SARAF BEAM LINES CONTROL SYSTEMS DESIGN

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Abstract

A new beam line was constructed and operated for the first phase of the SARAF LINAC in order to deliver beams to various experiments. In this report concept of the beam line and different subsystems are presented. The details on the hardware and control software are given.

INTRODUCTION

The first phase of the linear accelerator of Soreq Applied Research Accelerator Facility (SARAF) has been commissioned [1]. At the moment CW proton beams at energy up to 3.5 MeV and at intensity up to 1 mA are routinely operated, while deuterons beams at energy up to 4.8 MeV and beam intensity up to 1 mA are operated only at low duty cycle. A new beam line was built in addition to the existing beam dump line, in order test new targets while protecting the superconducting LINAC from dirt coming from the target. The beams are delivered to several experiments which have broad range of requirements. The new beam line infrastructures consist of several interconnected parts: magnetic beam optics elements, beam diagnostics elements, vacuum control and machine safety system (MSS) [2].

CONTROL OF BEAM OPTICS ELEMENTS

The purpose of the magnets control is the providing the magnet currents necessary for beam transport. The control system also provides the "magnets ready" interlock for the accelerator MSS. The following magnetic elements were used for control of beam optics: 1) Two 45° dipole magnets for transporting the beam to the new beam line. 2) Five quadruples lenses (two doubles and one single) for containing the beam and preparing the required beam spot for various targets. 3) two x-y steer magnets. All the magnets except the first doublet are water cooled. The thermo switchers with 60° limits are placed on the magnet coils. Some of the magnets (dipoles, a quadruple and steers) were DANFYSIK. The two doublets were recuperated from other institutions.

The magnet control hardware located in a mountable rack located in the RF Hall (approximately 30 meters from the magnets). It is containing NI compact reconfigurable Input/Output (cRIO) platform control system and the appropriate power supplies for each magnet.

The rack includes the following elements:

1. NI AI-9201: Analog input for reading the current of the different power supplies.
2. NI AI-9264: Analog voltage Output for setting the current of the different magnets.
3. NI AI-9425: Digital Input, for indication of the operation status of the power supplies and input signals for the accelerator MSS.
4. NI AI-9476 : 32-Channel, 24 V, Sourcing Digital Output, for operation of the powers supplies.
5. GenesysTM power supplies for dipole and quadruple magnets.
6. Delta Elektronika power supplies ES030-5 with changeable polarity, for the steerer magnets.

The control system provides "magnets ready" signal for the accelerator MSS. This signal requires the conditions when all the power supplies are enables, the chain of thermo switchers is intact and the current values on the dipole magnets in the predetermined range. The power supplies could be enabled only when there is sufficient magnet cooling water flow. The beam transport condition (beam line rather than beam dump) is chosen by signal received from the accelerator control system. In the case when the beam dump line is chosen the current on the first dipole is forced to be zero in order to get "magnets ready" signal.

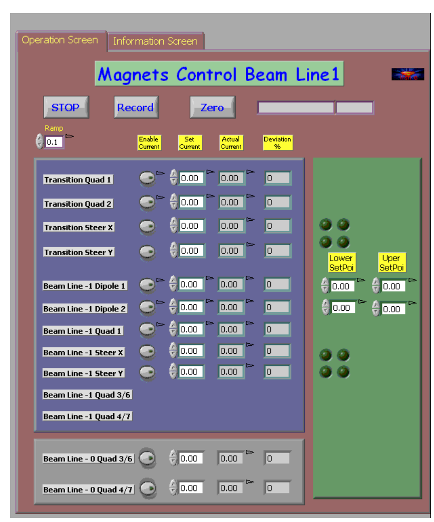

Figure 1: Beam lines magnets control system HMI.

