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# Upgrade of the 40m Vacuum System

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# Upgrade of the 40m Vacuum System

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## 1 PURPOSE

The purpose of this document is to outline ongoing improvements to the 40m vacuum system. The goals of the vacuum system upgrade are:

- To increase the automation of change-of-state procedures (i.e., most of the steps in transitioning from atmosphere to vacuum will be handled by electronics),
- To replace the current LabView/Metrabus controls with a VME processor and an EPICS interface, making the system more "LIGO-like" and allowing remote observation of the system status,
- To add more comprehensive hardware and software interlocking, both to protect against serious vacuum failures and to allow more confidence in the automated procedures,
- To fix oversights in the original vacuum design (HV interlock range, valves to protect ion pumps, etc.),
- To make the system easily upgradable in the future, and
- To make all necessary improvements with a minimum of changes to the system, given the short time frame and small number of personnel.

## 2 OUTLINE OF CURRENT SYSTEM

### 2.1 Hardware Layout

The 40m vacuum system schematic is shown in Appendix A (all appendices can be found at the end of Ted Jou's SURF report, included with this document). There are four main volumes in the system: the beam tubes and chambers, the cryopump (CP1), the residual gas analyzer (RGA), and the annuli at each of the five optical chambers. The interferometer is brought from atmosphere to about 0.5 torr by the roughing pumps RP1, RP2, and RP3, which are attached by a hose at the valve V3. Once this pressure is reached (roughly three hours), the hose is disconnected and the turbopumps TP1, TP2, and TP3 bring the system down to $2 \times 10^{-6}$ torr over a period of roughly a month, though this depends strongly on the temperature, the length of time that the system was vented, and the humidity at the time of the pumpdown. The cryopump and RGA volumes can be pumped down in the same manner, but are usually kept at vacuum when the chambers are open by closing the valves VM1, VM3, VC1, and VC2. Running the cryopump in parallel with the turbopumps can bring the chamber to $10^{-6}$ torr in as little as 72 hours. Calibrated leaks of helium and argon can be introduced in the RGA volume for calibration of the gas analyzer.

The fixed 1-meter mode cleaner is a separate volume. It has its own pump and cold cathode gauge with digital display, and is neither read out nor controlled by the main vacuum system.

The system was originally designed to allow vibration-free running by using the ion pumps instead of the turbopumps. IP1 was designated to pump the annuli, while IP2 through IP5 would keep the beam tubes and chambers at vacuum. This scheme has historically not worked for two reasons. First, there are no gate valves protecting the ion pumps when the chambers are brought to atmosphere. Thus the ion pumps are saturated during a vent and must be regenerated before they can be used. Second, the turbopumps cannot bring the widely-separated annuli below the level of $10^{-3}$ torr, which is too high of a pressure for the ion pump IP1 to function properly. A manual right-angle valve was introduced at IP1 in an effort to "fool" the pump into activating; closing the valve to a small aperture would reduce conductance, creating a pressure drop at the pump. Unfortunately, this effort failed to solve the problem.

## 2.2 Control Electronics

The flow of information in the 40m vacuum system is shown in the wiring diagram in Appendix A. CP1, TP1, the roughing pumps, and all of the valves communicate with the Vacuum Control Unit (VCU), an 80286 processor from Metrabus. Sense boards read state information for the valves and pumps as digital inputs. AC power for activating the valves and pumps is switched on and off at the VCU relay boards. The exceptions are the ten valves at the annuli; for these valves a digital control signal is sent from the VCU relay board, which activates an AC relay at the valve.

TP2, TP3, the ion pumps, the various pressure gauge controllers, and the VCU send information to the main workstation via RS-232 serial port connections. A serial port expansion unit allows the workstation to read and write to sixteen different RS-232 connnections.

The VCU, turbopumps, and main workstation are connected to a 3.1 kVA uninterruptible power supply (UPS). The UPS is sufficient to keep the system running through transient glitches, but reportedly cannot sustain power more than a few minutes, nor supply enough current to restart all of the pumps after sustained power outages. (Note: in the six months since the first version of this document, two significant outages have occurred, shutting down most of the computers on campus. In both cases the vacuum system remained operational, implying that the UPS may be sufficient after all).

