



Fermi National Accelerator Laboratory

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CUB DI(Deionization) Column Control System

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CUB DI (Deionization) Column Control Systems

By K. C. Seino

1. Introduction

For the old MR (Main Ring), deionization was done with two columns in CUB, using an ion exchange process. Typically 65 GPM of LCW flew through a column, and the resistivity was raised from 3 Mohm-cm to over 12 Mohm-cm. After a few weeks, columns lost their effectiveness and had to be regenerated in a process involving backwashing and adding hydrochloric acid and sodium hydroxide.

For normal MR operations, LCW returned from the ring and passed through the two columns in parallel for deionization, although the system could have been operated satisfactorily with only one in use. A 3000 gallon reservoir (the Spheres) provided a reserve of LCW for allowing water leaks and expansions in the MR.

During the MI (Main Injector) construction period, the third DI column was added to satisfy requirements for the MI. When the third column was added, the old regeneration controller was replaced with a new controller based on an Allen-Bradley PLC (i.e., SLC-5/04). The PLC is widely used and well documented, and therefore it may allow us to modify the regeneration programs in the future.

In addition to the above regeneration controller, the old control panels (which were used to manipulate pumps and valves to supply LCW in Normal mode and to do Int. Recir. (Internal Recirculation) and Makeup) were replaced with a new control system based on Sixtrak Gateway and I/O modules.

For simplicity, the new regeneration controller is called as the US Filter system, and the new control system is called as the Fermilab system in this writing.

2. US Filter System

The system provides controls for three DI columns. The PLC system consists of the Allen-Bradley SLC-5/04 controller, I/O modules and the IDT PanelMate 1500 operator interface. The main controls are housed in a Nema 4 enclosure (30"h x 24"w x 12"d). The valve actuator solenoids are housed in three Nema 4 enclosures (20"h x 24"w x 8"d) along with remote I/O blocks for individual DI columns. The solenoid enclosures are mounted on the face piping of the three columns.

The DI columns (Column-1, Column-2 & Column-3) are operated in conjunction with the Fermilab control system. For the Column-1 (as an example), the Fermilab system sends REQ1 (Request Column-1) to the US Filter system, which first enters in the Service Rinse Recirculation mode. After a minimum Service Rinse Recirculation time, it returns GRN1 (Grant Column-1) if the column resistivity is proper. The Fermilab system then sends USE1 (Use Column-1) to the US Filter system to put the column in Service. If the Fermilab system removes USE1, the Column-1 is put in Standby.

The original Allen-Bradley SLC-5/04 and IDT PanelMate 1500 application programs were written by US Filter. If one needs to modify the programs, one should refer to Ref. [8] and Ref. [9].

3. Fermilab System

3.1 Hardware

3.1.1 PLC

The PLC hardware system consists of a Gateway module (local controller/remote communicator) and a variety of I/O modules. The product line of these modules is called as Sixtrak and is made by Sixnet of Clifton Park, NY. The Gateway scans I/O modules and update the information on them under a program control, and it communicates with host computers via an Ethernet link. The Gateway has 1 Mbytes of flash memory (for firmware), 1 Mb of battery backed RAM (for data), a real time clock and a RS232 serial port for local diagnostics.

For our applications, we are using a few different types of I/O modules. They are analog input modules (instrumentation), digital input modules (24VDC) and digital output modules (relay).

For the main features of the I/O modules, one should refer to Ref. [2].

3.1.2 Instrumentation

The sensors, transmitters, actuators, solenoids and other field devices had been specified, purchased and installed by the Mechanical Support group. However, we did cabling/wiring, set key parameters, calibrated and did trouble-shooting on these field devices. For this reason, I will briefly make reference to their main features as follows.

