LIA-2 POWER SUPPLY CONTROL SYSTEM

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Abstract

LIA-2 is an electron Linear Induction Accelerator designed in Budker INP as an injector for full scale 20MeV Linear Induction Acceleratorfor X-ray flash radiography with high space resolution. Inductors get power from 48 modulators, grouped by 6 in 8 racks. Each modulator includes three control sub-devices connected via internal CAN-bus to an embedded modulator controller, which operates under Keil RTX real-time OS control. Each rack includes a cPCI crate equipped with x86-compatible processor board running Linux with CX-server. Modulator controllers are connected to cPCI crate via external CAN-bus and interact with CX-server via extended KOZAK standard. In modulator controller operation many software mechanisms are used e.g. different modes, detection of an internal sub-device offline state, request repost, addressing, system error and other.

LIA-2

LIA-2 is originally an electron linear induction injector for 20MeV Linear Induction Accelerator designed in Budker INP for X-ray flash radiographywith high space resolution. It is a facility producing pulsed electron beam with energy 2MeV, current 1 kA and spot size less than 2mm. Beam quality and reliability of facility are required for radiography experiments. Accelerating section consist of 96 inductors based on the amorphous ferromagnetic laminated cores. Each modulator feeds two inductors, total 48. All modulators grouped by 6 in 8 racks.

Basic LIA-2 parameters are presented in Table 1. The accelerator includes electron beam forming, accelerating and focusing system, high voltage pulsed power system, beam diagnostic system, high vacuum system and control system.

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 in the burst	2
Cathode heater DC power (kW)	2.5
Time interval between pulses in the burst (μs)	2 - 10
Pulse duration, flat top ±4% (ns)	200
Maximum repetition rate (Hz)	0.1
Min. beam spot size FWHM on the target (mm)	1.5

MODULATOR

Pulsed HV power supply system consists of 48 identical double pulse modulators, two charging units (one for each pulse) and coaxial feeding lines (20 cables for one modulator). Each modulator feeds two inductors in parallel and includes two Pulse Forming Networks (PFN) (one for each pulse), two cold cathode thyratrons TPI 1-10K/50 with a switched current 10 kA and working voltage 50 kV[1], two thyratron starters and a degausser (see Fig.1). Two starters (STR1/2) and degausser (DEG) are driven by Local Control Boards (LCB). In addition, each modulator is equipped by the controller (MC). 48 modulator controller, 144 LCB, 8 cPCI crates with CX-server and main control panel form HV power supply control system.

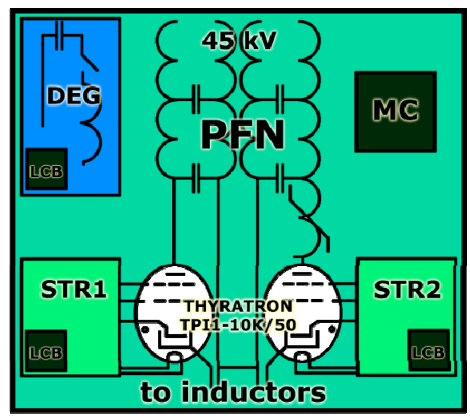

Figure 1: Modulator structure.

Hardware

Modulator controller is based on LPC2119 microcontroller by NXP. This microcontroller includes a 32-bit ARM7TDMI-S CPU with real-time emulation and embedded trace support, together with 128 kB of embedded high-speed flash memory. The LPC2119 contains various 32-bit timers, 4-channel 10-bit ADC, two advanced CAN channels, PWM channels and 46 fast GPIO lines with up to nine external interrupt pins. The microcontroller performs following tasks: communication with external server and internal sub-devices on CAN-bus (125kb/s), slow interlocks gathering (response time less than 60 ms) and processing, parameters calibrations, indicator control (on Serial Peripheral Interface (SPI)), internal sub-devices supply control and other. Modulator controller also includes Programmable Logic Device (PLD) EPM3128 by Altera. This PLD is based on MAX3000A architecture and contains 128 macrocells. The EPM3128 performs fast interlocks gathering and processing with response time less than 1 us. Modulator controller contains five inputs for fast internal interlocks with optic isolators, three inputs for synchronization pulses and output for final interlock with optic isolator. Inner structure of modulator controller with local control boards are presented on Fig.2.

Local Control Board is based on T89C51CC01 microcontroller by Atmel. This microcontroller implements 8-bit 80C51 CPU. The T89C51CC01 contains 32 KB flash memory and 2KB EEPROM, three 16-bit timers, 8 multiplexed inputs of 10-bit ADC, 5 outputs 8-bit PWM, one CAN channel and 34 digital I/O lines.

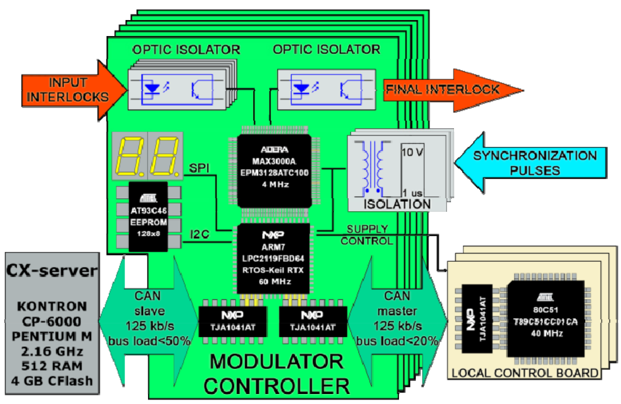

Figure 2: Modulator Controller and Local Control Boards.

Software

The modulator controller works under control of a Real-Time Operating System (RTOS) Keil RTX. The Keil RTX is a royalty-free, deterministic RTOS designed for ARM and Cortex-M devices. It allows creating programs that simultaneously perform multiple functions and helps create applications which are better structured and more easily maintained.

