Control System Design for the Hall A Polarized ^{3}He Target

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1 Introduction

An optically-pumped high-pressure polarized ^{3}He target will be installed in Hall A at Jefferson Lab in the summer of 1998 in preparation for experiment E94-010. The target will become part of the Hall A standard equipment.

This document describes the conceptual design of the control system for the target. The control system encompasses actual controls, signal monitoring, and related software. It can be divided into six subsystems: laser, NMR polarimetry, EPR polarimetry, target motion, reference cell, and temperature control & measurement.

The individual subsystems have been developed at different institutions and can in principle be operated independently of each other, with the exception of the EPR system which requires some elements of the NMR system. As a result, the existing control software is at present rather modular. Integrated software will be developed as time permits. The priority is to have a working system available by late August 1998.

Most of the target electronics will be installed in general purpose racks on the second floor of the counting house ("upstairs"). One advantage of this scheme is easy accessibility of the components. In addition, the components are not exposed to damaging radiation. The remaining control system hardware (such as sensors, motors, pre-amplifiers, etc.) will be mounted either on the target or in close proximity ("downstairs"). The laser electronics will be located inside the laser shielding hut downstairs.

The upstairs electronics will be connected with the target components in the hall by approximately 120 meter (395 ft.) long cables that will run in the cable trays in the personnel access tunnel. Small-amplitude RF signals will be carried by existing RG-213 coaxial cables. Digital control and low-current DC signals require twisted-pair cables that are not yet installed. In addition, several high-current low-voltage (12 A/36 V) cables are needed to power the Helmholtz coils that generate the magnetic holding field. These cables have also not yet been put in place.

A dedicated PowerPC model 800/80AV Macintosh computer running Labview data acquisition software will be used for target control. This computer will be set up next to the electronics upstairs and will handle data acquisition for the NMR and EPR polarimetry subsystems. Communication between the electronics and the computer upstairs will be via GPIB. Essential information from the Macintosh system will be injected into the laboratory standard EPICS data stream, using GPIB to pass data between the Macintosh and EPICS. The main motivation for employing the Macintosh is that the hardware already exists and the currently existing software runs on this platform.

A second type of DAQ will be used for analog data, TTL-level control signals, and serial communications downstairs, primarily for the laser, reference cell, and temperature measurement subsystems. This system will be based entirely on EPICS. I/O modules in a general purpose VME crate in rack 1H75B12 close to the target downstairs will provide the data acquisition interface. The VME crate belongs to the Hall A beamline system and is currently largely unused. Javier Gomez has approved its use for the ^{3}He experiment.

All data from the EPICS-based DAQ as well as important status information from the Macintosh will be displayed on Graphical User Interfaces (GUIs) on an X Windows workstation in the Counting Room. The GUIs will be written in MEDM and will run on the Hall A Control (`hac`) HP workstation. They will require only modest computing power and so should be able to run well on `hac`, which is a relatively slow machine. If necessary, `hac` can be upgraded with a second CPU, which has already been purchased and simply needs to be installed and configured.

To perform NMR and EPR measurements and to control the reference cell system, shift personnel have to go upstairs to the Macintosh computer. Since these measurements will be carried out only once every several hours, the inconvenience is acceptable. In the long term, the Macintosh will be replaced with a fully EPICS-based DAQ system upstairs. At that point, full control of all target subsystems will be possible via X Windows GUIs.

Each target subsystem is described in detail in the following sections.

2 Laser Subsystem

The target achieves nuclear polarization of ^{3}He via direct optical pumping of Rb vapor and subsequent spin-exchange between Rb and ^{3}He. Seven diode lasers (OptoPower OPC-D030-FCPS), delivering up to 30W of 795nm light each, provide

Function/Signal	C/M	Signal type
Laser on/off	C	TTL
Set/clear ready mode	C	TTL
Set/clear standby mode	C	TTL
Diode Current	M	analog 0–1.75 V
Diode Temperature	M	$\approx$ 350 mV, 10 mV/°C

Table 1: Remote control (C) and monitoring (M) signals for the laser subsystem.

circularly polarized light for the optical pumping process. Four lasers pump the longitudinal spin direction (target spin parallel to the electron beam), while the remaining three pump the transverse spin direction. Longitudinal and transverse mode are mutually exclusive. For the longitudinal mode, the laser light helicity can be quickly reversed by remote control to flip the target spin during data taking.

2.1 Laser Control

Each laser consists of a laser box that holds the laser diode arrays, associated electronics, and power supply, and a control box which permits local control. The laser box accepts TTL signals from the control box and provides analog signals for status monitoring via a DB25 interface connector.

We need local control of the lasers as well as remote control and monitoring from the counting house of selected signals, which are listed in Table 1. We plan to install a breakout box in the cable between the control and laser boxes to pick up the signals. This allows full local control via the control box at all times, and remote operation is possible without any reconfiguration. A diagram of the laser electronics and wiring is shown as part of figure 1.

2.2 Light Helicity Control

To achieve the desired circular polarization, the laser light is passed through a polarizing beamsplitter cube followed by a quarter-wave plate. Since the light emerging from the diodes is essentially unpolarized, it is necessary to use both linear polarization components from the diodes to take full advantage of the available laser power. Therefore, two beams are formed: The direct beam passes straight through the beamsplitter cube and a quarter-wave plate. The other component, reflected sideways by the beamsplitter cube, is reflected back toward the target by a mirror and passes through a second quarter-wave plate. This indirect beam impinges onto the target at an angle that has to be kept small to avoid depolarizing reflections from the target cell surface.

