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Forces Associated with the Deployment, Operation and Failure of the Neutral Current Detectors [1]

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Abstract

Simple, worst case estimates of the forces exerted on the acrylic shell of the D_2O containment vessel during the installation and under normal operation of the neutral current detectors are derived.

1 Introduction

The D_2O containment vessel of the Sudbury Neutrino Observatory (SNO) consists of an acrylic sphere, 1200cm diameter and 5cm wall thickness, containing 1,000 tonnes of D_2O. It is surrounded by approximately 7,000 tonnes of H_2O. In order that tensile stress in the shell of the vessel be minimised

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(to reduce the possibility of the acrylic crazing) the level of the H_2O is maintained so as to ensure that the sphere is constantly under compression. Under these conditions, the principal mode of failure of such a vessel is catastrophic buckling which can result from deviations from perfect sphericity and excessive local loads..

Located inside the D_2O vessel are 112 strings of cylindrical, gas filled, counters, arranged vertically on a horizontal grid of 1m spacing. Since these counters are buoyant, they must be anchored to the lower shell of the vessel, therefore they represent a source of local loading which must be considered in the light of buckling.

The counter strings will be installed in the vessel while it is full of D_2O, using a remotely operated submersible vehicle (ROV). This operation will inevitably impose some short term local loading on the acrylic shell.

2 Operational Loads

The arrangement of the counter strings is shown schematically in figure 1. Each string is made up by joining sub-components of 1 or 2 meters length. The subcomponents consist of nickel tubes, 0.254mm wall thickness, 50.8mm outside diameter. The tubes are pressurized to approximately 3 atmospheres (absolute) with a gas mixture consisting primarily of helium. For simplicity and conservativeness, we assume that the tubes are massless and that the only force is buoyancy due to water displacement. Thus the force per meter which the counter exerts while immersed in D_2O is;

$$\mathrm{V}.\rho.g$$

$$\pi \times (0.025)^2 \times 1.0 \times 9.8 \times 1.1 \times 10^3$$

$$\approx 22 \ \mathrm{Newton.meter}^{-1}$$

The loads imposed on a quadrant of the shell are given in table 1. Note that since the detector strings are made by joining 1 and 2 meter long sections, the lengths (and loads) given in table 1 should be rounded down to the nearest meter, however, it is conservative to say that the maximum buoyant load of