- (1) Pressure transmitters (Omega PX880-1K-GI): 316SS base, 316LSS diaphragm, 0-200 psi +/-0.25%, 12-40VDC, 4-20mA output, reverse polarity protection, 1/2" NPT female electrical connection.
- (2) Pressure meter (Omega DP25-E): 4-20mA input, 15-bit ADC, 4-digit LED display, 24VDC excitation, 4-20mA output, 115VAC power.
- (3) Flow transmitters (Peek Measurement 2120R): 0-3120 rpm (0-52 Hz input), 0-100 GPM with 1.5"ID pipe, +/-0.2% accuracy, 4-20mA output, 8-30VDC, 115VAC power.
- (4) Liquid level indicator (Gems SureSite 86158): Low temperature (300 degF) transmitter, length = 240", 4-20mA output, 10-40VDC input, +/-1% accuracy, junction box termination, 115VAC power supply module.
- (5) Resistivity meters (Thornton 200CR): 115VAC power, 0.0013-50 Mohm-cm with 0.1 constant cell, +/-0.5% accuracy, two SPDT relay outputs, two analog outputs (4-20mA), automatic temp compensation.
- (6) Flow meters (Red Lion IMI04107): 0-50KHz input, 0-100 GPM with 3" ID pipe, 4-20mA output, 12VDC excitation, 6-digit LED display, 115VAC/14VA power.
- (7) Pneumatic actuator solenoids (Mac #45A-LAD-DDAD-4BL=2132): Base mount body, 1/8" NPT port, manifold with flow control, 24VDC (0.32A), 48" lead wire, locking extended manual operator, grommet with MOV (electric connection).
- (8) Nitrogen gas pressure controller (Love Controls 26155-934): 4-20mA input, two 4-digit LED displays, +/-0.25% accuracy, two control outputs (4-20mA), PID and Fuzzy logic controls, 24VDC/50mA loop power supply, 115VAC power, nonvolatile memory (no battery required).

3.1.3 Installation

In 9/97, D. Sorenson's crew dismantled electric connections of the old DI plant. In 1/98, the two main enclosures were mounted onto the floor. In 2/98, 115VAC wiring was done for the two main enclosures, the liquid level indicator and the three electric solenoids. 480VAC wiring was done for all the motor starters. Cable trays and skeleton conduit were installed. In 3/98, the cable pull for the US Filter system was 97% completed. In the Fermilab main enclosure, Sixtrak modules, power supplies, wire ducts and terminal

blocks were installed, and the wiring among them was completed. In 4/98, the cable termination for devices/sensors was 90% completed. A considerable amount of time was used to connect high pressure air lines to valve actuators/solenoids. In 5/98, the cable termination for Flow (4), Pressure (15) and Resistivity (4) instruments was completed. On the Fermilab system, all the valves (32) were operated, and their status was properly read. On the US Filter system, all the valves (54) were properly operated.

We used several different types of cables -- (a) Belden #8761 for general use, (b) Belden #8719 for high voltage and 24VDC distribution, (c) Belden #9947 for digital I/O between US Filter and Fermilab systems, (d) Alpha 5610B2001 for Peek flowmeters, and (e) Belden #9463 (A-B 1770-CD) for Remote I/O.

To provide protection from dust, oil and water, we used Nema Type 4 or 12 enclosures and junction boxes, and we used liquid-tight conduit and connectors throughout the systems in CUB.

3.1.4 Manual Override on Valves

Each of the valve actuator solenoids is in series with a toggle switch, which has three positions (PLC, OFF and 24V). When the switch is at the PLC position, the valve is under the PLC control. When it is at the OFF position, the valve is closed, and when it is at the 24V position, the valve is opened.

3.2 Software

3.2.1 Software Tools

Two main software tools (i.e., Plant Floor and ISaGRAF) have been used to develop the programs for the MI LCW control systems including the CUB Fermilab system.

Plant Floor is a configuration and maintenance tool for Sixtrak I/O systems. Using Plant Floor's windows and menus, one assembles a graphic representation of each I/O system. Configuration choices let him customize each module in a given system. Once a system configuration is complete, the configuration is downloaded to the Gateway module of the system. Plant Floor is also a calibration tool for analog I/O modules, and it provides real-time displays for the maintenance and diagnostics on I/O modules.

The configuration of the CUB Fermilab system (ts13.6pj) is shown in Fig. 1 (panel layout) and Fig. 2 (module list).

ISaGRAF is a comprehensive control programming environment that makes Sixtrak I/O a high performance, yet inexpensive controller. ISaGRAF uses standard industrial PLC programming methodologies for designing powerful applications without the need of high level computer languages. ISaGRAF is created by CJ International of Seyssins, France, and it is sold by Sixnet as a part of the Sixnet software package.

An ISaGRAF project is a collection of individual programs and functions that form a complete control application. Each program controls one particular part of the application. In February 1993, responding to the need for standards to reduce training costs and guarantee portability, the IEC issued the IEC 1131-3 standard: a specification of five PLC languages that can be mixed in the same application. The five languages are (a) Sequential Function Chart (SFC), (b) Function Block Diagram (FBD), (c) Ladder Diagram (LD), (d) Structured Text (ST) and (e) Instruction List (IL).

For further details on ISaGRAF, one should refer to Ref. [1] and Ref. [2].

3.2.2 Device Organization

There are a total of 35 devices (valves and pumps) to manipulate for different

modes of operations and column uses. It is very important to organize the devices in such a way that the program can handle them in the most logical, efficient manner. The devices are divided into three groups (i.e., Mode, Column and Makeup devices). In Table 1, there are 17 valves and 2 pumps to manipulate for eight different modes. In Table 2 (1), there are 12 valves to manipulate for 9 different column uses. In Table 2 (2), there are valves and one pump to manipulate for doing Makeup on the three columns.