To reverse the light helicity by remote control, a half-wave plate can be moved into each beam using a motorized translator stage (Daedal 404XR with Compumotor ZETA driver). A single stage with a single motor is sufficient to move simultaneously the half-wave plates for all four lasers pumping the longitudinal direction.

The translator motor will be remotely controlled via serial communications. A 16-channel communications card is available in the general purpose VME crate in the hall.

2.3 Electronics design

Figure 1 shows a schematic of the laser control electronics.

The laser system requires 21 TTL output channels for control and 14 analog input channels for monitoring. The TTL signals will be provided by a standard Industry Pack (IP) module (Greenspring model IP-DIGITAL 48) which will be installed in the existing General Purpose VME crate in the Hall. The crate currently has four unused IP slots on the Motorola CPU card, one of which will be used for the laser control card. (If additional IP slots are needed, we can install an IP carrier VME card which provides four additional slots.)

An HP E1313A 16-bit ADC installed in the VME crate monitors the analog signals from the laser.

Simple twisted-pair cables (approximate length 20 meters) will be run between the crate and the laser hut. The IP and VME modules accept 50-conductor flat ribbon cable that can be interfaced to the twisted-pairs using simple converters installed in a breakout box next to the VME crate.

2.4 Software

To integrate the Greenspring IP module into EPICS, it is necessary to write a driver for the module. Yves has extensive experience in writing EPICS software and estimates that he will need about 2 weeks per driver.

Once the drivers are written, building a MEDM laser control GUI is a straightforward task which will take an expert about a week.

3 NMR Polarimetry Subsystem

The NMR system allows non-destructive measurement of the ^{3}He nuclear polarization. The target polarization is reversed via adiabatic fast passage (AFP) NMR, and the transient magnetization signal induced by this spin flip is detected by pickup coils around the target. The amplitude of the transition signal is proportional to the

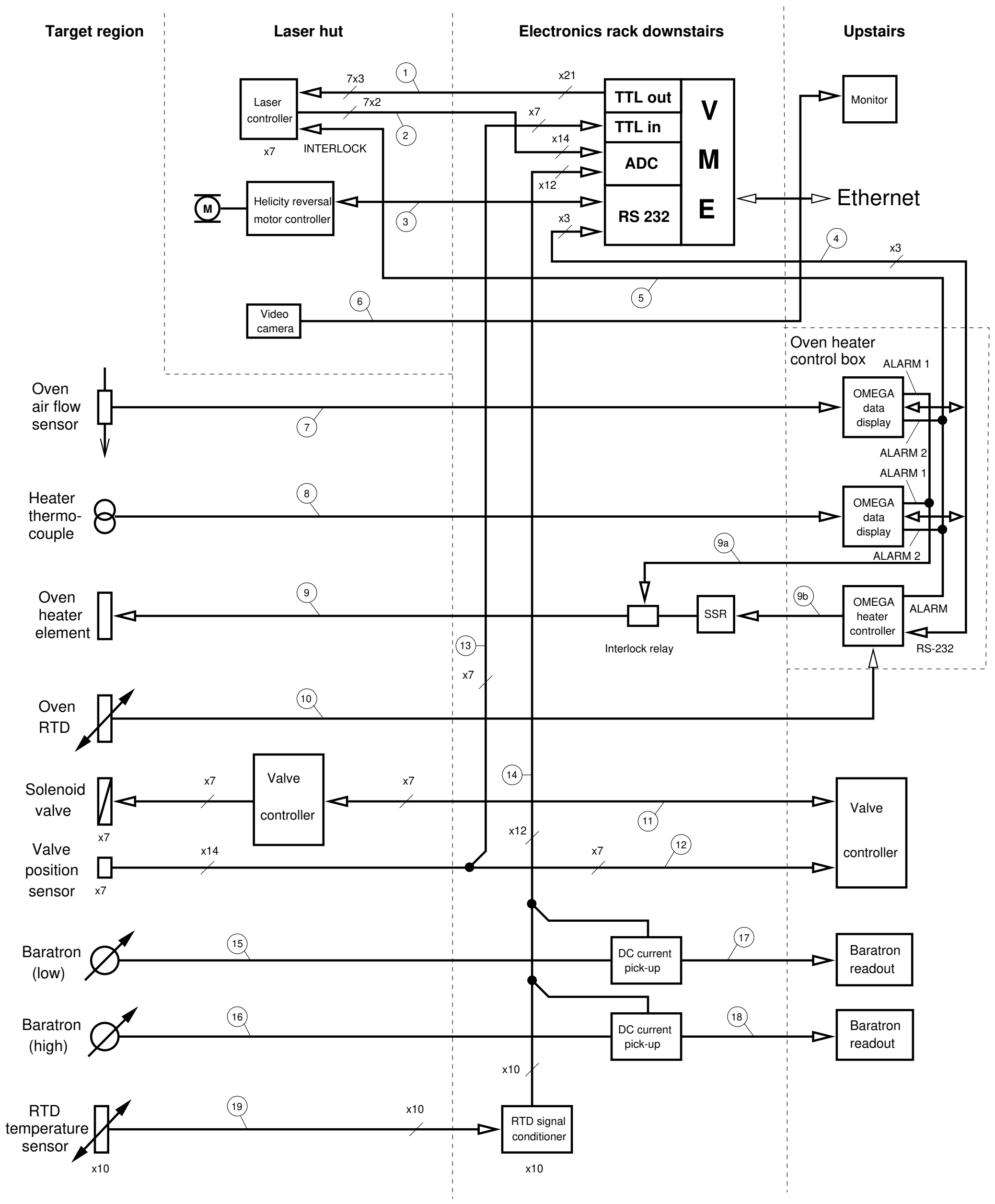

Figure 1: Schematic diagram of the laser, temperature control, and reference cell electronics. The circled numbers correspond to the cable list given on pages 16–18.