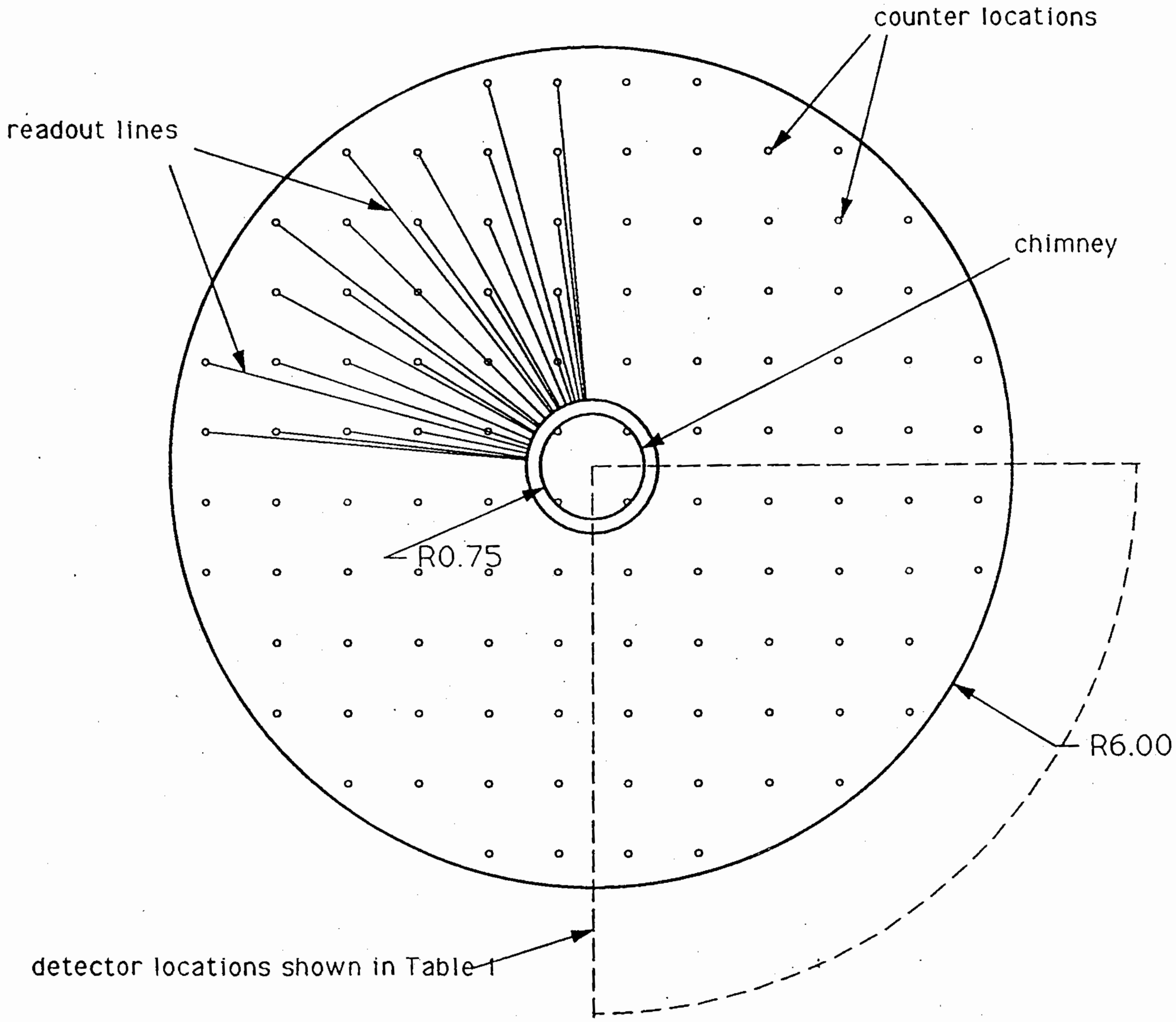

Figure 1: Plan view of the arrangement of the counter strings inside the acrylic vessel.

	1	2	3	4	5	6
A	11.92m 260N	11.56m 253N	10.87m 237N	9.70m 212N	7.87m 172N	4.69m 102N
B	11.56m 253N	11.22m 245N	10.49m 229N	9.27m 202N	7.35m 161N	3.74m 82N
C	10.87m 237N	10.49m 229N	9.70m 212N	8.37m 183N	6.16m 135N	
D	9.70m 212N	9.27m 203N	8.37m 183N	6.78m 148N	3.74m 82N	
E	7.87m 172N	7.35m 161N	6.16m 135N	3.74 82N		
F	4.69m 102N	3.74m 82N				

Table 1: Lengths and loads for the detector strings in one quadrant.

a counter will not exceed 260N. To this should be added a small load due to tension in the readout cable (≈10N).

Each detector string has a high voltage/readout cable attached to its upper end and exiting through the neck of the vessel. These cables are 6mm diameter and have a net buoyancy of 4% in order that they conform to the upper hemisphere of the acrylic vessel. In conforming to the wall of the vessel, the readout cable applies a net horizontal, inward force to the top of the detector string which results in the string being displaced from the vertical. This displacement force has two contributions;

Buoyancy in Vessel + Buoyancy in Neck

$$(\rho g \pi r^2 R \int_{\theta_1}^{\theta_2} \sin(\theta) d\theta + \rho g \pi r^2 L) \sin\theta_3$$

Where ρ is the density of water, R is the radius of the vessel, r is the radius of the readout cable and L is the length of immersed cable in the neck of the vessel. θ_1 and θ_2 defines the angular range over which the cable contacts the spherical shell of the vessel and θ_3 is the angle with respect to the vertical

Length	60cm.
Width	40cm.
height	20cm.
Weight (flooded)	25kg
Weight (in water)	neutral
Speed	0.5m/sec.
Max. thrust	15kg.
Weight of cable (in water)	2.5kg/20m.

Table 2: Preliminary specifications for the remote operated vehicle.

of the readout cable as it exits the top of the detector. Currently we don't have a value for θ_3, only a limit, $\theta_3 \leq \theta_2$. For an outermost counter (which experiences the largest displacement force but the smallest restoring force) of 3m length, this displacement force amounts to approximately 0.16N, assuming no frictional coupling of the readout line to the shell. This would only displace the top of the counter $\approx$ 2 cm. However, coupled with other possible disturbances (i.e. ROV snagging, excessive tension in the readout line, possible convection currents, etc.), significantly larger diplacements are possible. To avoid this situation an upper attachment point is required, over which the readout line passes.