Table 3 is a summary of CUB device operations, in which device binary patterns along with hexadecimal representations are shown for 10 modes, 10 column uses and 4 makeups. These device patterns are stored in three arrays in the program, and the patterns are retrieved from there when needed.

3.2.3 Program to Operate Columns

The program to operate the three columns was written in Sequential Chart, and its chart is shown in Fig. 3. The sequential program basically consists of steps (states), transitions (gates) and jumps. While the program is waiting in Step-3, it can go to 8 different branches (i.e., 000, 100, 200, 400, 500, 600, 700 & 800). For example, if TRes2 (MI system resistivity trip) occurs, the program goes through Branch 800 (steps and transitions in 800 numbers) and jumps to Step-408 at the end.

(1) With new MD and CU: On the console, if new MD (mode) and CU (column use) are specified, and if FC2 (new command indication) is sent out, the program passes Gate-9 and goes to Step-10, where it validate the MD/CU combination. If the combination is not valid, the program jumps back to Step-3 via Gate-112. If it is valid, the program goes to Step-13 via Gate-12. If it is for Column-1, it goes to Step-18 via Gate-17. If USE1 (Column-1 in use) is true, the program jumps to Step-29 via Gate-120. If USE1 is false, it goes to Step-21 via Gate-20. In Step-21, the program requests Column-1 from the US Filter system. If the US Filter system does not return GRN1 (Column-1 grant) in 140 sec with some reason, the program sets TOT1 (time-out on Column-1 request) true. If TOT1 is true, the program eventually returns to Step-3 via Gate-125. If USE1 is true, and if TOT1 is false, the program goes to Step-29 via Gate-25. In Step-29, the program reads device patterns from the three arrays and properly sets the devices for the specified mode, column use and makeup, and it returns to Step-3 via Gate-31. What has been said for Column-1 is also applicable to Column-2 (via Gate-217) and Column-3 (via Gate-417).

(2) With MD=9/CU=10: If MD=9 and CU=10 are specified on the console, the program passes Gate-105, it closes all the valves, it turns off all the pumps, and it clears USE<1:3>.

(3) With OFL1 or RGN1: If OFL1 (Column-1 in offline) or RGN1 (Column-1 in Regeneration) is set true by the US Filter system, the program passes Gate-205 and goes to Step-206, where it puts Column-1 in Idle and resets USE1. What has been said for Column-1 is also applicable to Column-2 (via Gate-405) and Column-3 (via Gate-505).

(4) With TS99SS or IS99SS: If TS99SS (status on all Tev LCW pumps stopped) or IS99SS (MI equivalent) becomes true, the program passes Gate-605 and goes to Step-606. In this step, it puts a column or two in Int. Recir. (Internal Recirculation). For Tev, using R1ACL (1st column for Tev) and R1BCL (2nd column for Tev), which have been already determined in Step-3, the program works on proper columns. For MI, it uses R2CL (column for MI).

(5) With TRes1: If TRes1 (Tev resistivity trip) becomes true, the program passes Gate-705 and goes to Step-706, where it determines which columns are bad. It then moves on to Step-708, where it puts a good column or two in Int. Recir., and where it puts a bad column or two in Idle. For two column operations, there are four cases (two columns are bad, 1st column is bad, 2nd column is bad, and two columns are good.). For one column operations, there are two cases (the column is bad, and the column is good.).

(6) With TRes2: If TRes2 (MI resistivity trip) becomes true, the program passes Gate-805

and goes to Step-806, where it determines whether the column is good or bad. It then moves on to Step-808, where it puts a bad column in Idle, or where it puts a good column in Int. Recir..

3.2.4 Overpressure Interlocks

(1) For the Tevatron LCW system, when P02 (LCW inlet regulated pressure) becomes higher than a specified high limit, PV60 (LCW inlet valve) is forced to be closed. When the condition comes into existence, TP02 (P02 trip) is set, and it is cleared by CL_TP02.

(2) For the MI LCW system, when P72 (LCW inlet regulated pressure) becomes higher than a specified high limit, PV29 (LCW inlet valve) is forced to be closed. When the condition comes into existence, TP72 (P72 trip) is set, and it is cleared by CL_TP72.

3.2.5 Delays on Valve Operations

(1) For an MI operation, when TRes2 occurs, and if the column is bad, it is put in Idle. However, there is a certain sequence to be observed (i.e., V85 is opened first, 5 sec delay is given, and then V28, V29, V<142:144> & V<511:531> are closed.

