MethodsX 3 (2016) 525–534

Contents lists available at ScienceDirect

MethodsX

journal homepage: www.elsevier.com/locate/mex

Vacuum system upgrade for extended Q-range small-angle neutron scattering diffractometer (EQ-SANS) at SNS

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ABSTRACT

The Extended Q-range Small-angle Neutron Scattering Diffractometer (EQ-SANS) instrument at the spallation neutron source (SNS), Oak Ridge, Tennessee, incorporates a 69 m^3 detector vessel with a vacuum system which required an upgrade with respect to performance, ease of operation, and maintenance. The upgrade focused on improving pumping performance as well as optimizing system design to minimize opportunity for operational error. This upgrade provided the following practical contributions:

- Reduced time required to evacuate from atmospheric pressure to 2 mTorr from 500 to 1000 min to 60–70 min
- Provided turn-key automated control with a multi-faceted interlock for personnel and machine safety.

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ARTICLE INFO

Keywords: Vacuum, Neutron scattering diffractometer, Spallation neutron source

Article history: Received 4 January 2016; Accepted 20 September 2016; Available online 23 September 2016

Original system configuration and performance

The EQ-SANS detector tank incorporates a double-walled design to facilitate the use of light concrete between the walls for fast neutron shielding as well as sintered boron carbide inside the tank for shielding of slow neutrons [5]. Initial evacuation of the tank was through a 10 m long, 160 mm diameter line by a Leybold SP250 screw pump boosted by a Pfeiffer roots-type blower with a rated

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http://dx.doi.org/10.1016/j.mex.2016.09.002
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speed of 754 cubic feet per minute (CFM). A Pfeiffer Model TMH521 turbomolecular pump with a rated pumping speed for air of 510 (l/s) backed by a Varian Tri-Scroll 300 dry scroll pump performed further evacuation. A convection-enhanced Pirani gauge on the blower inlet at the pump-end of the 160 mm diameter, 10 m long roughing line monitored pressure from atmosphere to low vacuum while a wide range cold cathode gauge attached at the pump-end of the high-vacuum line monitored the pressure once it reached high vacuum.

Since pumping on one end of a long tube results in a pressure gradient along the length of the tube [2], neither of these pressure readings accurately represented the true pressure in the tank during normal operations. In molecular flow, the pressure at distance X from the pump end of the tube is represented by

$$P_x = q\pi D\left(\frac{-X^2}{2CL} + \frac{X}{C} + \frac{L}{S}\right) \tag{1}$$

Where q is the outgassing rate per unit area, P is pressure, D is tube diameter, X is distance from pump end of tube, C is conductance, L is the length of the tube, and S is the pumping speed [2]. Values of X/L = 0.125, 0.25, 0.50, and 0.75 yield the following, respectively:

$$P_{0.125} = q\pi D\left(\frac{0.2344}{2C} + \frac{1}{S}\right) \tag{2}$$

$$P_{0.250} = q\pi D\left(\frac{0.4375}{2C} + \frac{1}{S}\right) \tag{3}$$

$$P_{0.500} = q\pi D\left(\frac{0.75}{2C} + \frac{1}{S}\right) \tag{4}$$

$$P_{0.750} = q\pi D\left(\frac{0.9375}{2C} + \frac{1}{S}\right) \tag{5}$$

Therefore, for a given pumping speed, conductance, outgassing, and tube diameter, the pressure gradient along the length of the tube is significant.

Electro-pneumatic gate valves mounted on the blower inlet and turbo pump inlet isolated the tank along with both the rough and high vacuum pumping lines. A custom software application on a Direct Logic 06 Koyo PLC with a 4-channel analog input attachment module controlled and monitored the evacuation cycle. A separate PLC controller monitored the tank pressure via two convection-enhanced Pirani gauges attached to the tank and provided a dry-contact closure interlocked to the neutron detector high voltage supply when the tank pressure was above 700 Torr or below 2 mTorr. However, this pressure monitor was not tied to the Koyo PLC controlling the vacuum system. Venting of the tank was accomplished by stopping the evacuation cycle on the PLC and manually opening a 25 mm manual angle valve.

An aluminum neutron window separates the detector tank from the sample environment and incoming neutron guide [5]. Consequently, separate vacuum systems evacuated these defined regions. A Pfeiffer Cube with a rated pumping speed of 80 l/s attached to the guide and sample environment via a manual isolation valve. This system had no pressure monitoring instrumentation other than separate pressure instrumentation included within the neutron chopper systems installed within the neutron guide.

The original detector tank vacuum system offered several opportunities for improvement. Primarily, the time required to evacuate the 69 m^3 detector vessel to 2 mTorr was 500–1000 min, as shown in Fig. 1.

The water vapor load in the detector tank was such that it adversely affected the life of the dry scroll pump [4] used to back the turbo pump. Secondly, the isolation valve for the Leybold roughing package

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