In practice the load experienced by this upper attachment should not exceed the restoring force due to the buoyant cable plus any tension in the readout line. This tension must be kept small or the buoyant readout line will no longer conform to the spherical shell. Therefore it is conservative to say that the operational load on the upper attachment point will not exceed a few Newtons.

3 Short-term Dynamic Loads

Essentially all dynamic loads are expected to occur during installation of the detector strings by the ROV. The preliminary specifications for the ROV are given in table 2. In figure 2, the ROV is shown in the act of transporting a detector string from the central delivery rack (used for pulling a detector string into the vessel) to the attachment point on the wall of the vessel. The ROV is enclosed in a smooth, impact absorbing shell. The only object projecting from the shell's profile is the attachment claw. This is designed to be compliant under loads exceeding the maximum detector string buoyancy and is plastic coated with no sharp corners. Potential short term loads could result from the following incidents;

1. Impact of ROV with acrylic shell, ($\approx$400N, $\ll$sec.).
2. Snagging of ROV on lower or upper attachment points, ($\approx$400N, $\leq$sec.).
3. Dead weight (flooded) of ROV applied to upper attachment point, ($\approx$250N, $\gg$sec.).
4. ROV applies full thrust against acrylic shell, ($\approx$150N, $\geq$sec.).
5. Excessive tension applied to readout line ($\approx$1000N, $\geq$sec.).

As can be seen, four out of five of these loads are associated with the ROV. In estimating the force resulting from impact or snagging (items 1 & 2) it is assumed that the ROV is traveling at full speed and is arrested in 1cm by the compliant shell or control cable. Item 5 is a conservative calculation of the force required to break a 6mm diameter polyethylene readout line, assuming high density polyethylene with a tensile strength of 5,500psi. Since the readout line passes over the attachment point, the total force could in theory be twice this amount. Although this load does not exceed the strength of the bond joining the upper attachment point to the shell of the vessel, it is is considered to be excessive, especially since this is potentially a long term load. Consequently, the Neutral Current Detector (NCD) Group have been requested to ensure that the readout string cannot sustain a load of greater than 250N, i.e. not to exceed the other long term for, item 4, a flooded ROV. The length of the ROV control cable is such that should the vehicle "die" in operation the cable will prevent it from coming to rest on the bottom of the vessel. A "dead" vehicle may fall from a considerable height ($\approx$11m) while servicing the upper attachment points, and impact the lower shell of the vessel, (note that this can easily be avoided by simply reeling in the surplus control cable attached to the ROV). The maximum (fully flooded) weight of

