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Complex Detector Vessel for Small-Angle Neutron Scattering (SANS) instrument for The Australian Nuclear Sciences and Technology Organization (ANSTO)

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Abstract

The design of any Small Angle Neutron Scattering machine contains a set of major elements. The first up-stream bit is used to filter the beam and select neutrons of desirable wavelengths. The next element is the collimator, narrowing the beam. Then, after the sample stage, a large detector vessel is placed. The purpose of the vessel is to create a clean high-vacuum environment for the detection system. The latter is the core element of a SANS instrument, therefore design of the detector vessel is an extremely important part of the manufacturing of the entire instrument.

The current paper describes the design of the detector vessel for the Bilby instrument at the Australian Nuclear Sciences and Technology Organization (ANSTO) in Australia. The Bilby is a new Time-of-Flight Small-Angle Neutron Scattering (SANS) instrument. A number of similar instruments are in operation and are being used successfully including one at NIST [1] and at the Institute Laue Langevin [2].

The engineering design of the vessel is developed by ADC based on a detailed concept created by designers and engineers of the Bilby project, seen in Figure 1 below.

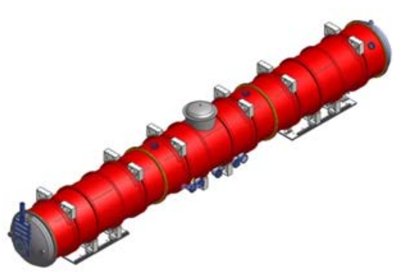

Figure 1: Complete detector vessel

Small Angle Neutron Scattering Technique

Small Angle Neutron Scattering (SANS) is a technique, similar to the often complementary techniques of small angle X-ray scattering (SAXS) and light scattering, used for investigations of structure of various substances, with spatial sensitivity of about 1 - 1000 nm. These are useful because many materials, substances and biological systems possess interesting and complex features in their structure, which match the useful length scale ranges that these techniques probe. This technique provides valuable information covering a wide variety of scientific and technological applications including chemical aggregation, defects in materials, surfactants, colloids, ferromagnetic correlations in magnetism, alloy segregation, polymers, proteins, biological membranes, viruses, ribosome and macromolecules.

SANS uses collimated a beam which hits the sample, scattering and is then recorded by the detection system. Experimental data, i.e. dependence on intensity on angle, contains information about structural features inside the sample.

There are numerous SANS instruments available worldwide.

Analysis of the data obtained can provide information on size, shape, etc., without making model assumptions, using so called *ab initio* methods; though any *a priori* available structural information helps to build more detailed model of the object under investigation.

During a SANS experiment, neutrons are elastically scattered by changes of refractive index on a nanometer scale inside the sample; which is the interaction with the nuclei of the atoms present in the sample. Neutrons are capable of interacting strongly with all atoms. This is in contrast to X-ray techniques in which the X-rays interact with electrons.

The scattering factor for X-rays increases with atomic number, so no difference is observed between H and D.

In turn, the scattering factor for neutrons is irregular and may be negative. The most commonly used feature is the sufficient difference between scattering by H and D, seen in Figure 2 below. This difference allows use of a very powerful technique called "contrast variation". Controlled exchange of hydrogen by deuterium allows for the design of material with desirable scattering density and ability to study the inner structure of the sample.

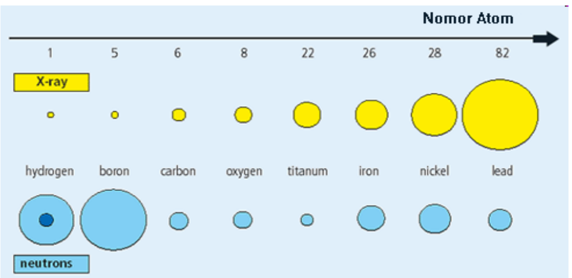

Figure 2:Neutron Scattering Length (b) represents strength of interaction between neutron and nucleus of scattering atom.

In zero order dynamical theory of diffraction, the refractive index is directly related to the scattering length density and is a measure of the strength of the interaction of a neutron wave within a given nucleus.

The most common use of the contrast variation is studying of proteins and DNA/RNA structures. Figure 3 below shows differences in relative scattering of bio-macromolecules in solutions with different percentage of D_2O.

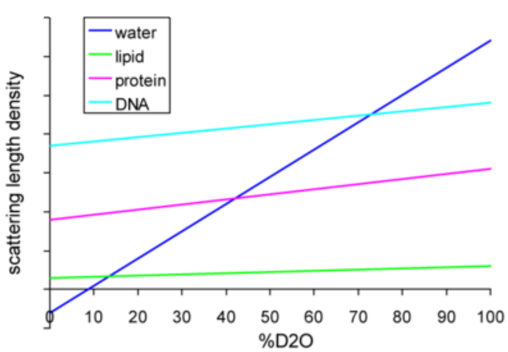

Figure 3: The relationship between the scatter of various biological macromolecules as a function of D_2O concentration.

