CONTROL SYSTEM FOR LINEAR INDUCTION ACCELERATOR LIA-2: THE STRUCTURE AND HARDWARE

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Abstract

Power Linear Induction Accelerator (LIA) for flash radiography is commissioned in Budker Institute of Nuclear Physics (BINP) in Novosibirsk. It is a facility producing pulsed electron beam with energy 2 MeV, current 1 kA and spot size less than 2 mm. Beam quality and reliability of facility are required for radiography experiments. Features and structure of distributed control system ensuring these demands are discussed. Control system hardware based on CompactPCI and PMC standards is embedded directly into power pulsed generators. CAN-BUS and Ethernet are used as interconnection protocols. Parameters and essential details for measuring equipment and control electronics produced in BINP and available COTS are presented. The first results of the control system commissioning, reliability and hardware vitality are discussed.

INTRODUCTION

Flash X-Ray radiography facilities are used for registration in hydrodynamic experiments. Linear Induction Accelerators (LIA's) are considered to be the most prominent source of electrons which are converted to gamma radiation [1]. The have because of their relatively low emittance, high currents(up to a few kA) and energy (up to tens MeV).

LIA-2 was originally designed as an injector for 20 MeV linear induction accelerator, but it can be used as an independent 2 MeV X-ray source for flash radiography with high space resolution. This machine has been built with the goal to keep the minimum possible emittace and therefore the minimum beam spot size on the target. The reliablity of the machine is of great importance. Basic parameters of LIA-2 are presented in Table 1.

Table 1: LIA-2 Basic Parameters

Parameter (Units)	Value
Maximum electron beam energy (MeV)	2.0
Maximum electron beam current (kA)	2.0
Number of pulses	2
Cathode heater DC power (kW)	2.5
Time interval between pulses (μ s)	2-10
Pulse duration, flat top $\pm 4\%$ (ns)	200
Maximum repetition rate (Hz)	0.1
Min. beam spot size FWHM on the target (mm)	1.5

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Let us note, that there are only a few linear induction accelerators for flash radiography around the world. Well known facilities are: FXR (Livermore Laboratory, USA), AIRIX (PEM, France), DARHT (Los-Alamos, USA), DRAGON (China) [2], [3], [4], [5]. The control system of DARHT-2 is described in [6]. The approach that allows us to get the minimum possible emittance leads to a large amount of controlled devices (for comparison DARHT-2 has 74 induction cells for 20 MeV installation, we have 48 induction cells for 2 MeV).

INSTALLATION STRUCTURE

The accelerating stucture (see fig. 1) includes 1 MV, 2kA diode whith dispenser cathode and 1 MV accelerating section placed just after the diode exit. Both sections of high-voltage pulsed transformer include linear chain of 96 induction cells put on accelerating tube.

The voltage for supplying inductors is generated by 48 identical modulators: pulsed power devices composed of pulse forming network, high-voltage switch (thyratron), demagnetizing generator and control electronics. Output pulse voltage is 50 kV, duration – 300 ns, output current comes up to 5 kA. Each modulator feeds two induction cells.

Low-temperature dispenser thermo cathode is heated up by a special 70 A generator. Cathode heating current should be turned off at the moment of shot to ensure zero magnetic interferention. Four short focusing solenoids are powered by pulsed current generators which should be synchronized. Three dipole correctors are powered by direct current. Beam diagnostic system consists of two beam current transformers, capacitor-based pulsed voltage dividers, X-Y strip-line beam position monitor (BPM) and movable Faraday cup.

Normal operating cycle of LIA consists of two stages: slow and fast. During slow stage the elements of installation are prepared for fast operations: forming networks and demagnetizing generators are charged, thyratrons are preset, the states of various elements are checked. The duration of slow stage is 20-30 ms. If all elements of LIA are in normal condition, then the fast stage is initiated. This stage starts from the moment of inductor's demagnetizing and finishes with beam generation. Duration of this stage is about 150 μs. If any failures occur during this stage, interlock subsystem disables the experiment start.