The main screen of the magnets control application is shown in Figure 1. The application allows the user to see whether the beam line or the beam dump is chosen for beam transport. The user enables the magnet supplies and set the desirable currents. The system presents the output current and the deviation from the required current for every magnet. The magnets are ramped to the set values with a ramping speed which also controlled by the user. For the two dipole magnets the upper and lower current threshold can be set thus enable preventing damage to the accelerator. The Information screen presents the status of thermo switchers, cooling water flow, beam line selection switch [3].

BEAM DIAGNOSTICS CONTROL

The purpose of the beam diagnostics system is beam tune and preparation beam on a target within requirements of specific experiment. The control of the beam diagnostics facilitates operation of the diagnostics elements. it also protects beam diagnostics from damage from intense beam. The beam line diagnostics consists of three of X_Y wire-profilers stations and adjustable beam collimators ("4-jaw").

Each X-Y scanner station consists of two "forks" installed in a 6-way cross. An electrically insulated 150 micron thick tungsten wire is stretched between the ends of the fork. Both ends of the wire are connected to electrical feedthroughs, so the resistance of the wire can be tested externally. The forks are moved vertically and horizontally perpendicular to the beam axis using linear motion mechanisms (Huntington) and stepping motors (NI, NEMA 23 T21NRLC). On each motion axis there are two limit switches, aimed to restrict the fork movement and thus to avoid damage to the system. The motion of the vertical and horizontal scanners is not performed on the same plane, thus, eliminating the risk of mechanical collision. After introduction into the beam, electrical charge collected on the wire is converted into voltage signal using a 1kΩ resistor. The dependence of the wire signal on its position yields information on the beam profile. These wire scanners can work only in pulsed beam (diagnostic mode) at a relatively low duty cycle. To synchronize the signal from the wires the master accelerator trigger was used as a trigger for digitizer. The wire scanners can't be used for CW beam operation (normal mode).

The control system hardware is installed in another 19' rack mountable in the RF Hall. The system is composed of several subsystems:

1. PXI chassis – with real time integrated control 8108, 2.53 GHz dual core.
2. Motion controller PXI 7350.which provides a fully-programmable motion control for the six independent axes of motion.
3. UMI 7774 for connection of the stepper servo drives (feedback and digital I/O) to the motion controllers.
4. P70360 stepper driver reading the signals from the UMI and provides the desired current to the stepper motors.
5. Digitizer PXI 5105 60MHz with eight simultaneously sampled channels.
6. The PXI 6229 digital I/O card that is used for general purpose.
7. The Motion controller (National Electrostatic Corp) provides control of the Slit Motor Drives

The control software project includes two parts: the RT controller software (PXI) and the Host computer (PC). The host computer Vi's handle the graphical user interface (GUI) and data record, while the RT controller loaded to the PXI includes the main operation Vi's and the Shred Variable Library (SV). This configuration of the VI's makes it possible to run the main program on the PXI without the need to operate the host computer, making it much more reliable and robust.

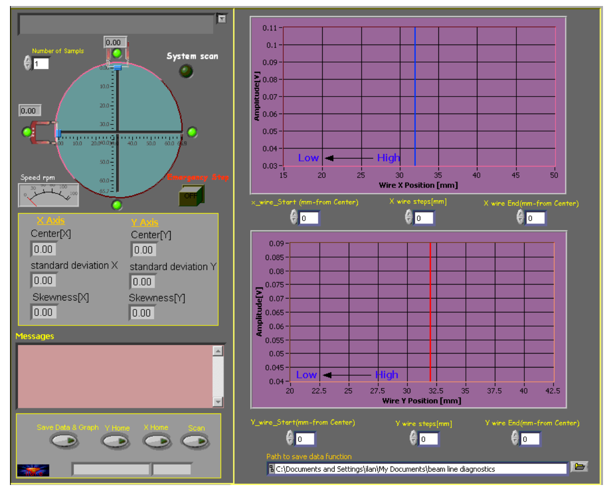

Figure 2: Diagnostics control system HMI.

