A TRANSIENT TOLERANT AUTOMATED CONTROL SYSTEM FOR THE LEDA 75kV INJECTOR*

M. Thuot, L. R. Dalesio, M. Harrington, D. Hodgkins, D. Kerstiens, B. Quintana, J. D. Sherman,
M. Stettler, D. Warren, and T. Zaugg, LANL, Los Alamos, NM
A. Arvin, S. Bolt and M. Richards, SRS, Aiken, SC

Abstract

The Low-Energy Demonstration Accelerator (LEDA) injector [1] is designed to inject 75-keV, 110-mA, proton beams into the LEDA RFQ [2]. The injector operation has been automated to provide long term, high availability operation using the Experimental Physics and Industrial Control System (EPICS) [3]. Automated recovery from spark-downs demands reliable spark detection and sequence execution by the injector controller. Reliable computer control in the high-energy transient environment required transient suppression and isolation of hundreds of analog and binary data lines connecting the EPICS computer controller to the injector and it's power supplies and diagnostics. A transient suppression design based on measured and modeled spark transient parameters provides robust injector operation. This paper describes the control system hardware and software design, implementation and operational performance.

1 INTRODUCTION

Accelerator Production of Tritium (APT) applications of high power accelerators requires high beam availability. To maximize beam-on time, rapid recovery from routine events, like injector spark- down, is needed. Reliable recovery from injector spark-down can be provided through computer based automated sequencing. For reliable operation, the data in computers must be protected from being corrupted by the severe EMI transients produced during the spark-down. Coupling between the high voltage power supply (HVPS) and the computer control system is a primary cause of the disruption or damage to computers/logic that occasionally occurs during injector high voltage spark-down. The HVPS circuitry, the method of connecting to the injector, and the physical layout of the injector determines significant EMI coupling parameters such as stored energy, peak current, discharge frequency, di/dt and dv/dt. Computer interface designs, based on circuit models that generate values for these parameters, can effectively suppress the transients and provide reliable operation in a harsh EMI environment.

2 MODELING THE SPARK DISCHARGE AND HVPS CIRCUIT

To estimate the peak current, di/dt, dv/dt and the frequency content of the spark transient, a spark-down circuit model of the LEDA injector and the HVPS was constructed. (See Figure 1). The values of the HVPS components in the model were set to the actual circuit values. The inductance of two of the major loops involved in the discharge of the injector control the natural frequency of the discharge current. These two loops are a large loop formed by the RG218 coaxial HV cable connecting the HVPS to the injector, and a much smaller loop formed by the source and the wave-guide above the grounded source table. The inductance of these conductors was calculated using the formula, from Ott [4], for the inductance of a conductor above a ground plane. These calculated inductance values were compared to actual circuit values by comparing the natural frequency of the calculated spark transients with oscilloscope traces taken during actual spark-down transients on the CW injector.

The HV coaxial cable that connects the HVPS to the injector was modeled as a transmission line. The model of the discharge circuit produced waveform records through SPICE analysis performed by a commercial software package, Electronic Workbench® running on a PC. Electronic Workbench represents the circuit as a schematic rather than a SPICE node list, which simplifies the modification of circuit values and connections.

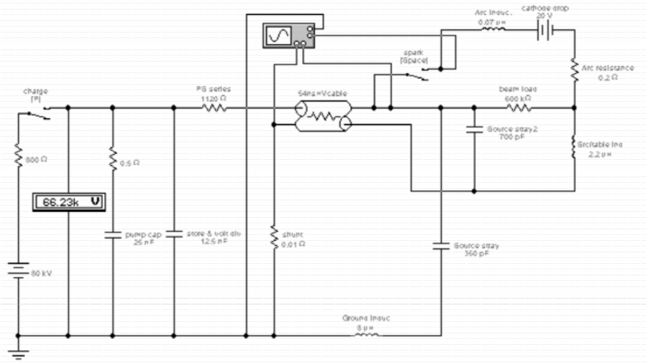

Figure 1. LEDA injector and HVPS transient analysis circuit model in Electronic Workbench®.

---

* Work supported by the U. S. Department of Energy under contract W-7405-ENG-36.

Email: mthuot@lanl.gov

2.1 Results of the spark-down transient analysis

The waveforms from the SPICE model of the injector and HVPS were analyzed to extract the peak current (300 to 1200 A), the transient current natural frequencies (2 to 6 MHz) and the maximum di/dt (~1E+10 A/s) and dv/dt (~2E+12 V/s). These parameters quantify the level of the source of the electromagnetic interference (EMI) the control system interface must suppress. If these levels or coupling from this source exceed the transient suppression capability of the control system interface, then they represent a threat to the proper operation of the control system.