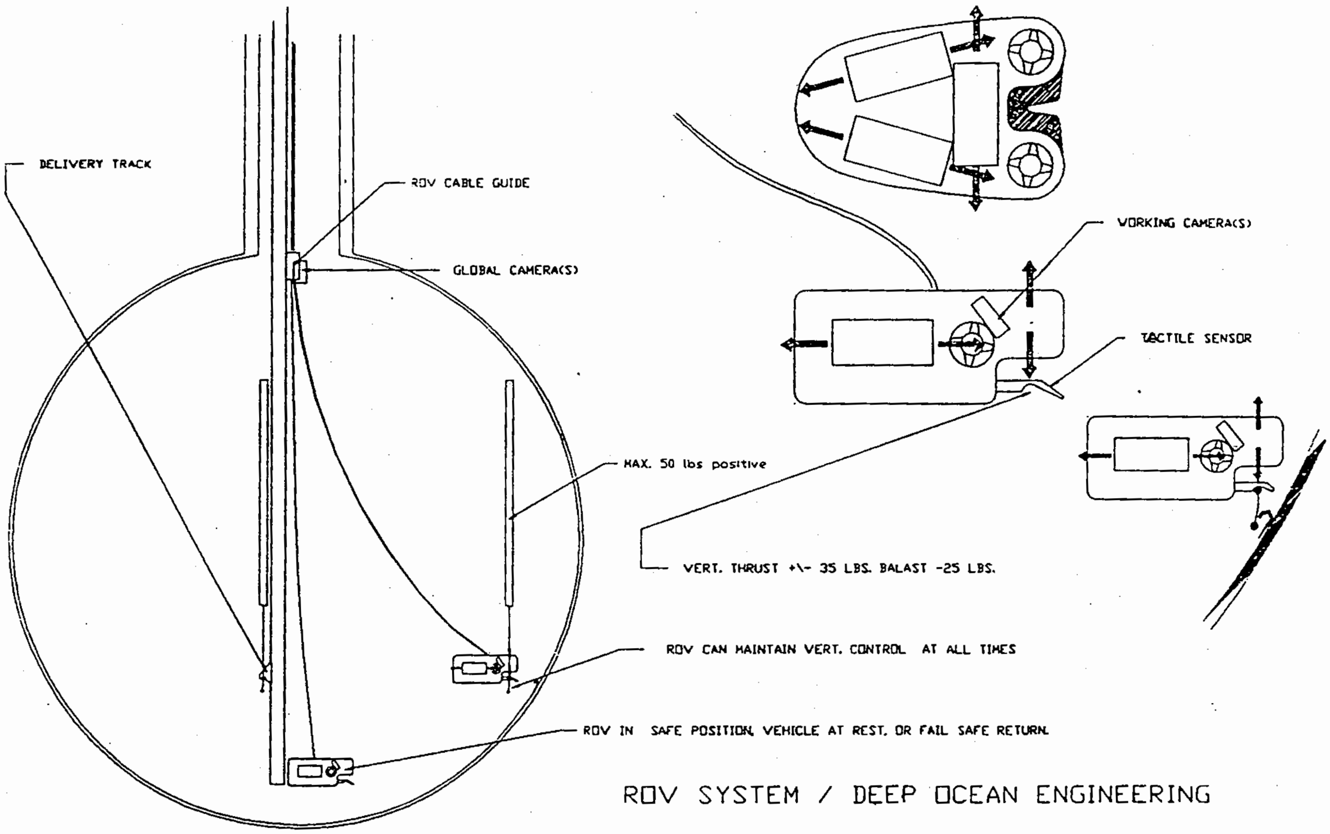

Figure 2: ROV deployment system (Deep Ocean Engineering, Inc).

a dead vehicle is 40% greater than the maximum thrust, which is capable of propelling the vehicle at 0.5 m.sec^{-1}. Since the resistance to an object moving in a fluid is crudely proportional to the velocity squared, the terminal velocity of a falling ROV will not be much greater than its operational velocity. The impact forces are therefore expected to be similar to that of item 1.

Another source of short-term loading is the possibility that the top of a detector string strikes the upper hemisphere as the ROV is traversing (at an incorrect depth) the vessel. This load is considered to be negligible for the following reasons; a) the maximum speed of the ROV is considerably reduced while carrying a detector string, b) The readout string imposes considerable drag as it is drawn over the surface of the vessel, c) The will energy absorbing cap of the detector string (see below) will be the first to impact the vessel wall.

4 Loads Associated with Failure

Failure loads arise if the detector string either breaks away from the ROV during deployment or from its attachment point during normal operation. The following illustrates possible failure scenarios;
1) A detector string breaks free from the ROV. If the string is a long one the total force accelerating it is high (≈260N) but the distance it can travel is short. If a short detector string breaks away from the ROV while it is deep in the vessel, then although the acceleration forces are low, the path of travel is long.
After the initial impact of the top of the detector string with the inside of the vessel, the detector string will then begin to pivot around the impact point until the lower end of the detector string strikes the vessel. However due to the increase viscous drag of the water (and hence energy dissipation) in this mode, it is considered that the initial impact would be the greatest.
2) A detector string breaks free from its attachment point. In this case the initial path of travel before contacting the vessel is short (≈15cm). The counter will however pivot round as described above.
Calculation of these impact forces (non-trivial) is presently under consider-

ation, however, it is recommended that simple, energy absorbing caps be fitted to both ends of the counter. A convenient time to conduct tests of such a device would be during the evaluation of the prototype ROV which is scheduled to take place January 1993.

5 summary

The short term forces associated with installation of the NC detectors and the long term operational loads transmited too the acrylic vessel are not significant.

The short term ($\leq$ sec.) will not exceed 400N. The long term forces ($\geq$ sec.) will not exceed 250N. To achieve the limit on the long term load, the NCD group has been requested to consider this limit when designing the readout lines for the detectors.

The forces (and possible damage) arising from a free detector string are difficault to estimate. It is prudent therefore to fit the detector strings with energy absorbing end caps and to test their effectiveness prior to installation of the detector strings into the acrylic vessel.