Wire scanners control application is shown in Figure 2-The right part of the screen presents the scan results as an X-Y graph and the scan parameters. The profile characteristics: centroid, standard deviation and skewness, are presented in the left middle screen. The upper left corner presents the current wires positions, their velocity and operation status (scan mode). Additionally there is a message field for error notifications and scan status. At the bottom left corner the user sets the operation mode. The application allows the user:

1. Scan process: the system starts the scan process based on the defined parameters (range, steps).
2. Returns the wire to the home "out of beam" position.
3. Save data file and plot picture
4. Emergency stop of the profiler movement.

In order to prevent damage to the system there are several software protection features:

In the scan process the system will not start if both limits (Home and Forward) are inactive. b) Scan process will be stopped if the home limit in the perpendicular second axis is inactive. c) If the requested scan distance is greater than the distance between the limits, then the program will correct it automatically with a corresponding message. The "diagnostics out" signal based on the status of the profiler limits is sent to the accelerator MSS. The accelerator cannot operate in full power mode if the profilers are inserted in the beam pipe.

The High Power Beam Slits "4Jaw Collimator"

The National Electrostatic Corp 4Jaw Collimator is located at the end of the beam line. Its purpose is to scrap the beam tails and eliminate possibility of irradiation of the target vicinity. The system consists of four cylindrical elements which intercept and define a partial beam which passes between them. The elements are constructed of tantalum, and are directly cooled, by de-mineralized water. Each cylindrical element has a power dissipation >1000 Watts with highest working temperature up to 200^{o}C. Position of each element can be varied in the range of 17 mm which defined by two limit switchers. The current from on each element can be read only for the case of CW beam. The data slit controller (from National Electrostatic Corp) handles the movement of the four slits.

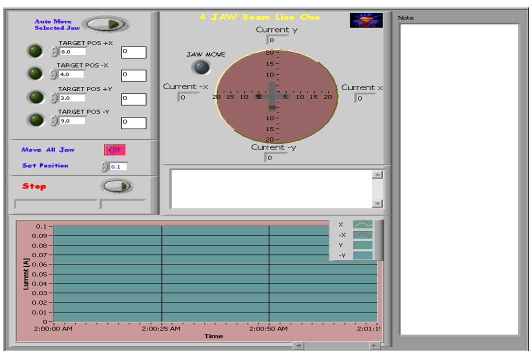

Figure 3: 4Jaws collimator control system HMI.

The main screen (Figure 3) enables the user to control the four slits. The right side of the screen presents the current location of each slit and the current evolving on it (mA). The left side enables the user to select which slit to move (by pressing the green button), and to which location (0-16mm). Moreover the user can choose to move all the slits simultaneously to the same location by using the command button "Move All". The centre of the screen presents the messages centre. The evolving current (mA) is shown in a graph format at the lower part of the screen.

BEAM LINES VACUUM CONTROL SYSTEM OVERVIEW

SARAF vacuum control system was designed by ACCEL and commissioned at SARAF. The system was delivered to SARAF team to control the accelerator's seven vacuum sections. The control system was able to display the vacuum reading, operate gauges (open and close commands) and start the pumps.

When the first beam lines were constructed, they required additional control mechanisms and a new design concept was tailored to control the new vacuum sections. In addition, the older accelerator vacuum control system and the new beam lines control systems were unified into one control system which standardizes the display and operation, and creates common principles on which the control system operates (Figure 4) [4].

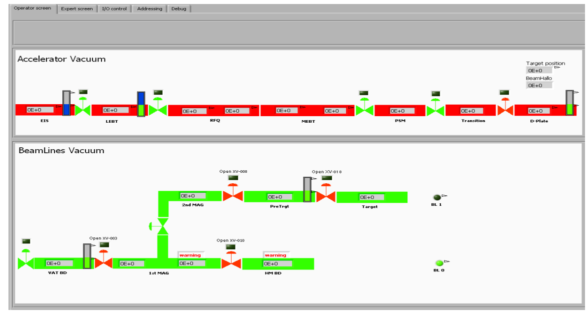

Figure 4: Vacuum control system HMI.

