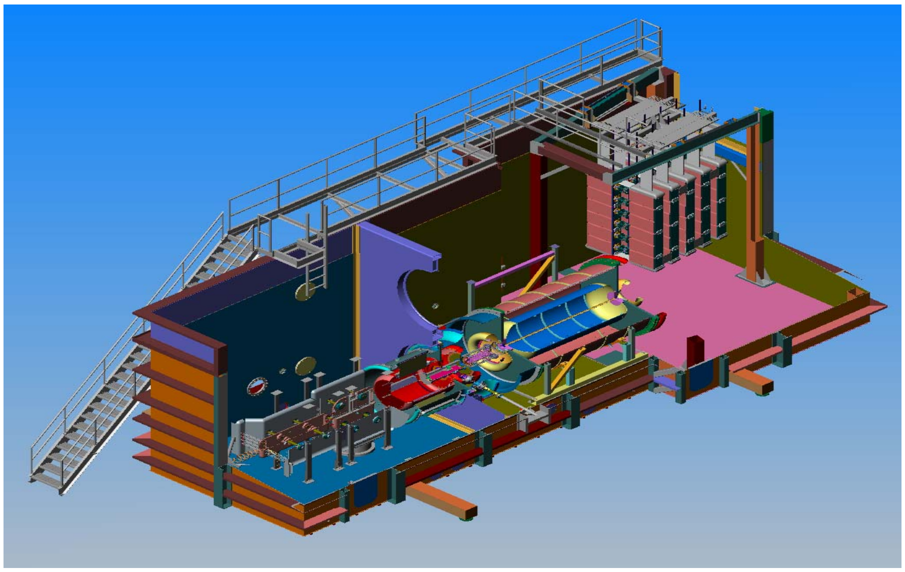

Figure 1 The Z20 module

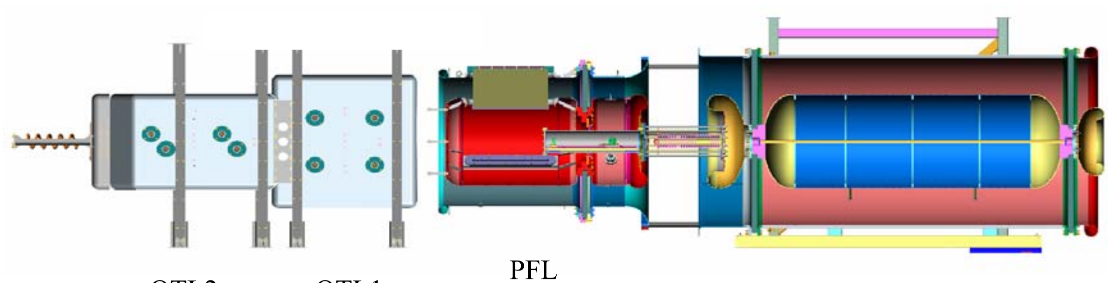

Figure 2 The details of the Z20 accelerator design

III. THE AUTOMATION SYSTEM

A. Control System Topology

A systems approach to automation was developed which uses National Instruments LabVIEW® software and Field Point® I/O hardware as the basis for this design. The system includes hardware and software to sequence and monitor the operation of the SF_6 gas system, laser trigger system, HV power supplies, and the programmable logic controller (PLC) for interlocks, oil diverter, isolation and energy dump relay functions. The system also includes a precision voltage measurement system for the measurement of the Marx voltage before and after the activation of the HV power supply isolation relays. The Control System uses five fiber optic Ethernet links to communicate with the remote subsystems from a Control Computer located in a shielded control room. This minimizes the possibility of ground loops and induced voltages and/or currents from affecting communications and systems operation. The Control Computer includes watchdog timer hardware to automatically disable the HV interlocks in the event of a computer hardware or software system failure. A block diagram of the Z20 Automated Control system is shown in Figure 3.