Three of the valves are hardware interlocked with pumps. V4, for example, will close if TP2 is running at less than 50% of its preset speed, to prevent backstreaming into the interferometer. V5 and TP3 are interlocked in the same way. This is accomplished by passing the valve control signal through a relay in the turbopump controller, which opens when the pump speed falls too low. The valve VC1 is also set to close when the cryopump CP1 becomes too warm. In this case a relay is held closed by a photodiode signal, which reads the light from an LED reflecting off the needle in the cryopump temperature gauge. If the needle moves out of the tolerable temperature range, the photodiode signal vanishes, opening the relay and closing the valve. Finally, the pressure gauge P1 is interlocked with the high voltage to the "shark" test mass controllers and the RF voltage to the in-vacuum Pockels cell. Both voltages are disabled when P1 rises above 3 millitorr to prevent arcing in the vacuum envelope. There is no upper threshhold for the P1 interlock; to operate the high voltage at atmosphere, the interlock must be disconnected.

## 2.3 Computer Control

The nerve center of the 40m vacuum system is a SUN SparcStation 1 called *tigress*. This workstation communicates with the VCU and the other system elements through the 16-port serial expansion unit. There are two LabView 3.0 routines running on *tigress* at all times. One controls all serial communications and continually updates pressure and state information from each connection. The other provides a graphical user interface which displays all of the valve states, pump states, and pressures, and allows changes by the user.

LabView and the VCU processor work together to create a "state machine", designed to prevent the user from putting the vacuum system in an unsafe state. The VCU memory contains a list of all acceptable states for the vacuum system. When a user attempts to change the status of a valve through the GUI, LabView checks the final state with the VCU list, and only executes the command if the resulting state is found. Documentation at the workstation lists the steps necessary for the user to bring the system from atmosphere to vacuum and vice versa.

Two sets of log files are continually generated and deposited in two separate directories on *tigress*. One lists the pressures from each Pirani, cold cathode, and ion pressure gauge in the system, while the other tracks the concentrations of twelve preselected masses as measured by the RGA (for example, the 28 amu concentration is monitored to check for $N_2$, a symptom of an air leak). Both sets of log files were to be regularly copied onto another SparcStation 1 (*gib*) for plotting, and this was intended to be the only network connection allowed to *tigress*. However, *gib* is no longer operative, and *tigress* currently accepts remote telnet sessions.

The vacuum system is extremely dependent on *tigress*. The workstation is the only source of user control; if it is shut down or crashes, the system will continue to run (the VCU processor and relay boards will continue to control the valves), but no changes can be made. If *tigress* were down in an emergency, the only option would be to cut power to the VCU, causing all valves to close. Neither *tigress* nor the VCU processor are Y2K compliant (both have had their dates rolled back in order to continue functioning). Finally, there is no interface between *tigress* and either EPICS or the network except for telnet, which is one form of connection that is least desired for such a critical device.

# 3 PROPOSED CHANGES

## 3.1 Ion Pumps

New gate valves will be introduced directly adjacent to the five ion pumps IP1 through IP5. These valves will remain closed through hardware interlocks (see section 3.5) unless the outside pressure is less than approximately $10^{-5}$ torr. Once these valves are installed, the ion pumps can be regenerated and used normally, without saturating during each vent of the system. These valves have been ordered and received, and are awaiting installation.

To properly pump down each annulus would require at least three small ion pumps (one at each end, one at the vertex), as well as at least one mobile turbopump to bring each annulus down to a pressure where the ion pump can function. This would require significant effort for a problem that may not be critical to the main vacuum envelope. The best solution may be to simply close valve VA6 during vibration-free running. The viton O-rings in the annuli seem sufficiently leak-tight with the turbopumps running at $2 \times 10^{-6}$ torr; if permeation becomes a problem once the ion pumps drop the pressure even lower, the additional ion pumps can be added later.