(2) For an MI operation, when the operation is changed from Int. Recir. to Normal, V35 is closed first, 5 sec delay is given, V28 & V29 are opened, and V85 is closed.

The above timings are implemented in the 'Update' program.

3.3 Communication between Nodes

If the CUB Fermilab system detects a status that all the LCW pumps are off on the Tev or MI system, it switches from the current mode to the Int. Recir. mode. For Tev, when the Tev front-end detects the status, it writes a bit to a C181 CAMAC module (Tev Crate \$DF, Slot-9). The Sixtrak Gateway (Node14) located in MCR (Main Control Room) then reads the bit on a DI (digital input) module, which is connected to the C181 module via a cable. The CUB Gateway (Node13) eventually reads the bit and takes a proper action.

For MI, the MI-60 Magnet Gateway (Node04) has the equivalent status on the MI LCW pumps. The CUB Gateway reads the status bit and takes appropriate action.

3.4 Console Pages

The I56 page and its subpages show all the activities of the MI LCW system including CUB. Fig. 4 shows a view of the CUB Fermilab system. The figure shows the status on pumps, columns and valves, and it shows analog readings (pressures, flows, resistivities and a level). At the right-top of the figure, the operator specifies the mode and usage for a column and executes them by clicking on FC2 under Resets. At the right-bottom, the operator specifies trip limits and monitors trip flags. Fig. 5 is a graphic view of the CUB Fermilab system.

4. Acknowledgments

I would like to take this opportunity to thank D. Still and S. Gordon for their excellent work on the project. Without their help, we could not have completed the project in time.

D. Still contributed a great deal in getting the electric connections of the old DI plant dismantled and in getting new things done (enclosures, 115/480VAC wiring, cable

trays, conduit, cable pull, etc. ---).

S. Gordon did excellent jobs in installing the Sixtrak system, the solenoid boxes and different types of instruments. He then pulled cables and terminated them for a variety of devices and sensors. He also connected high pressure air lines to valve actuators/solenoids and made them operational.

I can't list all the things that the two people have done in this limited space, and I may have missed some of the things that they have done.

References

- [1] ISaGRAF Version 3.00 User's Guide, CJ International, 1955.
- [2] Main Injector LCW Control Systems, K. C. Seino, 2/99.
- [3] CUB DI Column Control Systems, K. C. Seino, 2/99.
- [4] MI-60 Magnet LCW System Operations (Program Description), K. Seino, 2/99.
- [5] MI-10 LCW System Operations (Program Description), K. Seino, 2/99.
- [6] MI-52 LCW System Operations (Program Description), K. Seino, 2/99.
- [7] CUB DI Plant LCW System Operations (Program Description), K. Seino, 2/99.
- [8] PLC-500 A. I. Series Software Reference, Rockwell Software Inc., 1996.
- [9] PanelMate Power Series Configuration Editor User's Guide, Cutler-Hammer IDT, Inc., 1996.