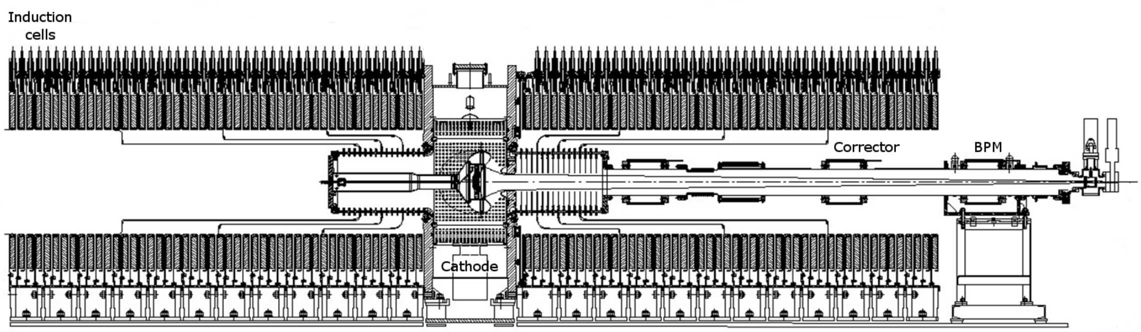

Figure 1: LIA accelerating structure.

CONTROL SYSTEM FEATURES

Let us formulate the features of control system of LIA. The hardware synchronization system is needed to provide trigger pulses to modulators during both stages of operation. The interlock system is an absolute necessity because of high experiment cost and preparation time. To ensure beam quality and to provide full information on installation performance more than 200 waveforms per shot should be recorded.

Planned time of operation of LIA is tens of years. Thus the control system must be based on modern widespread hardware standards and software.

Most of the controlled devices are high-voltage pulse generators. Special precautions should be taken to protect control electronics from high-voltage breakdowns. Electronics and transmission lines should also be protected against interference induced by high voltage pulses.

Control system must be scalable to allow adding induction cells. The most numerous control object is modulator. They are grouped in sections by 6 in each and linearly distributed along accelerator's length. It is convenient to have control elements structured accordingly.

Therefore we can formulate following features of the control system of LIA:

- Linearly structured
- Strict hardware synchronization
- Hardware interlock subsystem
- Adequate waveform recording subsystem
- High-power nature of the installation considered
- Based on modern widespread standards
- Scalable

STRUCTURE

The control system of LIA is functionally divided into four subsystems: pulsed power control subsystem, timing subsystem, waveform recording subsystem and interlock subsystem.

Pulsed power control subsystem is controlling all devices during slow phase of operation. This is mainly done by software using CAN-bus.

The timing subsystem generates and distributes trigger pulses to modulators and other devices. Each modulator needs 6 trigger pulses for proper operation. The delay of pulses initiating discharge should be individually adjusted for each thyratron with accuracy less than 10 ns. Other pulses may be set with accuracy about 100 ns. Altogether there are 288 timing channels.

The waveform recording subsystem provides information about installation state and beam quality. Flash radiography facilities are used to conduct very expensive experiments. To estimate the reliability of the installation, 96 "fast" signals (duration about 300-1000 ns) are recorded on each shot. Recorded data is stored and statistically analyzed. Overall accuracy around 1% for these signals is needed to ensure beam quality. In addition about one hundred technological signals are recorded and analyzed during the slow phase of operation.

The interlock subsystem prevents damage to the installation and prohibits experiment start if alarm signal from any of the devices is recieved. It has to be absolutely reliable.

The structure of the control system of injector is shown on fig. 2. High-voltage system for injector consists of 8 identical sections. Each section contains 6 modulators supplying 12 induction cells. Local controller performs all operations necessary for the functioning of section: modulator timing, waveform recording, interlock functionality, CAN-bus interaction. Local controller is 6U 8-slot CPCI crate installed directly at the modulators section rack. This is done to minimize cables length thus minimizing noise signals. Local controller is shown on fig. 3.

