TRACKING THE HELIUM BALANCE IN FREIA

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Abstract

In the FREIA laboratory at Uppsala University we test the super-conducting spoke-cavities for the European Spallation Source. Liquid Helium for cooling the cavities is provided by a liquefaction plant from which also a local user community at the University is served. Recently we encountered a leak due to a faulty valve which went undetected for some time and caused significant loss of Helium. In order to prevent such mishaps in the future we implemented a Helium tracking system that includes detailed accounting of Helium leaving and entering the closed system as well as all volumes containing Helium in the system. We describe the technical implementation and experience to date.

INTRODUCTION

In order to stimulate the development of advanced accelerator and instrumentation projects the FREIA laboratory [1] at Uppsala University was established in 2012, in part also as platform to participate in the development work for the European Spallation Source (ESS), in particular developing and testing the radio-frequency system for the spoke-cavity section and testing the cavities [2]. Other projects on the agenda are testing of super-conducting magnets and crab-cavities for the LHC upgrade and creating a coherent THz light source in Uppsala.

A central ingredient for the development and testing work is a significant Helium liquefier that feeds the cryostats in FREIA and is used to fill movable dewars to deliver Helium to external users at the adjacent Ångström laboratory and other departments of Uppsala University. The Helium system in FREIA is closed and almost all Helium is recovered, unless some mishap occurs. The gas delivered to external users is returned to a smaller percentage via a recovery system in the Ångström laboratory.

Since Helium is a limited and expensive resource and we encountered a serious loss due to a faulty valve in one of the compressors of the Helium system we decided to build a system that tracks the Helium in all subsystems within FREIA as well as all Helium leaving in dewars and the returned gas. The system compares the expected gas volume with the sum of all volumes in the subsystems and provides a continuously updated display.

Here we describe the system that is based on a Raspberry Pi running EPICS and communicating with some of the idiosyncratic sensors via a serial bluetooth link to the local intelligence that is provided by micro-controllers. The system uses a local database on the Pi and presents the status by a web-server. Interaction is implemented by php-scripts.

FREIA HELIUM SYSTEM

The Helium is compressed to 13 bar in a Kaeser compressor and passes through a Linde liquefier with a capacity of up to 140 l/h Helium at 4 K that enters an intermediate storage dewar with 2000 l capacity. From there a small fraction is tapped off into smaller dewars for external users and most is passed on to a distribution box that presently serves the HNOSS cryostat [3] with its own 1.8 K system including sub-atmospheric pumps for testing the spoke cavities with and without power-couplers at low and high power, respectively. Later this year a second consumer of Helium will be a cryo-module for the spoke-cavities. In 2017 a vertical cryostat will be added. The boiled-off Helium used for cooling the cavities is heated to room temperature and piped to a gas bag with a capacity of holding 100 m^3 warm gas. Once the gas bag is inflated above a limit three Bauer compressors are turned on to pump the gas into high-pressure storage, consisting of a large number of 200 bar bottles and returned to the compressor from where it can be directed to the purifier built into the liquefier. The total capacity of the system is a little over 2000 m^3 Helium at room temperature.

The gas to the external users is of course accounted for by entering the amount into a database and the gas returned through the Ångström recovery system passes through a mechanical counter back to FREIA and into the gas bag.

HARDWARE AND SOFTWARE

Initially it was not clear how to integrate the mechanical gas counter into the system and how to determine the volume of the gasbag and we therefore needed a large flexibility to integrate idiosyncratic sensors but still integrate well with the EPICS [4] based control system of FREIA. We therefore decided to use a Raspberry Pi [5] as the central hub of our system, install the EPICS base system on it [6] and writing an EPICS input-output-controller (IOC) on the Pi to communicate with external micro-controllers using the stream library. The micro-controllers then communicate RS-232 over any convenient medium, we chose bluetooth to be able to place the micro-controllers close to the sensors.

The Pi publishes all measured and derived (via EPICS CALC records) quantities on the control network such that other devices and programs can use them. Moreover, the Pi runs an `rrdtool` database [7] which logs several EPICS values by using the `caget` program and feeding them to the database. The `rrdtool` package produces nice-looking history plots of the logged data as picture files that are easily integrated on a web page. The web pages are published by an apaches2 web-server that runs on the Pi. Basic interactivity of the web-pages is provided via php-scripts and html-forms.

