# Differential Pumping System (DPS) monitor for FACET-II

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(Dated: August 25, 2023)

This summer, I worked on the Differential Pumping System (DPS) monitor in the Facility for Advanced Accelerator Experimental Tests (FACET-II) at SLAC. FACET-II works with plasma wakefield acceleration, which has the potential to make much smaller and more powerful accelerators. The DPS helps isolate the plasma and reduce the beamline to ultra high vacuum. However, the pumps are susceptible to tripping from the radiation around the experimental area. I improved the watcher script that monitors the DPS components and reacts to fault conditions. It now accounts for all of the good states and some extra fault conditions. Previously, there was no way to see that the watcher found an error or made any changes without checking the elog. To address this, I made a graphical user interface that displays the current states and turbopump statuses, as well as information about recent errors. This tool should help operators troubleshoot DPS errors quicker and more correctly. I also developed a flow controller upgrade to the gas delivery system that supports the plasma source, which will help with plasma density stability.

## I. INTRODUCTION

FACET-II is a facility at SLAC National Accelerator Laboratory that studies plasma wakefield acceleration (PWFA), which has the potential to make much smaller and more powerful accelerators. Pulses from the linear accelerator are split at the beginning of FACET-II for two-bunch production. Then, multiple times along the FACET-II beamline, the pulses are compressed longitudinally by dipole magnets and focused with quadruples.[1] Lithium plasma is used, and the plasma can be formed by the strong fields of the first bunch or with a Ti:Saph laser.

One draw of PWFA is that it has reached accelerating gradients far above that of traditional accelerators–plasma-based acceleration has reached[2] 50 GeV/m. A current challenge is that experiments have not yet achieved good total efficiency. They have accomplished great energy, acceleration gradient, charge, energy spread, and emittance, but never more than three at a time. Even so, the potential of PWFA is enormous.

The amount of radiation in and around the experimental area creates a challenge in maintaining nearby components. I worked on two tools to monitor and troubleshoot issues related to this. I also worked on improving a separate hardware component, though all three of these tasks helped protect and maintain plasma stability.

## II. DIFFERENTIAL PUMPING SYSTEM

### A. Overview

One challenge of FACET-II is that the beam is so intense that it burns holes through intercepting components. Beryllium windows are used to enclose the plasma in the experimental area, but some flow escapes through the hole drilled by the beam. The differential pumping system (DPS) is a series of eight pumps and conductance limiting tubes that helps isolate the plasma and reduce the beamline pressure to the ultra high vacuum required in the linear accelerator.

The DPS has four stages upstream of the experimental area and two downstream, each with a turbo-molecular pump, valves, and pressure gauges. Turbopumps reduce the inlet pressure by a compression ratio, so the DPS is designed to provide appropriate backing pressure to each turbopump. The pressure is highest closer to the interaction point (IP), so the two stages on either side each have a roughing pump to back their turbopump. The variety of valves and paths provide more flexibility, which is very important to operate in different experimental states or with some faulted pumps.

There is a lot of radiation in and near the IP from which the pumps are susceptible to tripping. This could put the DPS in a state that could harm the pumps, interrupt beam delivery, or cause loss of plasma.

For this reason, there is a DPS watcher MATLAB script running in the background (DPSvacWatcher.m). The watcher monitors the status of the pumps, valves, and pressures, and reacts to fault conditions. The watcher code previously only noticed a few good states and in some cases, would close a valve or stop a pump to make the system state safer. I rewrote the script to account for all the good states and a few extra scenarios where it should close a valve or stop a pump.

### B. DPS Watcher

#### 1. *Watcher Workflow*

The watcher will first check if the upstream and downstream are in good states. If not, it will check the foreline valves, since there are some pairs of valves that should not both be open at a time. Some of the stages have two foreline valves–one to back the turbopump with a roughing pump or a turbopump from a previous stage, and one to back the turbopump from the beamline. If both in one stage are open, the direction of flow will be disrupted, and the watcher will close the one to the beamline.

Then, the watcher looks at stages. Generally, a turbopump should only be on if its foreline valve is open, and vice versa. For stages with a roughing pump, the foreline valve of interest is the one by the roughing pump. For upstream stage 3, which has no roughing pump, both foreline valves are considered. The watcher will stop the pump or close the valve if there's a mismatch.

The controls system can tell if a turbopump is braking, but it will still register the pump as "running" until it has fully stopped. Thus, an exception is made in the code; if the turbopump is braking and its foreline valve is closed, that is safe. Similarly, if the turbopump is accelerating with the foreline valve closed, that is also safe. The pump setpoints are rarely changed, so they should only brake when stopping and accelerate when starting.

### 2. *Support for Health Monitor GUI*

The watcher also updates support PVs to be used by the health monitor GUI. PVs SIOC:SYS1:ML00:AO618 to AO627 have been reserved for this purpose, and are all used as booleans. AO618 and AO619 are used for the upstream and downstream states, and will be 1 if the state is good. AO620 to AO625 are used for turbopump statuses (US1, US2, ... DS1, DS2). These will be 1 if the pump is running and 0 if it is braking or off. AO626 is used by the watcher as the email flag–alarm emails will only be sent if this is 1. Finally, AO627 will be 1 if the watcher has found an error or made a change in the past 30 minutes.