Fig. 1 Module Panel Layout

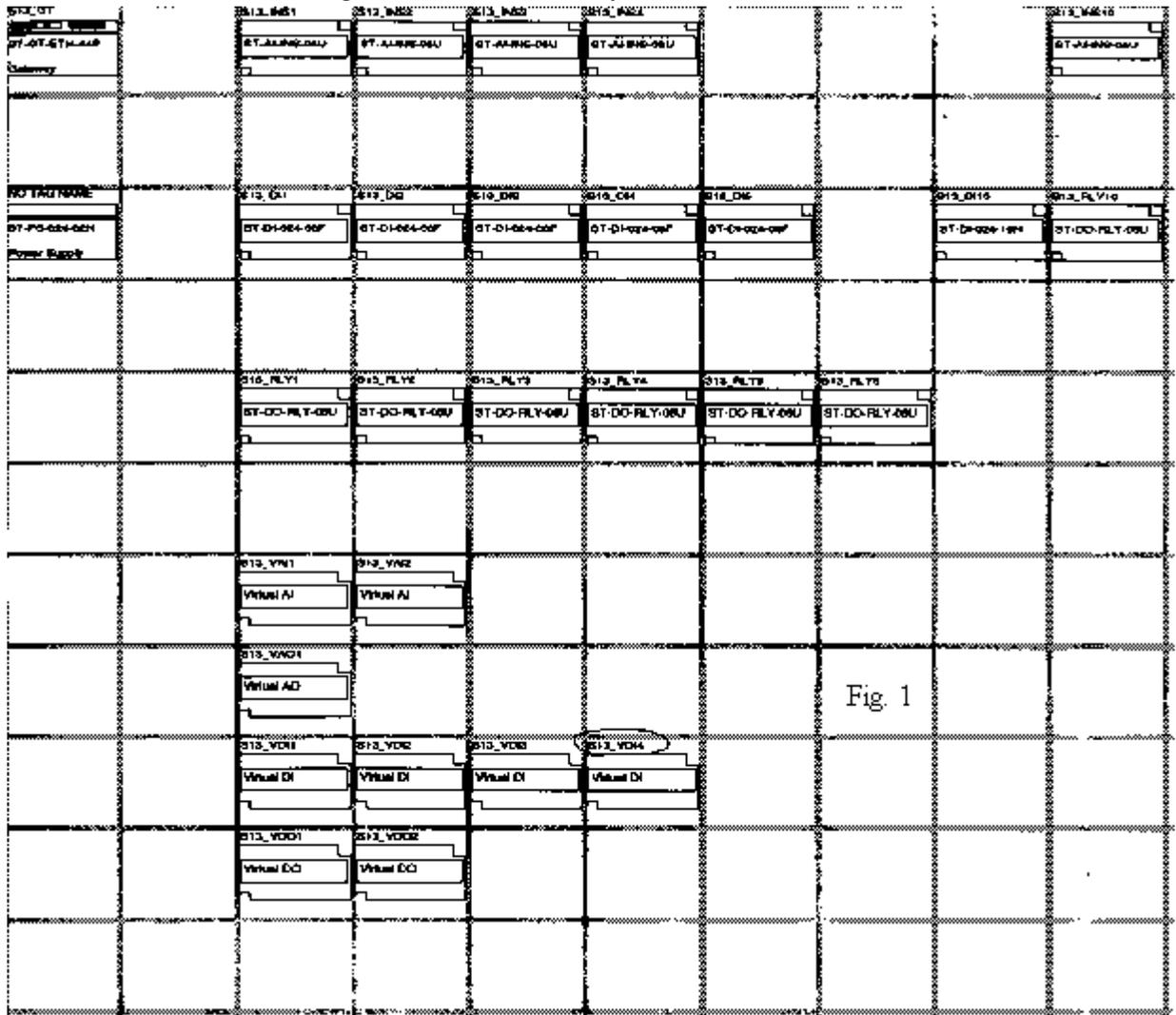


Table 3 – CUB Device Operations

1. Mode Devices

17	13	9	5	1	Hex	Mode	MD	Remarks
0xx0	x0xx	ooo o	1x11	xxxx	0oob o	MI Normal	1	
1xx1	x0xx	1111	0x00	xxxx	9ofoo	MI Int Recir	2	
0xx0	x0xx	ooo o	1x01	xxxx	ooo9 o	MI Makeup	3	
0xx1	x0xx	ooo o	0x00	xxxx	1ooo o	MI Reset	4	
xx0x	1x10	xxxx	x0xx	0100	0aoo 4	MR Normal	5	
xx1x	0x01	xxxx	x1xx	1011	21o4b	MR Int Recir	6	
xx0x	1x10	xxxx	x0xx	1100	0aoo c	MR Makeup	7	
xx0x	0x00	xxxx	x0xx	ooo o	oooo o	MR Reset	8	
0x00	ooo o	ooo o	ooo o	ooo o	oooo o	Mode Reset	9	
xxxx	xxxx	xxxx	xxxx	xxxx	xxxxx	CIm in Idle	10	

2. Column Valves

(*) 9	5	1	Hex	Column Use	CU	Remarks
xx0x	x0xx	0xx0	ooo	CIm1 Idle	1	
xx1x	x1xx	1xx1	249	CIm1 MI	2	
xx1x	x1xx	0xx0	240	CIm1 MR	3	
x0xx	0xx0	xx0x	ooo	CIm2 Idle	4	
x1xx	1xx1	xx1x	492	CIm2 MI	5	
x1xx	1xx0	xx0x	480	CIm2 MR	6	
0xx0	xx0x	x0xx	ooo	CIm3 Idle	7	
1xx1	xx1x	x1xx	924	CIm3 MI	8	
1xx1	xx0x	x0xx	900	CIm3 MR	9	
ooo o	ooo o	ooo o	ooo	CIm Reset	10	

Notes: (*) The valves<10:12> above are closed for Makeup.