Figure 1 shows a page where our colleague who manages the contact with external users has an overview of the system and can enter the amount of gas delivered to customers and

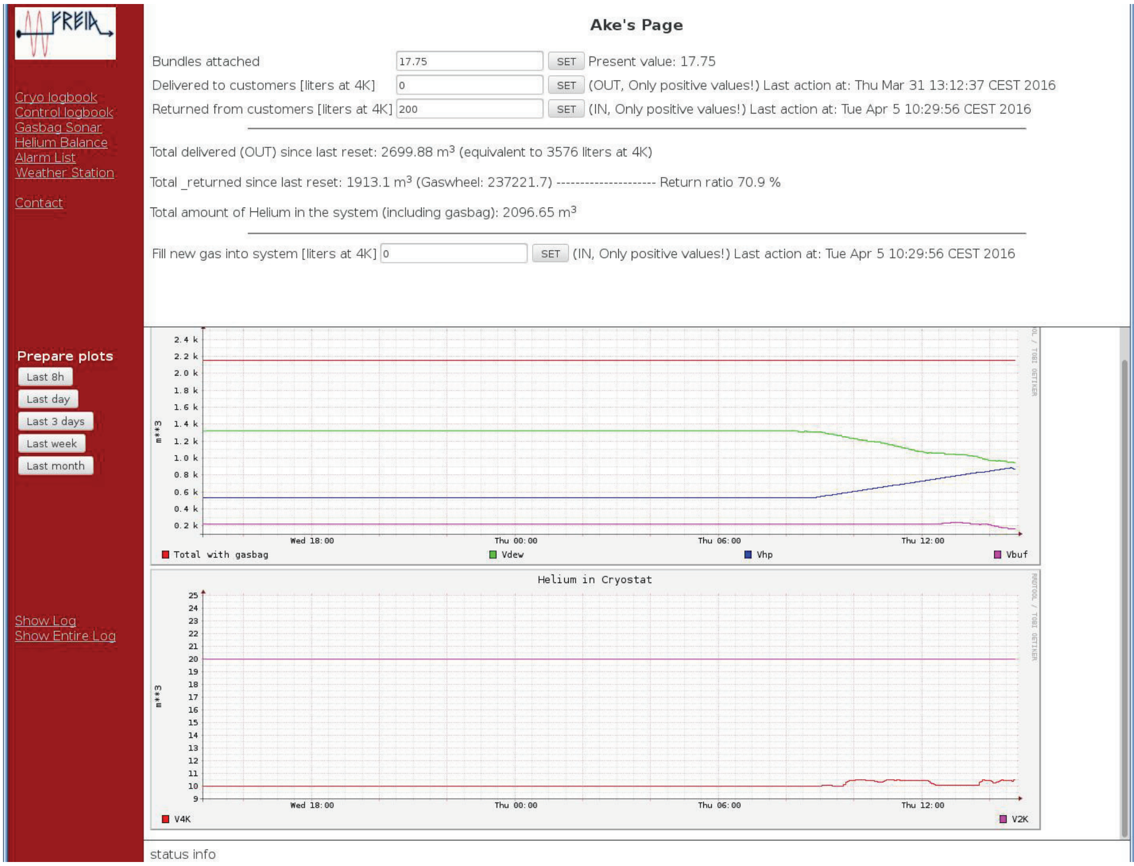

Figure 1: Web-page with the entries for Helium delivery and gas content in different subsystems.

gas returned in half-empty dewars as well as newly purchased gas. Also displayed are the accumulated gas delivered as well as the return ratio. The graphs below show the Helium content in the different parts of the system.

This rather open and flexible system turned out to be very convenient and extensible, without jeopardizing the rest of the control system. In particular students can extend the system [8].

The mechanical counter of the return gas was inherited from a previous Helium system at Ångström laboratory and lacked documentation. Some inspection revealed that it provides a DIN-19234 compliant signal on two wires which is basically a switch that briefly closes once every 1001 gas have passed the counter. We use an ATtiny85 microcontroller that can be programmed via the Arduino development system and count the closing switch by observing a recording one of its pins changing its state while using a weak pull-up resistor. The pin is polled regularly and an internal counter is incremented. The value is also stored in local EEPROM such that the system survives power cuts gracefully and restarts with its state preserved. The microcontroller is connected to a HC-06 bluetooth module and responds to a simple query-response protocol to the EPICS system on the Pi. The Pi asks 'COUNT?' and the micro returns 'COUNT nnnn', which is trivially implemented in EPICS protocol files. It turned out to be convenient to use the EEPROM of the microcontroller as non-volatile storage for several other variables such as the volume delivered to customers. Finally we added a LM35 temperature sensor to one of the analog pins to record the local temperature.

The second non-standard quantity to measure is the volume of the gas bag with the returned gas. We solved that by building a gasbag sonar with an ultrasonic HC-SR04 ranging detector connected to ATmega328 microcontroller that was flashed with an Arduino bootloader and can be programmed with the Arduino development system as well. The micro uses the same type of bluetooth module to communicate with the Pi with the query-response protocol described in the previous paragraph.

Finally we connected a BMP180 pressure sensor and a HYT-271 humidity sensor directly to the I2C bus on the Pi and wrote a small server program that communicates with the EPICS stream protocol via a socket on the Pi and uses the same type of query-response protocol. Together with the integrated temperature sensors this provides the functionality of a basic weather station.