Signal	Frequency	Amplitude	Current
Pick-up coil (after pre-amp)	100 kHz	mV	μA
RF drive coil	100 kHz	??	1.2 A
Holding field coils	DC	36 V	12 A

Table 2: Specifications of the NMR signals running between the target and the electronics.

target polarization. The polarization is usually flipped back to the original state after such a measurement. Optical pumping is disabled during AFP-NMR. The setup will allow NMR measurements for the longitudinal target polarization direction.

3.1 NMR Equipment Setup

A schematic of the electronics used for AFP-NMR is shown in Figure 2. An RF generator drives the RF coils around the target that induce the AFP spin flip. A pre-amplifier conditions the signal from the pick-up coils which is detected by a lock-in amplifier referenced to the AFP RF signal. Optionally, crosstalk between the RF and pick-up coils can be cancelled by feeding a compensating signal into the second lock-in amplifier input. This signal is appropriately attenuated and phase-shifted by an A-ϕ circuit. To sweep the nuclear spins through the Larmor resonance, the main target holding field is ramped at a fixed rate by stepping the (longitudinal) coil power supply.

The RF generator, lock-in amplifier, and main coil power supply are controlled via GPIB from a Macintosh computer running Labview. Most of the components will be located in general purpose electronics racks on the second floor of the counting house, as indicated in Figure 2. The control computer will be in the same room as the electronics. Only the pick-up coil pre-amplifier and signal conditioner will be installed downstairs near the target.

A number of signals must be transmitted between the upstairs electronics and the target downstairs. The signal specifications are detailed in Table 2. Small-amplitude RF signals can be sent via already existing RG213 low-loss coaxial cables. This includes the drive signal for the RF coils. Power for the holding field coils must be run through high-current cables which are not yet in place.

3.2 Software

The NMR control software is written in Labview and is largely complete. The code will run on the Macintosh computer upstairs and will communicate with the