## 3.2 Additions to Vacuum Envelope

The 1-meter fixed mode cleaner will be replaced by a 12-meter suspended mode cleaner, which will be part of the main vacuum envelope rather than a separate volume. The optical layout has not been finalized, but the mode cleaner will probably begin at the input optics chamber and run parallel to the south arm. The proposed end chamber is in storage in the 40m lab, and the other necessary hardware (beam tube, seismic stack) are still located in other LIGO facilities at Caltech.

Testing resonant sideband extraction at the 40m will also require an output optics chamber to be added adjacent to the beamsplitter chamber. This chamber is present in the 40m lab but needs to be baked. In addition, a new annulus and pneumatic right-angle valve will be required for this chamber, and signals from both will be added to the new EPICS control system.

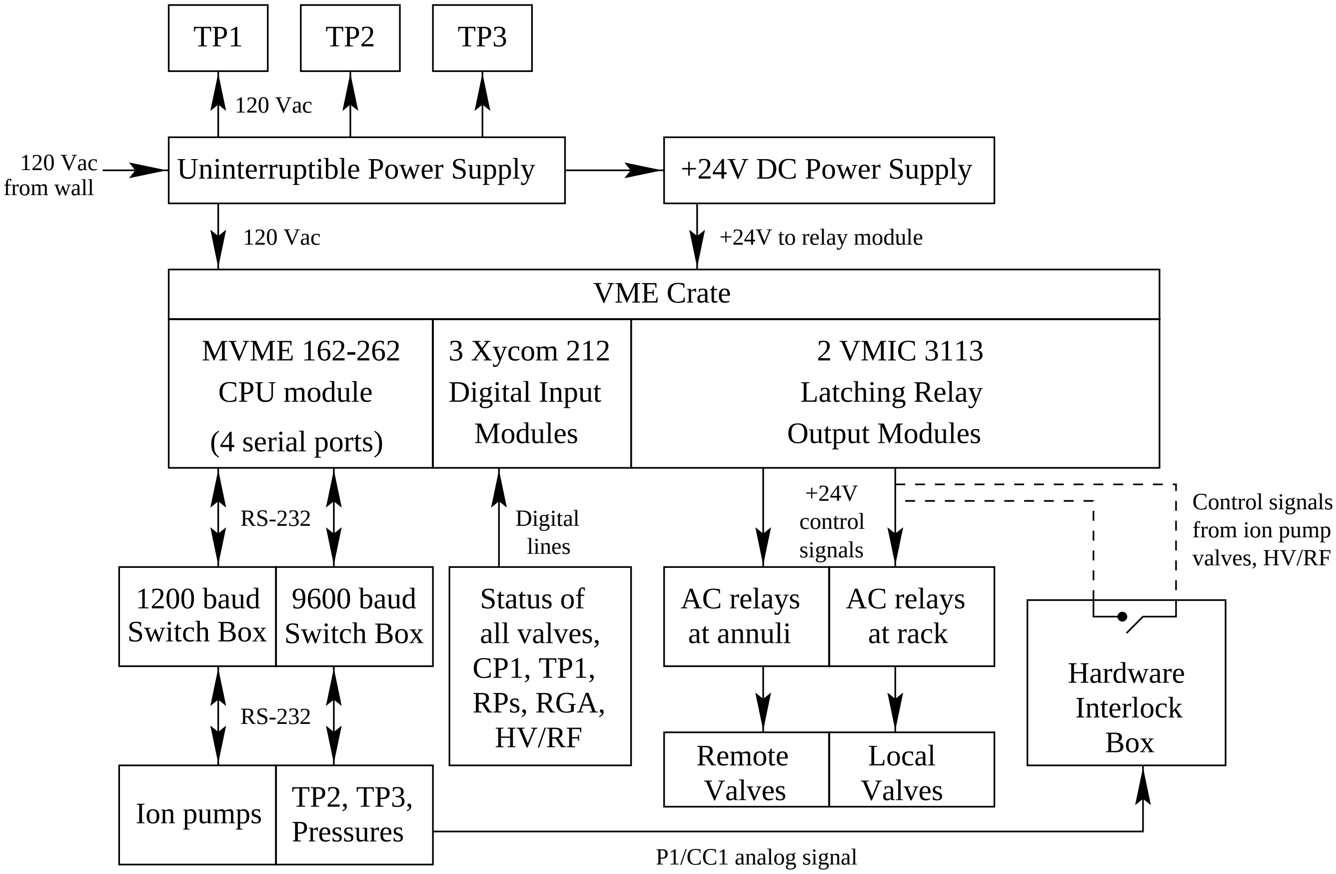
## 3.3 VME Control Electronics

The VCU will be entirely replaced by a VME crate, mainly to allow use of EPICS software as the control interface (see next section). To simplify the design, the modules have been chosen to closely mimic the functions of the original VCU (see wiring diagram on the next page). Two serial port connections in the VME162 processor module will communicate with two addressable serial port switch boxes, one for the ion pumps (which run at 1200 baud and odd parity), and one for the turbopumps and pressure gauge controllers (9600 baud, even parity). 96 channels of digital input will replace the sense boards, and two 32-channel latching relay modules will replace the relay boards. Latching relays are chosen over momentary latching relays or digital output to allow the valves and pumps to retain their state even if the power is interrupted or the VME processor fails or reboots. The remote valve control signals will be changed from +5V DC to +24V DC for better stability and to conform with industry standards. To reduce noise, AC power will not be sent from the relay module. Instead, +24V control signals will trigger AC relays clipped to the side of the electronics rack for all local valves and pumps (for the annuli, the relays will be located at the valve as before).

## 3.4 EPICS Interface

The LabView routines on *tigress* will be replaced by an EPICS interface. A SURF student named Ted Jou has already completed much of the programming work; the GUI's he developed can be seen in Appendix B, while the actual code can be found in the "Caltech/40mVac" folder in the EPICS area on *kater*. The first GUI (VacControl.adl) is similar in appearance to the LabView GUI, and allows the same control over individual valves. But rather than