3. Makeup Devices

1	Hex	Makeup	MK	Remarks
1001	9	CIm1 Makeup	1	
1010	a	CIm2 Makeup	2	
1100	c	CIm3 Makeup	3	
ooo o	o	Makeup Reset	4	

PROJECT: TS13.6PJ
STATION 13: (S13)GT

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MODULE TAG NAME	MODULE TYPE	I/O RANGE	SCAN TIME
*****	*****	*****	*****
S13_GT	ST-GT-ETH-44P		
S13_DI1	ST-DI-024-08F	X0-7	100
S13_DI2	ST-DI-024-08F	X8-15	100
S13_DI3	ST-DI-024-08F	X16-23	100
S13_DI4	ST-DI-024-08F	X24-31	100
S13_DI5	ST-DI-024-08F	X32-39	100
S13_DI10	ST-DI-024-16H	X40-55	100
S13_VDI1	Virtual DI	X56-63	100
S13_VDI2	Virtual DI	X64-71	100
S13_VDI3	Virtual DI	X72-79	100
S13_VDI4	Virtual DI	X80-87	100
S13_RLY1	ST-DO-RLY-06U	Y0-5	100
S13_RLY2	ST-DO-RLY-06U	Y8-13	100
S13_RLY3	ST-DO-RLY-06U	Y16-21	100
S13_RLY4	ST-DO-RLY-06U	Y24-29	100
S13_RLY5	ST-DO-RLY-06U	Y32-37	100
S13_RLY6	ST-DO-RLY-06U	Y40-45	100
S13_RLY10	ST-DO-RLY-06U	Y48-53	100
S13_VDO1	Virtual DO	Y56-63	100
S13_VDO2	Virtual DO	Y64-71	100
S13_INS1	ST-AI-INS-08U	AX0-7	1000
S13_INS2	ST-AI-INS-08U	AX8-15	1000
S13_INS3	ST-AI-INS-08U	AX16-23	1000
S13_INS4	ST-AI-INS-08U	AX24-31	1000
S13_INS10	ST-AI-INS-08U	AX32-39	1000
S13_VAI1	Virtual AI	AX40-47	100
S13_VAI2	Virtual AI	AX48-55	100
S13_VAO1	Virtual AO	AY8-15	100