ANS uses collimation of the neutron beam to determine the scattering angle of neutron experimental data, i.e. dependence of intensity on angle; contains information about structural features inside the sample.

Vessel Design Overview

The design consists of a large vacuum chamber (internal diameter 2,300 mm, length 20,020 mm, with straightness from front to back within ±10 mm) and complex long internal and external positioning systems. The vessel sections will be joined with mating flanges and captured O-ring seals. The sections shall provide relocation features such as dowel pins. Dowel pins should be a substantial diameter (minimum 1 inch diameter). The vessel will be designed and constructed as a pressure vessel ("subject to external pressure") in accordance with ASME Pressure Vessels. The vessel sections will be stress relieved after final welding but before final machining of the flanges. It is designed to be pumped down to 7.5 x 10^-5 torr and exhibit a maximum leak rate of 1 x 10^-7 mbar-L/sec. An internal track system is designed for the movement of two independent detector carriages over the length of the vessel. Each carriage is expected to have a minimum mass of 2,000kg. The Detector Vessel will be placed on an external track system to allow for no less than 1.5m of axial travel of the entire vessel, seen in Figure 4 below, the weight of which approaches 30,000kg.

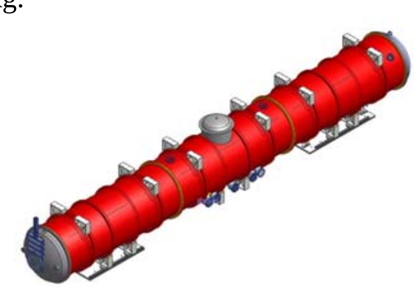

Figure 1: Complete detector vessel.

Brackets will be provided along the top of the vessel for lighting. Internal track supports will be formed and welded to either side of the bottom of the vessel for carriage guide rails. These rail supports will be parallel to the external vessel supports. Internal track supports will be +/- 5mm over the full length of the vessel. Internal supports will be fabricated and welded to the internal chamber above the track supports for cable wire way support.

External supports will be fabricated and welded to the bottom of the vessel. The weld points for these supports on the vessel require double wall thickness. External supports for a platform on top of the vessel will be fabricated and welded to the vessel. The weld points for these supports on the vessel also require double wall thickness.

Vessel Structural Elements

The vessel will contain a rear access full-sized hatch, front end, top hatch, and several ports.

Rear Hatch

The rear access hatch shall be a full-sized access hatch opening outwards. It shall be hinged (on the left side when looking from the rear of the vessel toward the front) in order to provide access. The hinge shall incorporate a feature to allow the hatch to close without any scrubbing of the seals and misalignment of the flanges, e.g. articulated hinges or similar. The hinge shall also incorporate a method to prevent the rear hatch opening past 90° and also to hold the hatch in this position for entry or maintenance.

Front End

The front end of the vessel is mounted to the front flange and supports a gate valve and contains two glass view ports. The front end of the vessel will also have a 630mm blanking flange for use during vacuum testing.

Top Hatch

The vessel will have a 1200mm diameter top hatch, which will be lifted by eye bolts attached to the hatch.

Ports

The vessel will be equipped with several ports. Where required, all ports are to be supplied with appropriate blanking flanges, seals and clamps to enable vacuum testing. Vacuum penetrations from 10 to 50 mm diameter shall be terminated with ISO-KF vacuum flanges, penetrations from 63 to 320 mm diameter shall be terminated with ISO-K vacuum flanges. The ports on the vessel are as follows:

- (1) 1200 mm d. hatch on the top of the vessel
- (1) 630 mm d. ISO-F for front gate valve
- (1) 250 mm d. ISO-K for vacuum pump connection
- (2) 320 mm ISO-K for turbomolecular-pumps, top
- (10) 320 mm ISO-K; cable feedthroughs (5/ side)
- (2) 8 inch CF flanges for viewports on the front end
- (1) 8 inch CF flange for viewport on the back hatch
- (4) 50 mm d. ISO-KF ports, leak check & gauges

A pop-off valve for pressure relief will be placed on one of the 50 mm ports to be delivered with the vessel. A vacuum evacuation valve will be placed on one of the 50 mm ports. A muffler is required on this port to keep noise levels below 85 dB (at a distance of 1 meter), to be delivered with the vessel. Eight (8) 320 mm flanges will have five (5) each, welded 4.5 inch CF nipples, these will be used for cable connector feedthroughs, as shown in Figure 3 below.

Figure 3: Flange with CF nipples for cable connector feedthroughs.

References

[1] C. J. GLINKA,* J. G. BARKER, B. HAMMOUDA, S. KRUEGER, J. J. MOYERt AND W. J. ORTS (1997). J. Appl. Cryst. (1998). 31, 430-445

[2] C D Dewhurst (2007). Meas. Sci. Technol. 19 (2008) 034007 (8pp) doi:10.1088/0957-0233/19/3/034007