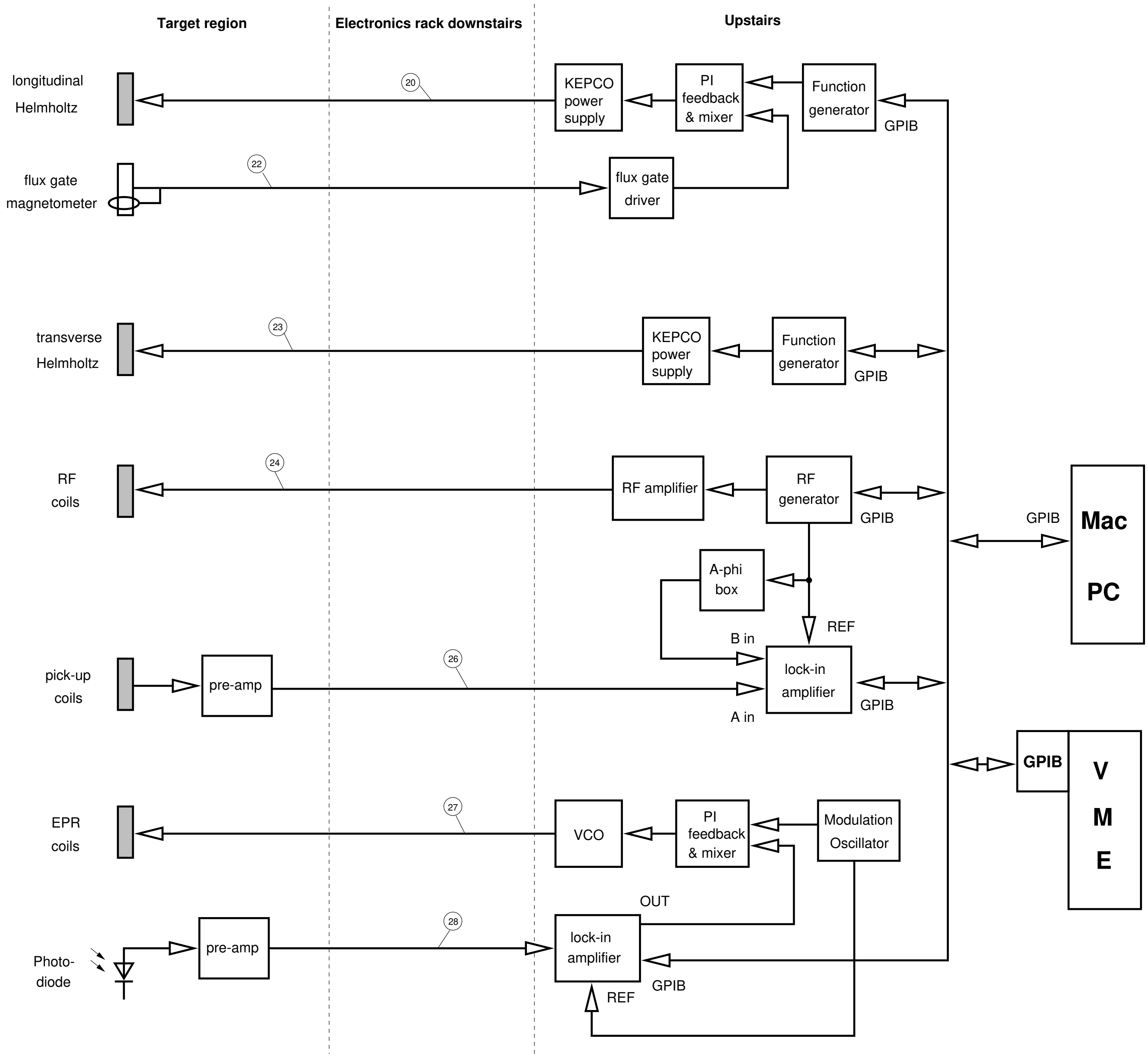

Figure 2: Schematic diagram of the NMR and EPR electronics. The circled numbers correspond to the cable list given on pages 16–18.

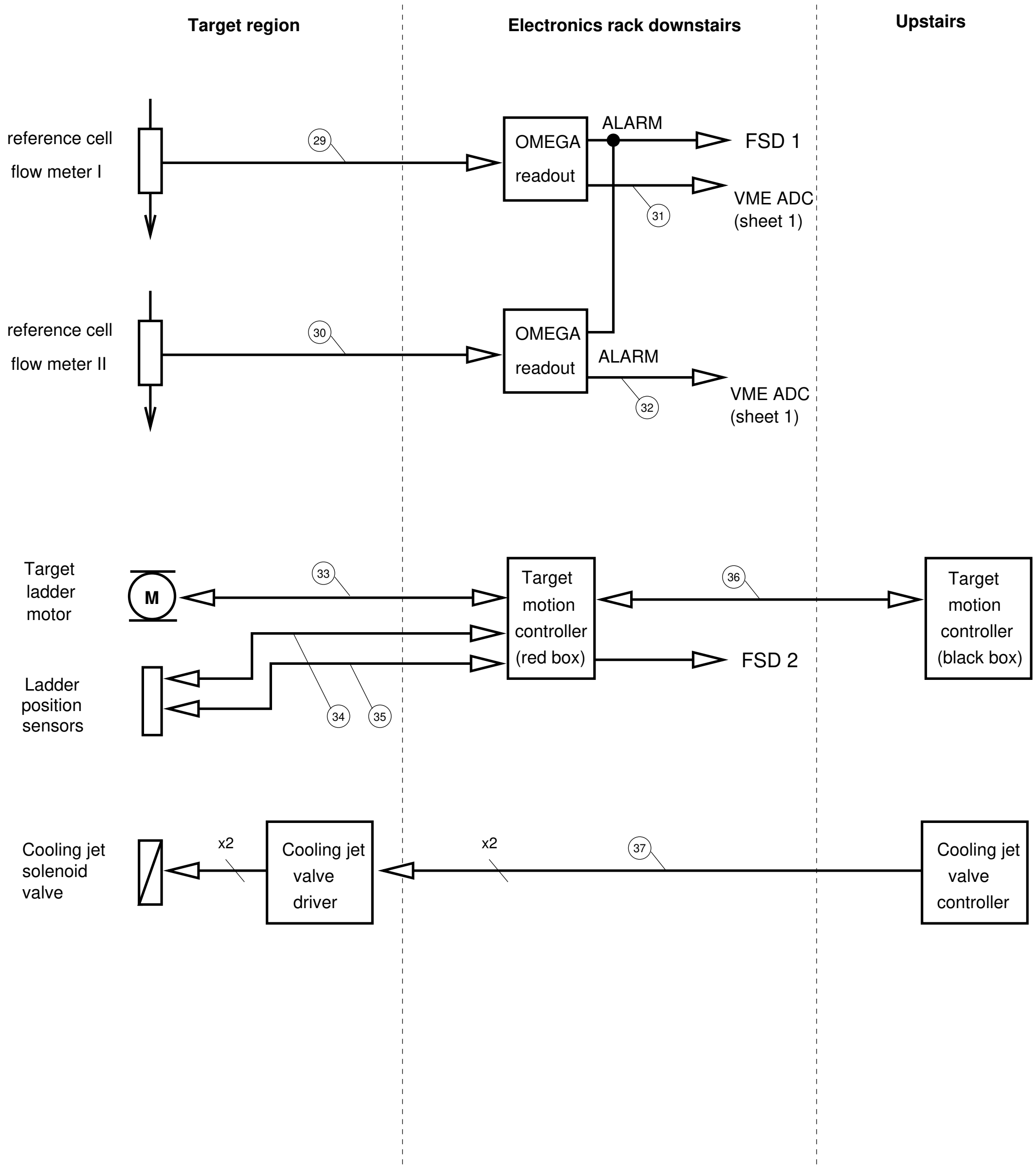

Figure 3: Schematic diagram of the cooling jet and target motion control electronics. The circled numbers correspond to the cable list given on pages 16–18.

hardware via the GPIB interface installed in the computer.