The control computer system also includes a network interface to the existing data acquisition computer which provides the analysis and validation of the shot data channels. The control system software implementation consists of the pre shot sequence, the repetitive shot state machine and the system shutdown sequence. The pre shot sequence allows for the entry of the sequence control parameters, changes the subsystems to remote operating mode and sets the SF_6 operating pressures. The shot sequence state machine then performs the repetitive shots. This state machine includes steps for checking the laser status, preparing the data acquisition system for a shot, performing the machine charging and firing, purging the SF_6 subsystems, obtaining the data review results from the data acquisition computer and preparing the shot charge cycle report. Upon the completion of all shots in the sequence, the system shutdown sequence returns the SF_6 and PLC systems to the local mode.

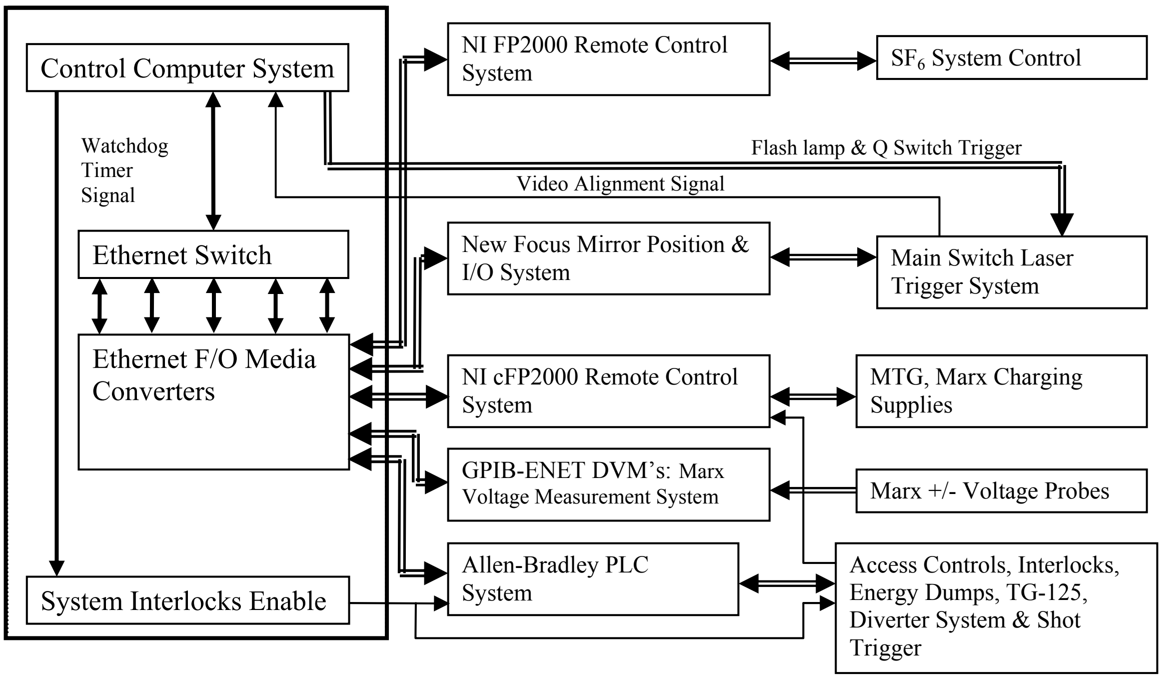

Figure 3 Z20 Control System Block Diagram

B. Z20 Hardware Subsystems

Subsystems that have been implemented are listed here with detailed descriptions that follow:

1) All SF_6 gas functions for Marx, Laser Switch, MTG and TG-125 components. These include controlling and monitoring pressures, purging and venting.
2) All high voltage power supplies (Marx, MTG and TG-125 Trigger Generator).
3) Oil Diverter operation.
4) Machine triggering (firing).
5) Precision monitoring of the Marx charge voltages (+ and -).
6) Remote operation of the LTS (Laser Trigger System). Including ball valve operation to isolate the LTS system in case of internal oil seal failure.
7) Access control to prevent personnel access to any dangerous areas of the accelerator. Includes warning beacons and horns in the high bay.
8) Data acquisition and review tasks look at data from the previous shot and determine whether the system should continue.