Principles of Design

The older accelerator control system is a simple system on which the raw information is displayed on screen with minimal processing (only scaling is performed on the vacuum readings to fit them to the various sensor types). Operation commands and statuses are also directly connected to the HMI and so no processing is done. Much unnecessary data was displayed on screen, as well as some dysfunctional controls which created an unfriendly system to use.

To correct these issues, a new display method was chosen, which minimizes the operators need to read and process the vacuum readings. The system was reorganized to display current status of the system according to a simple colour code, where green status is good (and open in case of gauge display), red status is bad (or closed), yellow status is hardware error and gray status is initial state. In normal mode, where all vacuum readings are correct and no set points were triggered, the display is all green.

The beam lines control system includes a control software element for every physical hardware element. This allows the system to be parametric, as each new addition of hardware such as gauges, pumps and sections requires a similar addition of compatible control element and with relative ease (Figure 5).

The control elements are all similar, and are configured by a central configuration method which is located at the HMI expert screen. The complex system which was implemented in the older accelerator vacuum system was reduced to a collection of control elements running in parallel and is reflective of the vacuum hardware elements installed in the facility.

Any information or feature which is not necessary and/or required during normal operation of the system was removed from the main operator HMI control panel and placed in the HMI expert screen. All configuration methods and features were placed in configuration tabs available to expert operators only.

Additional Features

As the system now shows a full view of the vacuum system, it allows the addition of new control displays such as beam blockers which are now displayed in the HMI operator screen. Additional layers of information can be added or removed from the HMI according to the operators requirements.

The control system processes the information retrieved by the control channels and indicates hardware errors in addition to good or bad operation status. Processing the current state of the vacuum system in real time also allows the implementation of machine safety procedures, so that the system can prevent the operator from making basic mistakes such as open gauges when they should not be opened.

The application includes an alarm scheme which warns the user from various situations such as gauge override command localized hardware issues.

Implementation

The system is implemented using Labview and National Instruments data acquisition (DAQ) devices. The parallel characteristics of the system require methods to prevent race conditions especially at the data out points. The parallel functions are managed by a top layer, which handles the I/O channels of the DAQ device. As there is only one DAQ device handling the I/O it has to be controlled via one connection from the control system. The management layer of the application communicate with the control elements, and convey the current snap shot of the output signals to the DAQ device. In addition, the input signals are read by the same layer and distributed to the control elements running at the system.

To prevent access to the shared resource which is the output signals snap shot, the control elements use semaphores to lock access to the output table and update its relevant signals. When done updating, the control element releases the semaphore allowing for another element to update the table and so forth.

To allow fast addition of control elements, the system is configurable. Each element is controlled by its function which is instanced when the application is started and runs continuously. As each control element acts the same, the point of configuration is when it is instanced. This configuration is done via configuration tables, so that the user has full flexibility to configure the system without changing the source code apart from instancing a new control element.

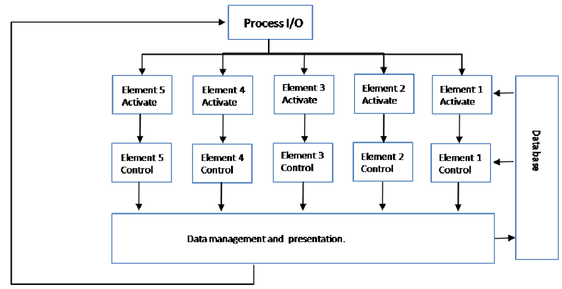

Figure 5: Vacuum control system block diagram.

SUMMARY

The SARAF beam lines control systems consists of various hardware design by the SARAF engineering team, and are currently in various stages of operation and delivery.

REFERENCES

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