Features

- Royalty-free, deterministic RTOS with source code.
- Flexible Scheduling: round-robin, pre-emptive, and collaborative.
- High-Speed real-time operation with low interrupt latency.
- Small footprint for resource constrained systems.
- Unlimited number of tasks each with 254 priority levels.
- Unlimited number of mailboxes, semaphores, mutexes, and timers.
- Support for multithreading and thread-safe operation.

In the modulator controller Keil RTX is used with following features.

• Main clock	60 MHz
• System clock	1 kHz
• Round-Robin task switching	
• Number of concurrent running tasks	20
• Task stack size	200 bytes

Main cycles

• Watchdog check	800 ms
• Interlocks check	50 ms
• Indicator refresh	300 ms
• Settings saving	1 m
• Internal management	45 ms

Modulator controllers are connected to cPCI crate via external CAN-bus and interact with CX-server [2] via extended KOZAK standard [3].

Addressing

Each modulator has unique functional address which sits in CAN connector. Based on this functional address modulator controller identify its network ID and physical address. Network ID is used in communication with CX-server and physical address is continually displayed on the front indicator. Physical address consists of a figure and a character. The figure indicates modulator rack serial number and the character indicates modulator serial number in this rack. All modulators with even character have even network ID. If one wishes to replace a modulator, one just removes old modulator and inserts a new one, than modulator identifies all addresses by itself.

Offline state detection and request age

One of the most important mechanisms is detection of an internal sub-device offline state. There are four counters (three individual and one shared) that define current state of internal sub-devices. Sub-device sits in offline state if counter value is less than minimum value and it sits in online state if counter value is greater than maximum value. Values of these counters are changed when internal communication task running. Counter value is decreased when the sender in a request processing task is recognized. Value of the shared counter will increase when there will be no more messages in a specified time domain (timeout for internal receive). Values of individual counters will increase when individual message will be sent for suitable sub-device. Also multi-request about current sub-devices states is sent if shared counter value is less than maximum level. Knowledge about current states of the internal sub-devices is especially important if sub-device sits in offline state and there are several messages for him. In this case all requests for this sub-device aren't sent but remembered.

All requests have an age counter. Value of the age counter is started to increase only when request is sent for suitable sub-device. Request gets old and then will be added in FIFO for sending if age counter value of this request is greater than maximum level. This mechanism is worked only when internal sub-device is online, but multi-request is sent until all sub-devices get offline.

Modes

Each modulator can be in one of six modes (*Sleep, Experiment, Action, Adjustment, Programming* and *Emergency* - ***SEAAPE***). On the Fig. 3 possible transitions from one mode to another are presented. Essentially one mode differs from another by Mask of Admissible Commands (MAC) which is used at the request reception.

Sleep is an initial modulator mode. All internal sub-devices of the modulator are switched off. In this mode operator can write minor settings (e.g. heating time of a hydrogen thyratron, masks of the enabled internal interlocks etc.). Final interlock is active.

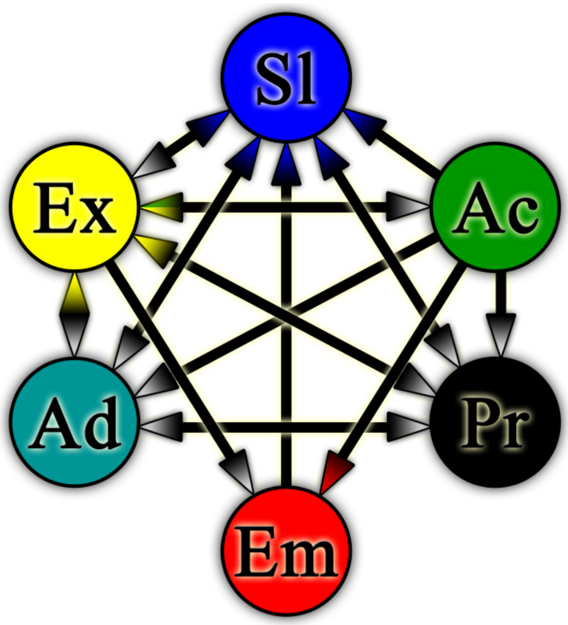

Figure 3: Possible transitions from one mode to another.

- Button or power reset
- Watchdog timer reset
- Main shot
- Enabled interlock
- Command

Experiment is a basic modulator mode. All internal sub-devices of the modulator are switched on. In this mode operator can write major settings (e.g. heating current of a hydrogen thyratron, discharge arc current, degausser voltage etc.) and minor settings (like in *Sleep* mode). Final interlock is managed by current enabled internal interlocks. This mode is necessary for test LIA-2 shots. It is necessary to perform approximately one hundred shots in order for final main shot to be performed without any problems, because experiment with main shot is very expensive.

Action is a mode of main shot. In this mode operator cannot change any settings. If any enabled internal interlock appears then final interlock would active and modulator would change mode on *Emergency*. After main shot modulator change mode to *Experiment* by itself.

Adjustment is a mode for calibration of measured signals and other auxiliary procedures. Final interlock is active.

Programming is a mode for firmware download to the microcontroller. Final interlock is active.

Emergency is a mode when there is enabled internal interlock. In this mode all internal sub-devices are switched off, interlocks are hold and final interlock is active. Operator should change mode to *Sleep* for exit from this mode or reset microcontroller.

Modes approach makes all system more fail-safe and decrease human factor.

REFERENCES

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[2] D. Bolkhovityanov "UI-oriented Approach for Building Modular Control Programs in VEPP-5 Control System", Proc. PCaPAC-2006, Newport News, VA USA, October 2006.

[3] http://www.inp.nsk.su/~kozak/designs/designs.htm