The coupling between sparks in the HVPS and the control system follows several paths, each with some coupling constant that primarily depends on the natural frequency of discharge circuit. Capacitive coupling from the HVPS' high dv/dt through the high impedance electric field is relatively easy to shield. Proper grounding of the metal enclosures surrounding the HVPS and of the shields on signal cables will eliminate almost all of the dv/dt driven interference. The only area of the injector system where this EMI source may dominate is if unshielded cables or transducers are exposed to the high voltage circuits. The effect of this, sometimes unavoidable, coupling can be minimized by shielding the exposed cables and transducers and/or shunting their stray capacitance with an RC low pass filter.

The most likely path of EMI into the control system is di/dt (Φ) coupling through the transient low impedance (magnetic) field. This low impedance field is much more difficult to shield. Coupling paths will exist through any mutual inductance between the HVPS discharge circuits and the control system. To control low impedance coupling, the best defense is the reduction of the inductance of all source and signal loops. This source of EMI may be suppressed on signal cables by installing isolators that break the low impedance loop formed by the signal cable conductors and thus convert the Φ induced voltage into a common mode voltage on the isolators. This defense is usually effective, but it can fail if the frequency and/or amplitude of the source of the EMI is extreme, thus driving noise current through the isolators. If the isolators are preceded by a passive low pass filter, the effect of extreme di/dt is mitigated. Our design employs this arrangement with the low pass filters followed by isolators built into the wiring terminal barrier strips.

3 GROUNDING

Proper grounding will reduce the coupling of the spark induced transients into the data acquisition system. There are three grounding systems of particular interest: the AC power system, the HVPS system and the signal cable/data acquisition system. After analysis of the transients estimated the transient frequencies, an elegant solution to the issue of AC power conducted interference was indicated. The thickness of common construction materials used in electrical power distribution systems is much greater than a skin depth at the transient frequencies. This fact allows the use of conduits and junction boxes for barrier shields and permits effective safety and transient current grounds to be easily made. A three phase shielded isolation transformer is employed to isolate the three phase ac power to the HVPS thereby limiting the coupling of spark transients to the AC power lines. The secondary wiring of this transformer is enclosed in rigid conduit to prevent coupling to the data acquisition environment. Another shielded three-phase transformer provides three isolated single phase 115v power sources for “clean” power for the computer and ADCs, “semi-clean” power for the vacuum controls and “dirty” power for the injector auxiliary power supplies.

The HVPS is grounded for safety and the injector is also grounded by the beam line. To avoid a large ground loop with high transient currents, the HVPS cable must be shielded and the shield must be grounded at both ends. This arrangement insures the HVPS transient discharge current (primarily) flows back along the cable shield since the coaxial cable/shield is in “cutoff” [4]. Measurements made on the CW LEDA injector demonstrated a greater than four times reduction in ground displacement voltage at the injector after grounding the high voltage cable shield at both ends. The concurrent advantage is that the inductance of the primary transient discharge loop, a major source of Φ coupling, is greatly minimized.

The few hundred signal cables are wired from the injector transducers with shielded twisted pair cable with the cable shields connected to a system ground point at the low pass filters. This arrangement helps convert normal mode transients into common mode transients due to the distributed capacitance of the cable shield. The low pass filters effectively attenuate the high frequency common mode transients. The shielded twisted pair cables transferring the signals from the low-pass filter circuits to the signal isolators have the shields grounded at the isolator end, again to help convert any remaining normal mode transients to common mode since the isolators attenuate only common mode transients.

4 TWO STAGE SIGNAL FILTERING AND ISOLATION

The analog isolation board and low-pass filter board were designed from the transient parameter analysis data to protect the control computer and data acquisition electronics from spark-down transients. The passive low-pass (1 to 100 kHz, -3 db) filter board is an RC network, built into a terminal barrier strip, placed in the field wiring junction box close to the injector to shunt the brunt of the spark down energy. This filter is used for all analog and binary input and output channels.

The analog and binary isolation boards are located near the computer and ADCs to provide common mode attenuation and to isolate signal ground loops. The analog isolator also provides isolated power, 1, 2, 5, 10 signal gain and a 100 ma. current driver output if needed. Assembly and wiring costs are both reduced by packaging/mounting the isolators on Phoenix Contact rails in the trunk wiring junction box. (see figure 2) The isolators provide 1500 Vrms isolation a with a -3 db frequency of 6 to 60 kHz, depending on component selection.