require the user to perform every step in transitioning from atmosphere to vacuum or back, the user can select a final state using the pull-down menu in the second GUI (VacState.adl). EPICS will perform most of the steps in the state transition automatically. For safety reasons, some steps will not be automated (connecting the roughing pump hose, for example), requiring a competent user to be present during major changes. The user will be cued to perform these steps by a message displayed in the GUI. The third GUI (VacMonitor.adl) shows the system monitor that will allow a remote user to check the status of the vacuum system.

# Proposed Information Flow Diagram



Also included in Ted Jou's SURF report are the logic for each major state transition, which still needs to be reviewed. In addition, the code does not currently include the type of "state machine" procedure in the current system, in which all pumps and valves are compared to a list of allowable states before each transition. The 40m review committee has stated that the state machine code was a hindrance to operating the previous system, and that if enough thought is given to hardware and software interlocking, state machine code should be unnecessary.

## 3.5 Other Hardware Changes

Here is a list of other hardware items (and their current order status) needed to complete the system upgrade:

- A changeover valve for the nitrogen supply (ordered); this will automatically switch to a backup cylinder when the nitrogen pressure falls below the minimum necessary to operate the large gate valves (80 psi).
- A pressure transducer and digital display (received) for the nitrogen supply.
- Five cold cathode gauges and four Convectron gauges (ordered) for both the output optic chamber bake and for any diagnostic needs during the commissioning of the new system. The Convectron gauges work in the same pressure range as Pirani gauges.
- A pressure gauge controller with serial port (ordered). The controller has two channels for cold cathode gauges and two for Convectron gauges. This will replace the current mode cleaner controller, which does not support serial communication. The current controller will be used for the OOC chamber bake and as a roaming display for the new diagnostic gauges.
- A spare filament for the RGA (not yet ordered), as well as repairs for the RGA display (not yet ordered).
- Foils for clean storage of any in-vacuum components (received).
- A roughing pump (getting quote), turbopump (getting quote), thermal blankets (received), and temperature controllers and heating tape (some in storage, others need to be ordered). All will be used for a mobile pumpstation for regenerating the ion pumps.