1) Gas System

The first subsystem to be remotely operated was the SF_6 Gas system. Since a manual system (which needs to be maintained for manual operation and testing) had been installed several years ago, it was necessary to provide a parallel system for the remote operation for controlling and monitoring pressures, venting and purging these subsystems. Pressure regulators were purchased which allowed remote setting and monitoring of the pressures. Additional 3-way valves were necessary to allow switching between local and remote operation.

2) Marx Charging System

Next was the implementation of the Marx charging and triggering supplies. Again, these subsystems were not procured with options to allow remote control, therefore major modifications were made to allow for remote operation and monitoring functions. These subsystems were interfaced with Field Point I/O for communications of control and monitor signals. Control of the TG125 trigger generator is remotely controlled using the existing Allen-Bradley PLC. This PLC communicates to the shield room via fiber optic Ethernet links.

A critical parameter in the testing of the Z20 system is the actual charge voltage on the Marx capacitors. A subsystem was designed and installed which allowed the monitoring of these voltages using a precision high voltage divider along with high resolution digital voltmeters which can be read remotely. These signals are converted from GPIB to Ethernet and transmitted to the shield room via fiber optic links. These voltages are displayed and recorded with the main control system.

3) Oil Diverter and Other PLC Functions

The Oil Diverter system, which is a high voltage safety subsystem, operates through the PLC. Other functions performed by the existing PLC are safety interlocks and enabling signals for the high voltage power supplies. Emergency Stop (E-Stop) functions are also detected by the PLC and provide notification that an E-stop button has been activated. These functions will be a part of the area personnel access control system.

4) Machine Triggering

Firing of the Z20 module is accomplished immediately upon completion of the charging of the Marx and MTG subsystems. The PLC system checks for all other permissives and issues the FIRE command to the MTG chassis through the TG-125 pulse generator. The LTS then fires at a preset time after the Marx has erected.

5) Precision Marx Voltage Monitoring

Two precision voltage dividers are used to sample the Marx charge busses and send their output voltages to the chassis which contains the DVM's. The precision digitized voltages are read by the control system computer via fiber optic links.

6) Laser Trigger System

The Laser Trigger System (LTS), which is the fast triggering system for the gas switch, is controlled and monitored via fiber optic links to and from the shield room. These functions are for checking the alignment of the laser beam on the switch and making adjustments as necessary. Fast triggering of the laser is accomplished using fiber optic links deriving fast timing signals from the shield room.

The LTS uses a NewWave Research Inc. Tempest® Nd:YAG laser quadrupled to 266nm to trigger the gas switch. Software was developed to provide interactive control of the laser and to operate the four piezoelectric motors used on the two mirror mounts during the laser system alignment process. The software operates in two different modes. In the manual alignment mode, the position of the laser beam can be interactively changed while viewing the alignment image on the computer monitor. In the automated mode, the image is captured and archived as part of the test data. The image is used to verify the laser firing functionality but is not used to automatically define a new laser beam position.

7) Access Control

Personnel access control is being implemented using an existing access control system in the high bay. Links are being designed and installed for operation with the Z20 testing. If any of the access control gates are breached, or an E-stop button is activated, the system will shut down operation immediately and notify security as well as operations personnel.

8) Data Acquisition and Review

This process will be controlled by the control system computer. The data acquisition system (DAS) uses a LabVIEW® application to control the digitizers and to record the data to the DAS computer. The LabVIEW® application then uses the NI "IDL Script-Node" application to call a Research Systems Inc. IDL procedure to process the data file and compare individual shot waveforms to the expected stereotypical waveform at that monitor location for a normal shot. Depending upon the fits between the waveforms, a "Go / No Go" flag will be returned to the control system computer. A "Go" flag will continue the shooting sequence while a "No Go" flag will terminate the process and initiate an accelerator shut down and notification procedure.

IV. SUMMARY

The basic topology for an automated terawatt pulsed power facility has been implemented. To date, a series of six sequential shots, at full machine voltage has been accomplished using the new system. These shot sequences were observed by qualified operators in the event manual intervention was necessary. As we gain confidence in the control system, unmanned operation will be pursued. It is anticipated that full automatic operation will be functional within the next few months.

V. REFERENCES

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