Six modulators are connected to common CAN bus, which is used for their setup and controls slow changing parameters. Trigger pulses for demagnetizing and thyratron preparation are received from central crate and split to all modulators using the F-16 splitter board. All other fast thyratron pulses are generated using digital delay line which is started by a trigger pulse from main controller.

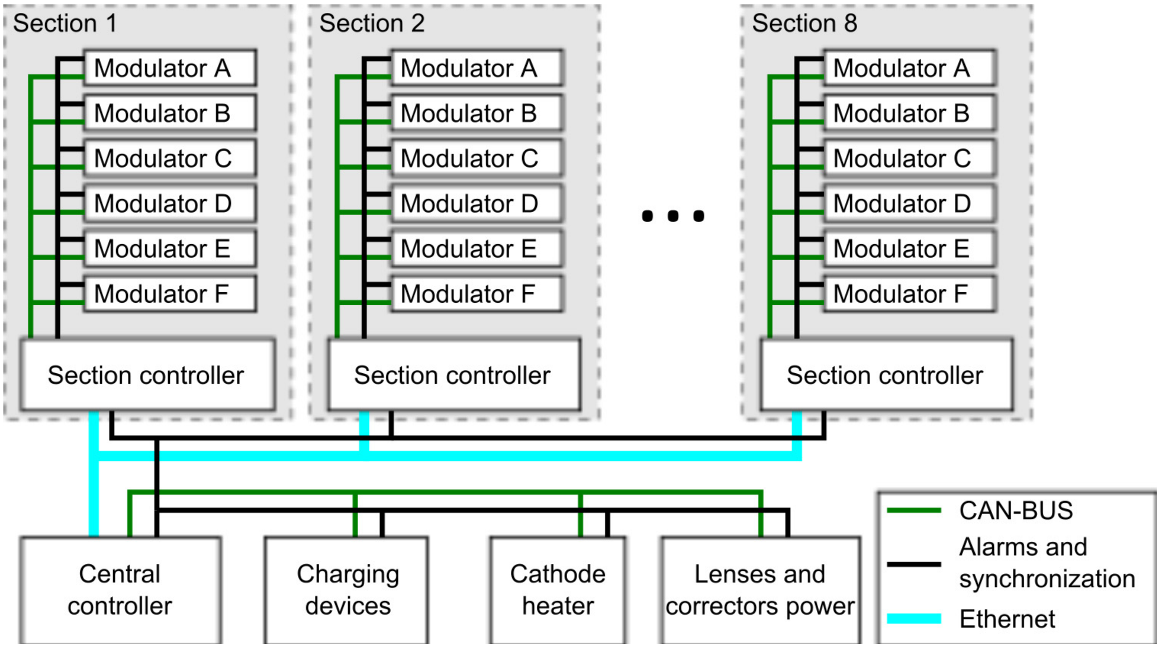

Figure 2: The structure of LIA control system.

Local controller also gathers alarms from all modulators and generates section alarm signal.

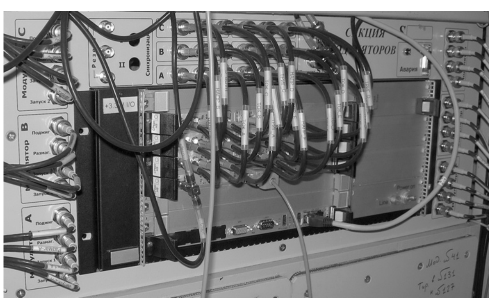

Figure 3: Local controller.

The central controller synchronizes and supervises local controllers operation. It controls charging devices, lenses, BPM and cathode heater via CAN-bus. It also gathers alarm signals from sections and raises general alarm in case of breakdown in any section. All controllers and operator's PC are interconnected using Ethernet.

The hardware synchronization of the installation is done using general following pulses: local controller starts, demagnetizing and thyrathron preparation signals, cathode heater turn off, lenses starts, experiment start. This pulses are transferred using coaxial lines.