The NMR data should also be available to the standard EPICS system so that they can be recorded on tape. To this end, a GPIB interface will be installed in a VME crate in the upstairs counting house. This VME crate will be supplied by Clermont-Ferrand. The Macintosh will periodically send target polarization data and other relevant information to this GPIB device. EPICS software will read these data and make them available for general processing and display. The EPICS driver for the GPIB card already exists and requires only minor modifications. Some additional software, such as a GUI, must be developed, but this is a straightforward task expected to take less than a week. This work will be done by Yves.

4 EPR Polarimetry Subsystem

EPR polarimetry detects the shift of the Rb Zeeman resonance due to the magnetic field created by the polarized ^{3}He. These shifts are rather large (typ. 0.25%) and easy to detect. To isolate the shift due to ^{3}He, the ^{3}He polarization is reversed via AFP and the difference in the EPR frequency between the two polarization states is measured. As with the NMR system, EPR capabilities are implemented for longitudinal target polarization only.

The following description of the EPR electronics reflects our current plan for setting up the system. Details might need to be modified during the testing phase of the equipment.

4.1 Electronics design

Figure 2 shows the equipment setup for EPR measurements. The RF field at the EPR resonance is created by a small coil mounted on the side of the pumping cell. It is driven by a Wavetek Model 80 voltage-controlled oscillator (VCO). The VCO is frequency-modulated with a 200 Hz sinusoidal signal from a modulation generator. The fluorescence from the cell is passed through a D_2 filter and is detected by a photodiode. The photodiode signal is boosted by a pre-amplifier and measured by a lock-in amplifier. The lock-in is referenced to the VCO modulation frequency so that the measured signal is proportional to the *derivative* of the EPR line shape. A home-built proportional-integral (PI) feedback system and mixer adjust the DC level at the VCO input to keep the lock-in signal zero, *i.e.* at the center of the line. The EPR frequency is measured at the VCO output with an HP 5334B frequency counter. The counter averages over 100 cycles of the input signal to eliminate the effect of the frequency modulation.

To determine the EPR frequency accurately, it is necessary to keep the magnetic holding field stable to one part in 10^5. To this end, a flux-gate magnetometer is

Signal	Frequency	Amplitude	Current
Photodiode (after pre-amp)	200 Hz	mV	μA
EPR coil	6 MHz	5 V(?)	500 mA(?)
Flux-gate magnetometer	DC	??	??
RF drive coil[1]	100 kHz	??	1.2 A
Holding field coils[1]	DC	36 V	12 A

Table 3: Specifications of the EPR signals running between the target and the electronics.

placed near the target. The magnetometer output controls the holding field power supply via a PI feedback circuit. A small compensating coil driven by a stable constant current source cancels part of the holding field to keep the field measured by the magnetometer within its measuring range of ± 5 G.

The instruments are controlled and read out via GPIB from a Macintosh computer. This computer is the same as that used for NMR. The EPR electronics will be upstairs in the same location as the NMR setup, except for the pre-amplifier for the photodiode which will be downstairs.

The EPR signals that must be transmitted between the Hall and the electronics upstairs are specified in Table 3. Existing RG213 cabling can be used for all small-amplitude signals. The high currents required to drive the Helmholtz coils require additional cabling as described in section 3.1.

The EPR hardware orders have arrived and the equipment is currently being tested at Jefferson Lab.

4.2 Software

As with the NMR system, the EPR software will be written in Labview and will run on the target control Macintosh. Communication between the Macintosh and the instruments will be via GPIB. Some code from the SLAC experiments exists, but is not based on Labview and therefore must be converted. Work on this conversion has started at Princeton. Parallel software development will be done at Jefferson Lab once the electronics has been set up.

The interface between the EPICS and the EPR system will be exactly the same as with the NMR system. It will not require any additional work beyond that described in section 3.2.

[1] Shared with NMR

5 Reference Cell Gas Subsystem

The purpose of the reference cell system is to provide an indirect measurement of the target thickness. A direct measurement of the thickness of the actual polarized ^{3}He gas is difficult because the gas pressure cannot be determined easily. To measure the target thickness, the reference cell is moved into the target position and filled with ^{3}He gas. The ^{3}He pressure is adjusted such that the scattering rate from the reference target equals that from the actual polarized target. A Baratron gauge allows precise determination of the gas pressure. Five RTD sensors attached to the cell provide temperature information (see secion 6.1).

5.1 Control System Design

The reference cell system consists of a remotely controlled gas manifold with a high-pressure nitrogen and a ^{3}He supply bottle and two Baratron pressure transducers, as well as the reference cell proper. Seven pneumatic valves facilitate remote operation. The valves are driven by compressed air of approx. 80 psi pressure, which is available in the Hall. The air flow to the valves is controlled with solenoid valves. Microswitches mounted on the air actuators allow remote position readback.

The solenoid valves are controlled manually from a custom-built control device which will be located in the upstairs counting house. LEDs display the valve status. Seven logic signals (TTL or similar) are sent from the upstairs control electronics via twisted-pair cable to the gas system near the target. Another custom-built device converts the logic signals and drives the solenoid valves.

Two Baratron power supply and readout instruments will be installed upstairs and connected to the Baratron transducers downstairs via 100 meters of twisted-pair cable. The Baratrons have 4-20 mA current outputs. The current signals of the Baratron are passed through current converter modules (Acromag model A5B32-01). These modules use a precision resistor of 20 Ohms to convert current to voltage. They provide signal isolation and sophisticated filtering. The output of the modules is read via EPICS by an HP E1313A 16-bit ADC in the general purpose VME crate. The total resistance of the Baratron current loops (approx. 220 meters of cable) must not exceed 400 Ohms.