Fig. 2

Fig. 2 Module List

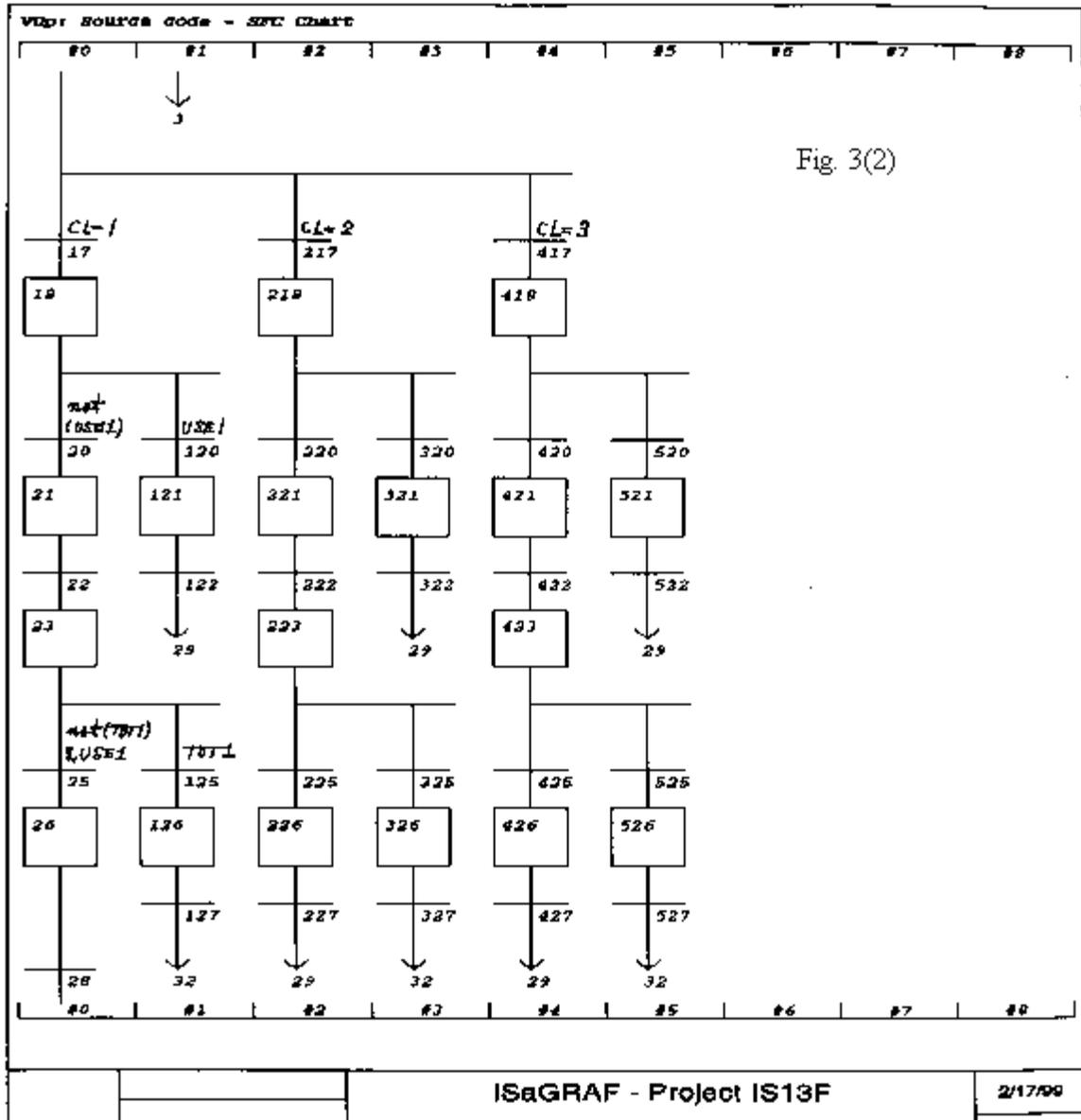


Fig. 3(2) Sequential Program (is13B) Part 2

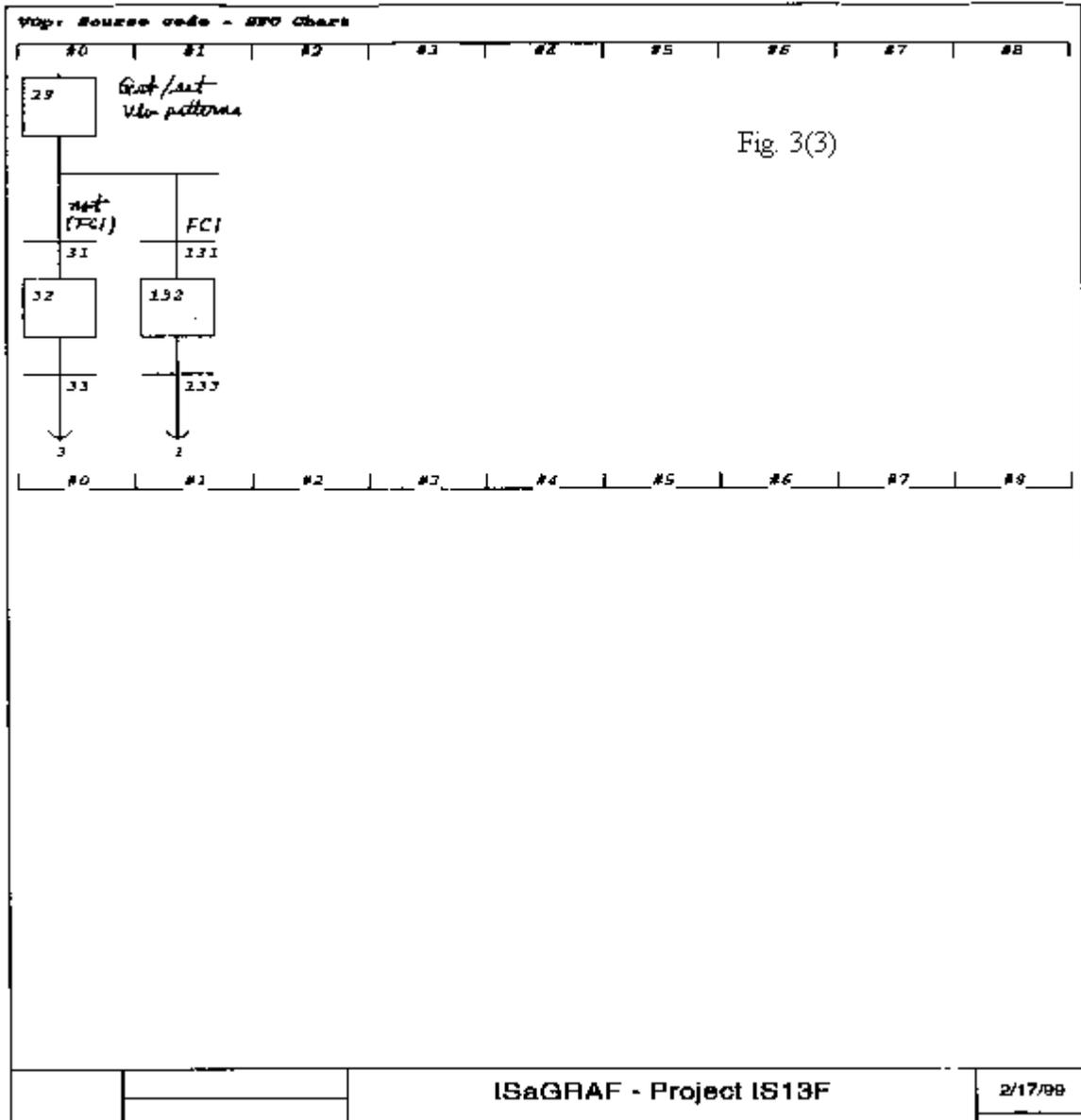