Hardware

Common mezzanine card (PMC) and CompactPCI standards were chosen as a hardware basis for control system. CompactPCI was chosen as a widespread industrial standard compatible with x86 architecture. It allows to use widespread operating systems (Windows, Linux) and benefits from wide range of COTS automation equipment. PMC cards allow interchanging host system (CompactPCI, VME, PCI,...), thus electronics made for the LIA control system could be used for other tasks. CompactPCI rear input output (RIO) modules are used to effectively cope with huge amount of cables.

LIA is high current and high-voltage facility with operation cycle in nanosecond time region. Therefore survivability of electronics at the environment of periodic high-voltage discharges is an issue. We decided to develop hardware directly interfacing to high-voltage devices ourselves. Doing this we have the possibility to improve the survivability of hardware if needed. This approach proved to be useful to overcome false shots due to imperfect grounding in synchronization subsystem. We have unified hardware of all controllers to make maintenance easier.

Four modules were specially developed in BINP for use in LIA control system. Waveform recorders ADC200-ME and ADC812-ME were developed for waveform recording sub-system. Both of them are in PMC standard. Their specifications are given in table 2. ADC200-ME is used for the measurement of fast signals: inductor currents and voltages, BPM signal, signals form faraday cup and current transformers. ADC812-ME is used for slow waveforms recording. Inputs of two ADC812-ME's are placed on CPCI RIO module that is also used to route device alarms to F-16.

Two other modules were developed for interlock and synchronization sub-systems: DL200-ME (digital delay line with built-in interlocks) and F-16 driver/splitter. DL200-ME specifications are shown in table 3. Interlock channels are optically decoupled to protect the board from high-voltage breakdowns. FPGA is used to allow a pro-

Table 2: Waveform Recorders Specifications

	ADC200-ME	ADC812-ME
Channels	2 simultaneous	8 simultaneous
Conversion rate	200 MSPS	5 MSPS
Accuracy	12 bit	12 bit
Memory	1M×2×12 bit	1M ×2×12 bit

grammable interlock logic. There are two modifications of DL200-ME firmware, fast and slow. Fast modification (DL200-ME-F) is used in local controllers. Slow modification (DL200-ME-S) is used in main controller, provides 80 ns step and has specific interlock logic.

Table 3: DL200-ME Digital Delay Line Specifications

Output channels	16
Step	5ns (80 ns for S modification)
Jitter	<0.5 ns
Counter	15 bit (23 bit for S modification)
Interlock channels	16
Alarm channels	2

F-16 is a RIO CPCI module. It has two modifications: driver and splitter. F-16 driver is controlled by DL-200ME. It forms 16 decoupled synchronizing signals and gathers alarm signals. Another modification is F-16 splitter that splits two incoming signals on 8 outputs each. It is used to split slow synchronization pulses from main controller to all induction drivers in section.

Kontron [7] CP-6000 processor boards are used as central processing units in all crates. They have 2 Ethernet ports (4 with backplane) and PMC mezzanine slot. 4GB CompactFlash memory contains OS and control software.

Two boards are used as mezzanine carriers for PMC modules: Kontron CP-690HS and a module with built-in CAN controller constructed in BINP. TEWS [8] TPMC810-10 is used as a mezzannine CAN controller with two DB-9 connectors.

CONCLUSION

Features of LIA control system were formulated and the structure of the control system was designed. CompactPCI and PMC standards are used for control system hardware. Hardware for the control system has been developed, manufactured and tested in operation. Some of this hardware is used at other works in BINP.

LIA-2 was tested at single pulse regime of operation. Diamaeter of the electron beam diameter on the target (FWHM) less than 1.3 mm was achieved. Further experiments are continued on the customer site. High survivability of hardware was demonstrated in the environment of high-voltage discharges. The experience gained during creation and operation of LIA is usable for design of the control system of 20-MeV flash X-Ray radiography complex.

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