An electronics rack will be installed next to the laser hut behind a radiation shielding wall to hold the reference cell electronics and other components. The solenoid valve driver box will be put here. In addition, a 19 in. backplane (Acromag model ABP01 with power supply AXPRT003) will be installed in this rack to hold the current conversion modules as well as the RTD input modules used in the temperature measurement system (see section 6.1). The backplane has 16 slots. Two will be used for the current converters and 12 for the RTD input modules, leaving two spare slots. The rack will also hold the target oven heater controller (see section 6.2).

5.2 Software

While the valve control is entirely manual, the two pressure signals will be read by computer and provided in EPICS. The signals will be read by the ADC in the downstairs VME crate using EPICS. Some very basic software must be developed to accomplish this. Minimal work is necessary to include the pressure signals in the target GUI.

6 Temperature Readout and Control Subsystem

6.1 RTD sensors

Important parameters both for the optical pumping process and the target density determination are the temperatures of the target glass cell as well as the reference cell.

Temperatures will be measured by three-wire 100Ω Pt RTD sensors (Omega model F3105) which provide a measurement range of 0-600°C. Seven sensors will be mounted at various points on the target cell and five sensors, on the reference cell.

The RTD signals will be converted to standard 0-5 VDC analog signals using RTD converter modules (Acromag model A5B34-04). In addition to linearization and conversion, these modules also provide signal filtering and isolation. They will be installed in the same 19 in. backplane as the current conversion modules for the reference cell pressure gauges (see secion 5). The analog data are sent to the HP E1313A 16-bit ADC in the general purpose VME crate in the Hall. The ADC is read via EPICS.

6.2 Target oven heater

Optical pumping of Rb vapor requires temperatures of typically 180°C. To achieve these conditions, the optical pumping cell is surrounded by a thermally insulated oven which is heated by a continuous flow of hot air. The oven temperature must be stable within about ± 3°C. Remote control and monitoring of the absolute temperature is desired.

Pressurized air of approx. 15 psi pressure will be provided by a dedicated compressor in the Hall. The air will be heated by an 800 W resistive element driven by standard 120 VAC line voltage. The hot air is then directed into the target oven via heat-resistant plumbing. The heater power will be controlled by a solid state relay

(SSR) (Omega SSR240DC10). The SSR accepts a control signal of 3-32 VDC into 1 kΩ. A process controller (Omega CN77540-C2) monitors the oven temperature using a 100Ω Pt RTD sensor (Omega model F3105) and drives the heater via the SSR to regulate the temperature. The controller will be run in PID mode. It can be programmed and monitored via serial RS-232 communications.

The heater system represents a significant fire hazard and so requires good fail-safe protection. Three interlock conditions can occur: Heater overtemperature, oven overtemperature, and stop of air flow. Each variable will be monitored by a dedicated instrument. An interlock will disable the heater as well as the lasers. Interlocking the lasers is important as the laser light contributes a significant heat load to the target oven.

The oven temperature interlock will be generated by the process controller itself. The heater air flow will be monitored by an air velocity sensor (Omega FMA-905) which is read by a display unit (Omega DP41-E-S2R) that provides an alarm function. Similarly, the heater temperature will be measured by a thermocouple (Omega 5SC-GG-K-30-36) that is read by another display unit (Omega DP41-TC-S2R). The interlock outputs are isolated mechanical relays. All electronics will be installed upstairs; only the various sensors will be downstairs. The termocouple will be connected to the display unit via thermocouple extension wire. The circuit design for the interlock system is shown in figure 4.

6.3 Cooling jet monitoring and interlock

Four cooling jets will provide a continuous flow of helium to cool the target cell windows when beam is present. The gas flow through these jets will be monitored with two flow meters, one each for the cooling jet lines for the short and long target positions. If the flow should stop, a Fast Shutdown (FSD) signal will be generated to shut down the accelerator and prevent damage to the target cell. The flow meters are low-cost meachnical units from McMillan. Their signals will be monitored by two digital readout instruments (Omega DP25) that provide a relay-switched 24 VDC signal for the FSD. This system is the responsibility of the MIT group.

6.4 Software

The driver for the VME ADC and serial communications card already exists. Software development is required for an intermediate-level driver for serial communications with the process controller as well as for the target GUI where the temperatures and heater status will be displayed and the heater can be controlled. As the GUI is written in MEDM, the amount of work is expected to be relatively small.

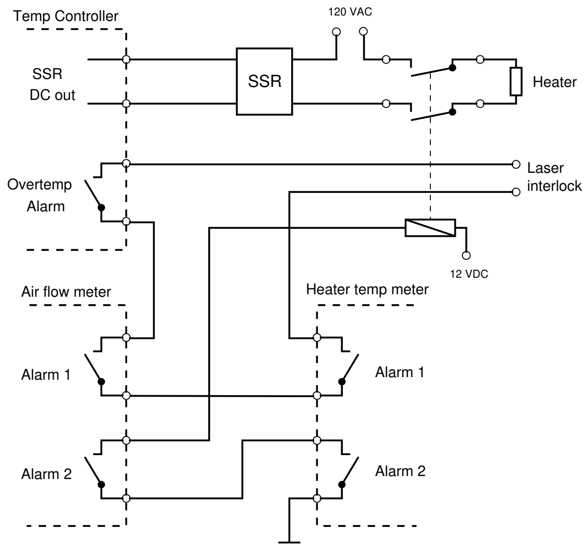

Figure 4: Schematic diagram of the heater interlock circuit. All relays are closed in normal operation and open if an interlock occurs. The two alarms of the air flow and heater temperature meters will be programmed for the same setpoints.