EXPERIENCE

The hardware of the system is in operation since late 2015 and runs reliably, only the bluetooth connection was lost a few times. The open character of the entire system leads to

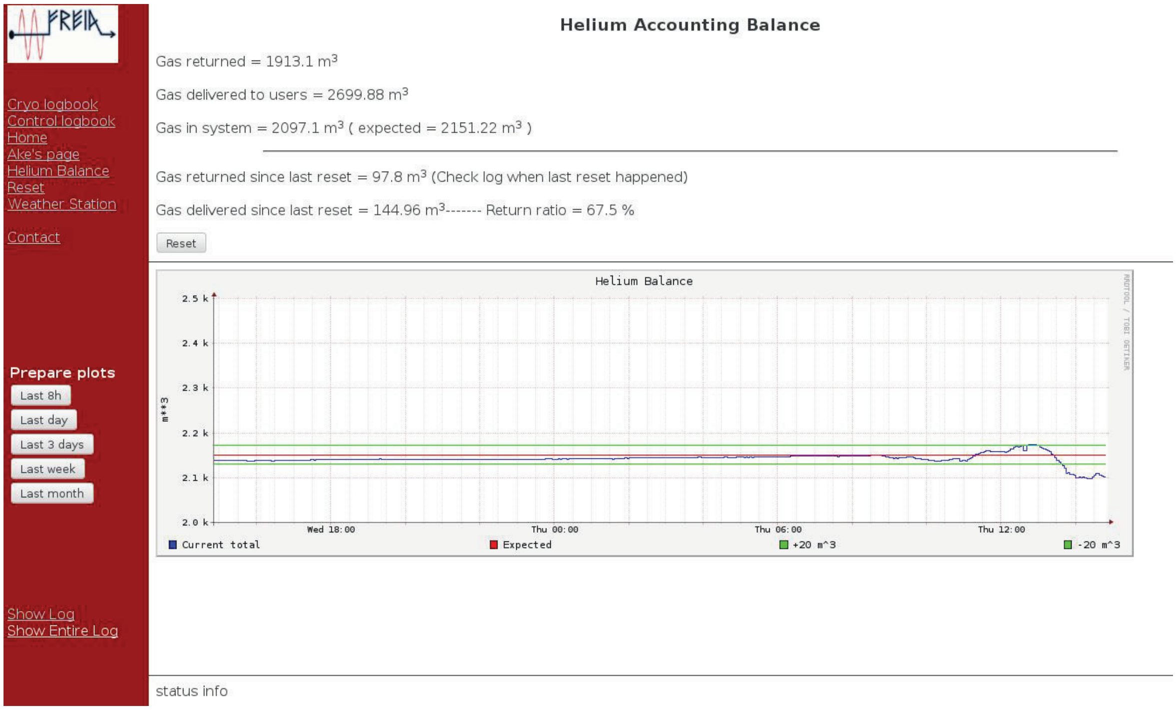

Figure 2: Web page with overview of the Helium balance system.

many ideas that in turn lead to continuous improvements and additions of new features that we attempt to implement without breaking existing functionality.

Our system contains Helium both in liquid and in gaseous form and we decided to convert all quantities to the equivalent volume in m^3 at normal conditions (300 K, 1 bar) where we use the conversion of $V(\text{gas at 300 K and 1 bar}) = 0.755[\text{m}^3/\text{liter}]\times V(\text{liquid at 4 K})$. The volume of all vessels containing Helium gas is known we use the readings of pressure gauges to proportionally scale to the equivalent volume at 1 bar.

We can reset the calibration of the Helium tracking system which reads the current amount in all volumes and subtracts the delivered and returned gas to calculate a calibration constant. At a later time the expected volume is given by the calibration constant plus the returned gas minus the delivered gas and then be compared to the actual current volume in all vessels. A picture of the web page displaying the expected value in red with $\pm 20\,\text{m}^3$ green tolerance lines and the current value in blue is shown on Fig. 2.

CONCLUSIONS

The system is a useful additional feature to the cryogenic system in FREIA that will help us in the future to quickly identify unexpected losses of Helium. Presently we understand the system to a level of about 2-3 percent of the total Helium volume and we continue to improve the accuracy and calibration constants in order to increase the predictability.

ACKNOWLEDGMENTS

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REFERENCES

[1] M. Olvegård et al., *Progress at the FREIA Laboratory,* Proc. IPAC'15, p. 3072-3074.

[2] H. Li, *RF Test of ESS Project Superconducting Spoke Cavities at Uppsala University,* these proceedings.

[3] R. Santiago-Kern et al., *The HNOSS horizontal cryostat and helium liquefaction plant at FREIA,* Proc. IPAC'14, p. 2759-2761.

[4] Epics, `http://www.aps.anl.gov/epics`

[5] Raspberry Pi, `http://www.raspberrypi.org`

[6] Installing EPICS on the Raspberry Pi, `http://prjemian.github.io/epicspi`

[7] RRDtool, `http://oss.oetiker.ch/rrdtool`

[8] A. Hjort, M. Holberg, *Measuring mechanical vibrations using an Arduino as a slave I/O to an EPICS control system,* `urn:nbn:se:uu:diva-257545`