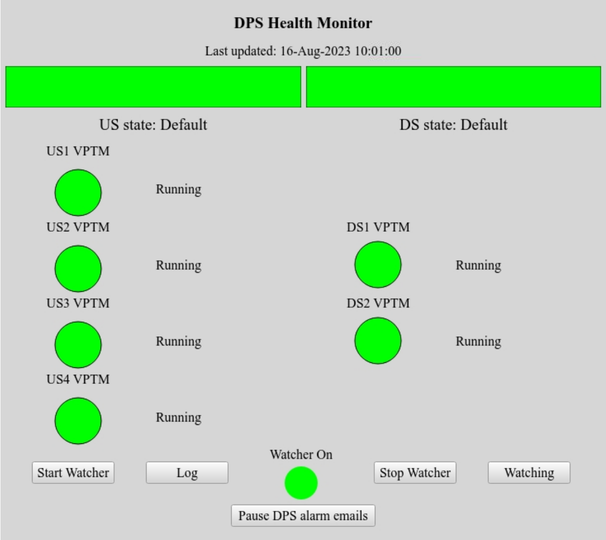
String messages are stored in PVs SIOC:SYS1:ML00:CA201 to CA 204. CA201 is a string reporting when the watcher was last updated. CA202 and CA203 report the current upstream and downstream state names. CA204 stores the last error message and a timestamp.

This version of the watcher started running on production on August 17.

## C. Health Monitor GUI

Without checking the elog, there was previously no way to see that the watcher found an error or that it changed something. This is not ideal, since the DPS is complex and hard to judge quickly by eye if something is wrong. I created a graphical user interface (GUI) in PyDM to go along with this watcher and help address this problem. From this panel, you can see if the states are good, tell if the watcher has made changes recently, and do various things to the watcher itself.

There is no separate python support script for the GUI. Every label, indicator, and button that changes is linked to a PV and may have rules written in Qt Designer. All indicator circles/banners except for the "Watcher On" one are connected to the boolean PVs described in the previous section. They will turn red if the PV is 0.



DPS Health Monitor

Last updated: 16-Aug-2023 10:01:00

US state: Default

DS state: Default

US1 VPTM Running

US2 VPTM Running

US3 VPTM Running

US4 VPTM Running

DS1 VPTM Running

DS2 VPTM Running

Watcher On

FIG. 1. DPS Health Monitor GUI

The VPTM status labels will either say "Running," "Braking," or "Off." This is independent of the watcher and is solely controlled by a rule looking at the VPTM rotation status and braking status. Above the "Start Watcher" row of buttons, these labels are the only things that will be updated if the watcher is off.

The "Start Watcher," "Log," "Watcher On," "Stop Watcher," and "Watching"/"Bypass" buttons/indicators are the exact same as on the general FACET-II watcher panel. Note that only one log panel can be open at a time; if someone had it open and then I click "Log," it will close their window and open it on my screen.

The pause/resume DPS alarm emails button is tied to AO626. The code actually has one button to pause emails and one to resume them, but both have a rule to make sure only the appropriate one is visible. If AO626 is 1, the visible button will be "Pause DPS alarm emails." Pressing it will make AO626 be 0, making the email flag in the watcher 0, turn the "Pause DPS alarm emails" button invisible, and make the "Resume DPS alarm emails" button visible. The opposite will happen after pressing "Resume DPS alarm emails."

The health monitor GUI is accessible in the Diagnostics section on the LI20 vacuum page, as well as the DPS full schematic page. It has been running on production since August 17.

## III. GAS INJECTOR SYSTEM

### A. Overview

Helium is also used to bookend the lithium in the experimental area. Lithium vapor is required for generating the plasma, so the beampipe is heated to 800-1000 degrees Celsius to vaporize the solid lithium. When a hot lithium gas particle hits a cold helium one, the helium gets knocked back out to the edges, and the lithium falls down. This essentially results in a wall of helium on either side of the lithium.[3]

The helium flow was previously controlled by a manual flow controller. This controller is very sensitive to ambient temperature and other external conditions, resulting in a 2% swing in helium pressure. Since this is not good for plasma stability, I set up and tested a new digital mass flow controller (MFC). We have the MKS GM50A013103SMM020, a device with 1000 sccm full scale flow range, a DB15 port for inputs/outputs, and an ethernet port for configuration.

## B. Setup

I made a DB15 connector for testing that isolated pins 2-5, 7, and 8. Pin 2 was for the flow signal output, which I connected to a multimeter. Pins 3 and 4 were for closing and opening the valve respectively, and did not end up being used. Pin 5 was listed as "Power Common," and I connected it to the power supply's ground. Pin 7 was used to power the MFC, and it took +15 to +24 VDC. I connected it to a power supply and only used 15.2 VDC. Lastly, pin 8 took 0 to +5 VDC as the flow setpoint. This was connected to a second power supply with a shared ground to the other power supply.