7 Target Motion Subsystem

7.1 Requirements

The polarized ^{3}He target system holds 3 different targets, the actual polarized target cell, a water cell for NMR calibration, and the reference cell. At the same level as the water cell, there will be a solid BeO target for alignment. In addition, there will be an opening above the reference cell that allows the beam to pass through the apparatus undisturbed.

The targets are mounted on a vertical target ladder that can positioned using a stepper motor. The motor must be able to drive the target ladder to five different fixed positions, three of which correspond to the three targets, the fourth to the open (no target) configuration, and the fifth to the position used for NMR measurements where the target cell is surrounded by the pick-up coils. A total vertical motion range of approximately 15 cm is required.

7.2 Mechanical and Electronics Design

We will employ a system originally developed at SLAC in 1994 for experiment E-154. Vertical target motion is provided by a screw-driven cylinder (Industrial

Devices Corporation model S21205A). The cylinder incorporates a 200 step/rev stepper motor with a 1:12 gear providing a position repeatability of about $\pm 15\mu$m at a maximum load of 350 kg. The range of motion is 30.5 cm. Magnetic reed relays are mounted on the cylinder for position feedback. Also, a linear potentiometer is available to indicate the cylinder position.

Motor control and position readback is accomplished by custom-built electronics. With the push of a button, the target can be driven to the positions determined by the reed relays. A digital display indicates the current target position in arbitrary units. The electronics is divided into two parts, a local control box and a remote driver. The local box ("red box") will be placed behind a shielding wall next to the laser hut about 10 meters away from the target, while the remote controller ("black box") will be upstairs near the NMR/EPR electronics and target control computer. Connections between the components will be made with 30 unshielded AWG 18 cables (see cable list).

Currently, the driver electronics does not provide a computer interface. Therefore, target motion will have to be initiated manually from the remote controller upstairs. Since target changes are expected to be infrequent, this inconvenience is acceptable. Computer control will be implemented as time permits.

7.3 Development Work

Several modifications will have to be made to the SLAC electronics. First, the existing system allows indication of only three target positions, but five positions are desirable for the TJNAF target. Two more reed relays will be added to the motorized cylinder and two more LEDs to indicate the two additional positions. This job is straightforward and is currently being worked on by a student from William & Mary.

Second, the electronics must provide a Fast Shutdown (FSD) interlock signal to the TJNAF accelerator that will be activated whenever the target is moved. This will prevent accidentally moving the target while the beam is on. Target changes require Hall A personnel to telephone MCC and request temporary masking of this FSD channel. The FSD signal will be generated by the "red box" controller. Again, the necessary modifications are straightforward and will also be done by the W&M student.

No software development is necessary for the target motion control at this time.

A Cable List

Following is the list of cables that will be provided by Jefferson Lab for the polarized ^{3}He target system. For circuit schematics, please refer to Figures 1–3. Jack Segal has taken responsibility for this job.

No.	Type	Conductors	Description	Length (ft)	Terminators	
1	UTP	21 pairs	Control signals from VME TTL output register (Greenspring IP) to laser controller in laser hut	125	none	none
2	STP	14 pairs	Analog data from Laser controller in laser hut to VME ADC (HP1313A)	125	none	none
3	STP	2 pairs	1 RS-232 channel from VME serial card (VMIC 6016) to helicity motor controller in laser hut	120	RJ-11	none
4	STP	6 pairs	3 RS-232 channels from VME serial card (VMIC 6016) to Omega temperature controller (Micromega CN77544) & data displays	400+15	3×RJ-11	none
5	UTP	1 pair	Interlock signal from Omega oven control box to laser controller in laser hut	425	none	none
6	RG-213	1	Video signal from camera in laser hut to monitor in target control area upstairs	425	BNC	BNC
7	UTP	2 pairs	Analog signal (4-20 mA) and 15V power (50 mA) from oven air flow sensor (Omega FMA-905) to oven heater control box	475+100	(Omega)	none
8	T/C wire	1 pair	Thermocouple signal from oven heater thermocouple to oven heater control box. Wire already bought!	400+100	(SMP)	(SMP)
9	Line power	3	120VAC line voltage from oven heater control box output to oven heater element (800 Watts max.)	100+10	Line plug	none
9a	UTP	1 pair	Interlock relay control signal from oven heater control box to interlock relay	425+100	(Mil)	(Mil)
9b	UTP	1 pair	SSR drive signal (0-5 VDC) from oven heater control box to SSR	425+100	(Mil)	(Mil)
10	STP	2 pairs	Temperature signal from oven RTD to oven heater control box	400+100	none	none
11	UTP	16 pairs	Logic control signals and status feedback from valve controller to valve solenoid driver	400+100	none	none