- An insulated metal cage (still under review), a second RGA (in storage, may need expensive replacement parts), a heater and fan (need to order), and temperature controllers (need to order), all for the bake of the output optics chamber.
- On/off monitors for the roughing pump power, RGA, and HV/RF switch (still under review), to be read through the VME digital input module.
- Calibrated leaks (still under review) closer to the LIGO standard may replace those currently in use.
- Serial port adapters (need to order) for converting RJ-45 cables to DB-25 and DB-9 pinouts at the gauge controllers, pumps, and serial port switch boxes.

The future of the UPS is not clear. While the UPS currently protects the system from power glitches, and has successfully weathered two recent outages, it may still be a liability in any prolonged power failure. Upgrading to a 6 kVA or larger supply is extremely expensive. One compromise solution may be to disconnect the least critical turbopump from the UPS (probably TP3, since it pumps mainly on the annuli), reducing the load so that it can more easily sustain and/or restart the other two pumps.

### 3.6 Interlocking

The hardware interlocks for TP2/V4, TP3/V5, and CP1 are external to the VCU/Metrabus electronics. They will work equally well whether the control signals come from the VCU relay board or the VME relay module. Two other hardware interlocks, however, need to be designed and built:

- HV/RF – The high voltage interlock must be redesigned to operate for a 24V DC control signal rather than 5V. In addition, an upper threshhold of 500 torr will be placed on the interlock. This will allow operation of the HV/RF electronics at atmosphere without the unsafe practice of disabling the interlock.
- IP gate valves – The ion pump gate valves must be prevented from opening if the IFO pressure is above $10^{-5}$ torr to prevent saturation of the pump. A software interlock is not sufficient for this, in case

the IFO pressure rises (from a leak or other source) while the VME processor is down.

In the full LIGO installations there is an additional hardware interlock to prevent gate valves from opening when there is vacuum on one side and higher pressure on the other. A similar interlock was originally planned for VM1, VC1, and V1, to prevent sudden venting of the IFO. It turns out, however, that it is not mechanically possible to open these valves if the pressure differential is more than a torr, so this interlock has been considered unnecessary.

Several other less critical interlocks can be handled in software:

- RGA alarms – Alarm levels can be set for the 41, 40, and 28 amu lines in the RGA. When these partial pressures cross a preset limit, a digital signal is sent to the VME input, which will protect the turbopumps by closing V1, V4, and V5.
- Nitrogen supply – The new nitrogen supply pressure display can communicate by serial port, and can warn the control system if the nitrogen pressure is dropping below 80 psi. This allows the system to close the large gate valves VM1 and V1 before there is no longer sufficient pressure to do so.
- Air leak – The VME can be programmed to close VM1, VC1, and V1, isolating the IFO, if the pressure is above $10^{-5}$ torr and rising (though we have not yet mathematically defined "rising").
- TP1 – The Osaka turbopump does not have the convenient monitoring relay that the Balzers turbopumps do. It does, however, have a digital output which signals a failure. This can be read by the VME digital input, and V1 can be ordered to close to protect TP1 from backstreaming.
- RP – The roughing pumps will start releasing oil if left pumping on the IFO too long. V3 can be instructed to close if the IFO pressure drops below 0.35 torr (the roughing pumps are supposed to be disconnected at 0.5 torr).

# 4 COMMISSIONING PLAN

The 40m lab is still waiting for building modifications, including roof repair and the removal of one wall. Meanwhile the VME crate has been assembled, and the serial communication system is being studied in detail. During the construction the EPICS code will be brought to maturity, and most of the plumbing and wiring should be completed in spring 2000.

# 5 SUMMARY

The following points include both tasks still to be completed and subjects requiring further thought:

- The uninterruptible power supply must be studied further to judge if it is sufficient for its job.
- A decision must be made about the best way to handle the annuli during vibration-free running.
- Will the pressure gauge and RGA information be logged as before? And how will this be done?
- A detailed wiring diagram must be drawn up in Protel with the help of CDS.
- The database entries in Ted Jou's EPICS code must be assigned to real hardware channels in the digital input and relay output modules.
- The hardware interlocks must be designed and built, and alarm handling routines added to the EPICS state code.
- Eventually, we have to put it all together!