Fig. 3(3) Sequential Program (is13B) Part 3

Fig 5

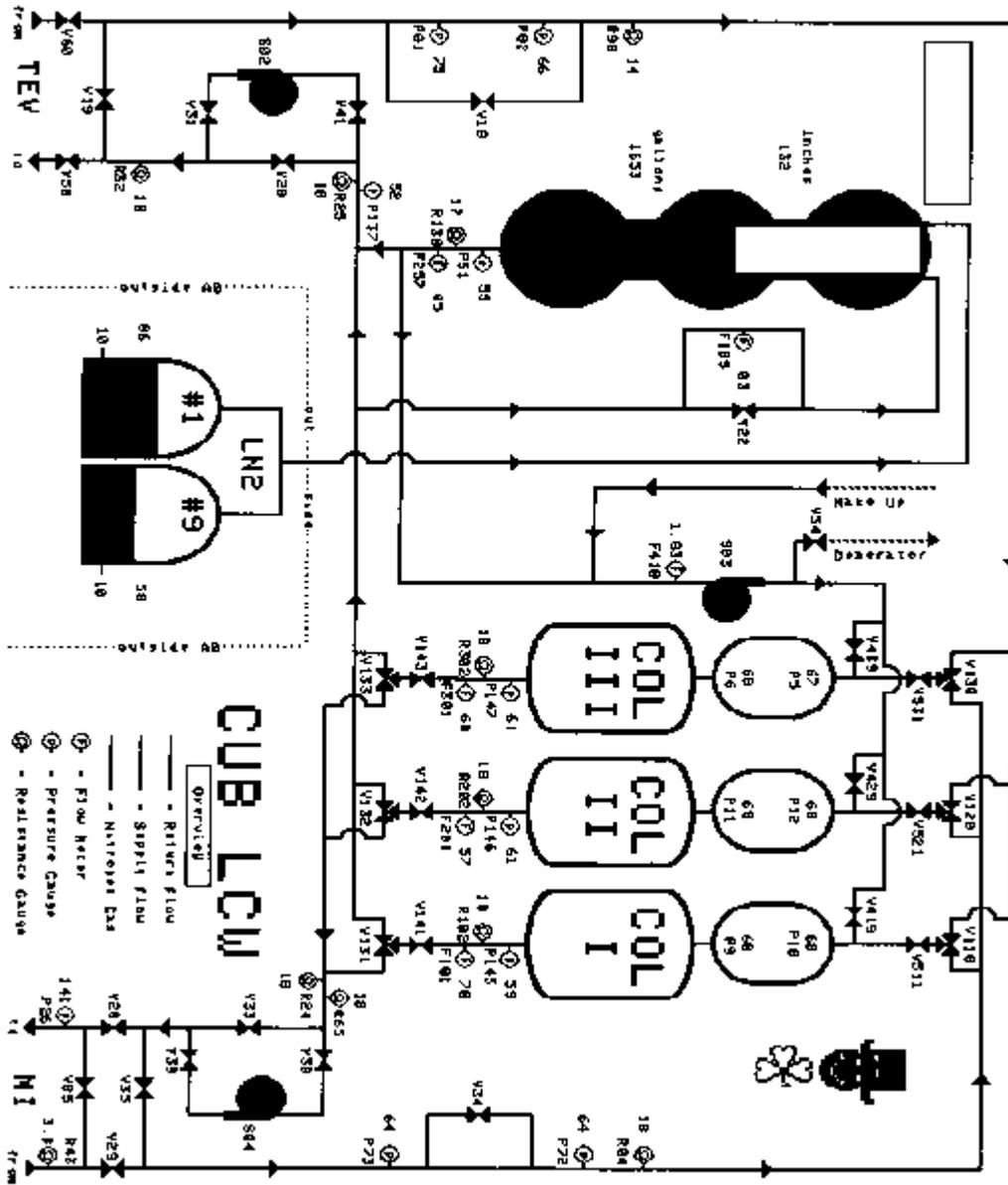


Fig. 5 Graphic View of CUB Fermilab System