No.	Type	Conductors	Description	Length (ft)	Terminators	
12	UTP	7 pairs	Status signals from solenoid valves to VME TTL input module (VMIC 1182)	100+100	none	none
13	UTP	7 pairs	Status signals from solenoid valves to valve controller	400+100	none	none
14	STP	14 pairs	Analog data from RTD and current signal conditioners (Acromag A5B34) to VME ADC (HP1313A)	100+100	none	none
15	UTP	1 pair	Analog signal (4-20 mA) from Baratron low pressure transducer to current signal conditioner (Acromag A5B34)	15	none	none
16	UTP	1 pair	Analog signal (4-20 mA) from Baratron high pressure transducer to current signal conditioner (Acromag A5B)	15	none	none
17	UTP	1 pair	Analog signal (4-20 mA) from current signal conditioner to Baratron readout	400+100	none	none
18	UTP	1 pair	Analog signal (4-20 mA) from current signal conditioner to Baratron readout	400+100	none	none
19	STP	20 pairs	Analog signals from target RTDs to RTD signal conditioner (Acromag A5B34)	60	none	none
20	AWG 2	2	Power (36V/12A) from Kepco power supply to longitudinal Helmholtz coil	400+100	none	none
21			(deleted)			
22	Belden 9536	6, shld	From flux gate magnetometer sensor (Bartington Mag-03MC) to power supply unit (Bartington Mag-03PSU)	400+100	(spcl)	(spcl)
23	AWG 2	2	Power (36V/12A) from Kepco power supply to transversal Helmholtz coil	400+100	none	none
24	RG-213	1	RF signal from RF amplifier to RF coils	400+100	BNC	BNC
25			(deleted)			
26	RG-213	1	NMR signal from NMR pre-amp to lock-in amplifier	400+100	BNC	BNC
27	RG-213	1	RF signal from EPR VCO to EPR coils	400+100	BNC	BNC
28	RG-213	1	EPR signal from EPR photodiode preamp to EPR lock-in ampliifier	400+100	BNC	BNC
29	STP	2 pairs	Cooling jet gas flow signal from McMillan gas flow sensor no. 1 to data display (Omega DP25)	60	none	none
30	STP	2 pairs	Cooling jet gas flow signal from McMillan gas flow sensor no. 2 to data display (Omega DP25)	60	none	none

No.	Type	Conductors	Description	Length (ft)	Terminators	
31	STP	1 pair	Analog data from cooling jet gas flow readout no. 1 to VME ADC (HP1313A)	100	none	none
32	STP	1 pair	Analog data from cooling jet gas flow readout no. 2 to VME ADC (HP1313A)	100	none	none
33	–	16×AWG 18	Control signals and power from target motion controller (connector J1B) to target ladder motor	60	(spcl)	(spcl)
34	STP	3 pairs	Feedback signals from target ladder motor assembly to target motion controller (connector J2B)	60	(spcl)	(spcl)
35	STP	3 pairs	Feedback signals from target ladder motor assembly to target motion controller (connector J3B)	60	(spcl)	(spcl)
36	–	30×AWG 18	Control signals and position readback from target motion controller downstairs to target motion controller upstairs	400	(spcl)	(spcl)
37	UTP	4 pairs	Logic control signals from cooling jet valve controller to valve driver	400	none	none

NOTES:

1. Abbreviations: UTP: unshielded twisted pair; STP: shielded twisted pair; T/C: thermocouple.
2. Terminators: "none": Either no terminators required (e.g. screw terminal, solder connection) or we will find a suitable connector after the cable is installed; anything in parenthesis (e.g. "(spcl)"): special connector from instrument manufacturer is available, we will attach it ourselves.
3. If no wire gauge is specified, any typical cable with the given number of conductors is acceptable. If the wire gauge is given, it means the minimum required; the wire can be thicker.
4. Twisted pairs (shielded or unshielded) can be separate or bundled in a multiconductor cable. For the shielded cables, a multiconductor cable with the given number of conductors is preferred, if easily available.
5. A quote for the Belden cable is attached. Please try to get this type, no replacements.
6. Assumptions for cable length estimates: instruments upstairs to cable tray entrance: 15ft.; upstairs cable tray entrance to pivot downstairs: 325ft.; pivot cable exit to ^{3}He target: 30ft.; pivot cable exit to electronics next to laser hut:

30ft.; pivot cable exit to inside of laser hut: 50ft.; electronics next to laser hut to VME crate in rack 1H75B12: 100ft.

7. If cable is required for permanent installation in the EEL lab, the cable length is given as (length for hall)+(length for EEL).

B Responsibility List

Task	Responsible Group	Responsible Person
Laser control box	Caltech	Dave Pripstein
Helicity reversal electronics	Caltech	Dave Pripstein
Laser readout & software	Clermond-Ferrand	Yves Roblin
NMR hardware – primary system	U Kentucky	Wolfgang Korsch
NMR hardware – spare system	Temple U	Zein-Eddine Meziani
NMR software	Temple U	Sebastian Incerti
EPR hardware – primary system	U Kentucky	Wolfgang Korsch
EPR hardware – spare system	Temple U	Zein-Eddine Meziani
EPR software	Princeton U	Ioannis Kominis
Target Motion System	Clermont-Ferrand	Yves Roblin
	William & Mary	Pibero Djawotho
Reference Cell hardware	MIT	Tim Black
Reference Cell software	Clermont-Ferrand	Yves Roblin
Cooling jets	MIT	Tim Black
Temperature readout	Clermont-Ferrand	Yves Roblin
Temperature controller	Temple U	Zein-Eddine Meziani