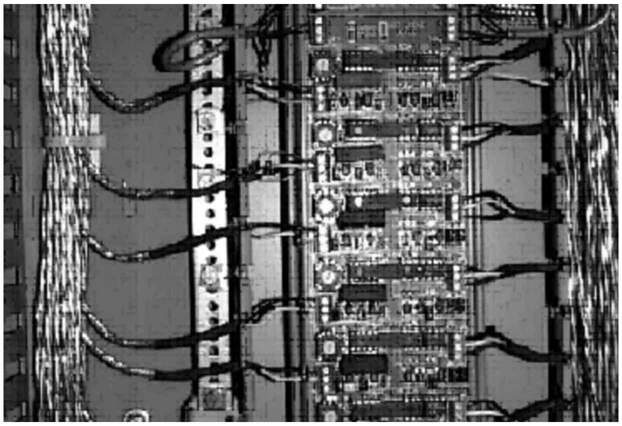

Figure 2: Junction Box Rail mounted Analog Isolators

This two stage transient suppression system has been in use for about four months and has demonstrated its effectiveness. The fourth spark the injector system experienced, shortly after the wiring, filters and isolators had been installed, interrupted computer operation. An inspection revealed that several ground wires on the filter boards were misconnected, bypassing the filters. Once corrected, there has not been any loss of data or computer interrupts during more than 200 spark-downs.

5 EPICS CONTROL AND AUTOMATION

EPICS is a toolkit for building network distributed process control and data acquisition systems. EPICS (originated at Los Alamos) is now developed jointly by a collaboration of >100 institutions, including accelerators, light sources, telescopes, detector collaborations, universities, etc.[5]. EPICS provides control and monitoring of the LEDA injector. Logic in the EPICS run-time database enforces proper operation of the injector to provide equipment protection, as outlined in the LEDA injector standard operating procedure. This logic controls the order in which devices may be turned on when starting up the injector. Logic is used to check the injector status to determine if a controlled device may be safely operated. This status consists of both discrete status, including the PSS (Personnel Safety System) and cooling water flow, and analog read-back/thresholds which determine whether or not the injector is in a state that is proper for operations initiated by the injector operator or by an automatic sequence. Control thresholds are available to the operator to modify as needed for running beam in varying conditions. For example, the HVPS thresholds are different when conditioning the injector than when operating.

To provide automatic shutdown and recovery from injector sparks, sequence logic was implemented in an EPICS database. The spark detection is based upon the voltage read-back of the FuG HVPS and is executed at a rate of 10 Hz. When this voltage drops below a specified threshold, the ion source microwave power is disabled. The operator may adjust the spark detection threshold as necessary, depending on injector operating conditions. In the automatic spark recovery mode, the disabling of microwave power is followed by a few seconds delay which allows the system to stabilize. Then the magnetron power is reset to the set-point recorded before the spark. The automated recovery from spark down will be repeated, if necessary, up to 3 times within a 30-second time frame. If a fourth spark occurs within the 30-second time frame, the automatic recovery sequence is disabled by logic until an operator intervenes, preventing a series of continuing sparks from causing damage.

The automatic shutdown and recovery has functioned well for the past four months of operation under most conditions. There are, however, conditions when the injector insulators are degraded and the injector experiences a rapid series of external sparks. The 10 Hz software detection in this case is not sufficient, so we have implemented fast hardware logic to provide adequate spark detection and shutdown under these conditions.

6 CONCLUSIONS

Reliable computer automation of processes operating in a high-energy transient environment can be assured by employing proper grounding and transient suppressing computer interfaces. Modelling the transient sources leads to computer interface designs that are effective in transmitting control signals while attenuating transients. By employing a cost-effective two stage transient suppression system, reliable EPICS based automation of the LEDA injector has been demonstrated.

7 REFERENCES

[1] Status Report on a dc 130-mA, 75-keV Proton Injector, J.D. Sherman et al., Rev. Sci. Instrum. 69 (1998) 1003-8.
[2] CW RFQ Fabrication and Engineering, D. Schrage, et al., Proc. LINAC98 (Chicago, 24-28 Aug. 1998) (in press).
[3] The Success and the Future of EPICS, M. Thuot, et al., Proc. LINAC96 (Geneva, 26-30 Aug. 1996).
[4] H. W. Ott, Noise Reduction Techniques in Electronic Systems, Wiley-Interscience 1976.
[5] http://www.atdiv.lanl.gov/aot8/epics/epicshm.htm