After the MFC was on for more than 30 minutes, I followed instructions in the manual to zero it. The flow signal out was stable around 0.01-0.02 V at no pressure differential, and this number did not change after zeroing.

## C. Ethernet Options

The following are some operations that can be done using the ethernet connection on the side: change the gas settings, plot the flow data, send a set point digitally, update the MFC's firmware, set a ramp time, and zero the MFC. Many of these require the user to be in SETUP mode. The current mode is displayed on the bottom of the webpage. To switch from MONITOR mode to SETUP mode, go to the Configuration tab and type "config" as the password at the bottom. See more information in the web browser tutorial. I set up helium as a new gas and set the ramp time to 5000 ms. If the MFC is connected to ethernet, for our purposes it could be operated entirely remotely.

## D. Tests

I initially tested the MFC in End Station B with nitrogen gas, making sure it turned on and the flow signal out would ramp to match the setpoint. I used two acrylic manual flow controllers to estimate the flow in SCCM. These both reported SCFH for air, but the response was linear with varying setpoint voltage. I did the same tests with helium gas.

Next, the MFC was installed in its intended position in the klystron gallery. Before testing, the tubing around the MFC was leak checked with Snoop. We adjusted the setpoint voltage until the pressure in the experimental area stabilized around 9.96 torr. This corresponded to a setpoint of 3 V. After turning the setpoint down to 1.5 V, the experimental area pressure settled around 5.18 torr. The system was left in that state overnight to see how stable it would be.

The results from this test are in Figure 2, compared with the results from testing the manual flow controller in December. The pressure during the digital MFC test was much more stable, never going higher than 0.5 percent difference (in magnitude). Figure 3 shows the digital MFC results with the ambient temperature in the gallery at that time. It is possible the ambient temperature was affecting the voltage output of the power supply or the MFC itself. To reduce this, the MFC could be stored in a temperature controlled electronics case.

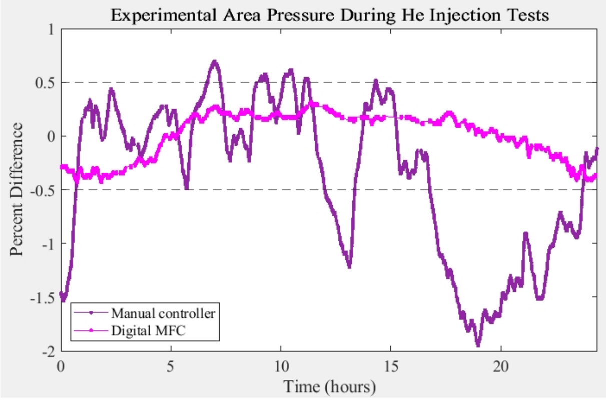


FIG. 2. Experimental area pressure during the digital MFC test and manual controller test

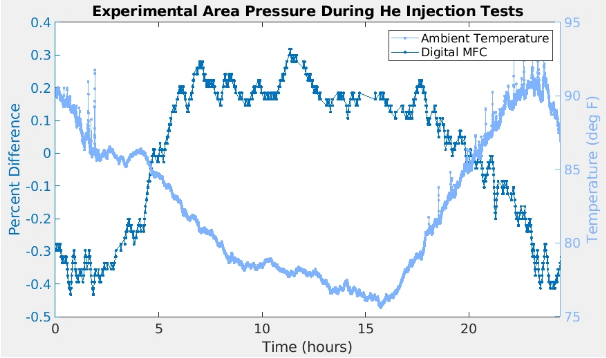


FIG. 3. Experimental area pressure during the digital MFC test, with ambient temperature in the klystron gallery plotted on the other axis

## IV. CONCLUSIONS

This summer, I improved the DPS watcher to make it more robust. I also made the DPS Health Monitor GUI to make troubleshooting more efficient. Finally, I worked on a MFC upgrade to improve plasma density stability and ease of operation.

## ACKNOWLEDGMENTS

I would like to thank my mentor, Doug Storey, for his valuable guidance throughout my internship. Thank you to Juan Cruz Jr. for helping me with setting up the MFC. I also want to acknowledge the FACET-II group for being so helpful. Thank you to Hillary Freeman, Arturo Garcia, and Rebecca Flores for organizing everything, and thank you to the other interns for making this such a positive experience.

This work was supported in part by the U.S. Department of Energy, Office of Science, Office of Workforce Development for Teachers and Scientists (WDTS) under the Science Undergraduate Laboratory Internships Program (SULI).

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[1] M. J. Hogan et al., “Plasma wakefield acceleration experiments at FACET,” New Journal of Physics **12**, 055030 (2010).

[2] P. Muggli and M. J. Hogan, “Review of high-energy plasma wakefield experiments,” Comptes Rendus Physique **10**, 116 (2009).

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