UNDER PRESSURE

As an underwater vehicle submerges, the hydrostatic pressure on its surface area increases at a rate of approximately one bar per 10.6m of water depth. By the time it reaches thousands of metres, delicate components such as the vehicle's electronic instrumentation are subject to very considerable pressures. For this reason, electronic equipment is housed in specialised protective enclosures.

There are two types of enclosure, 'one-atmosphere' and 'oil-filled'. . Many companies offer both types and so the selection is based on the application.

A one-atmosphere enclosure is essentially a sealed vessel, the wall thicknesses of which being sufficient to withstand any extreme ambient external pressures imposed on it. This method is principally used for marinising commercial off the shelf electronics. Once the lid is secured on the cannister or bottle, everything inside is trapped at atmospheric pressure.

The 'oil-filled' alternative takes advantage of the fact that liquids are virtually incompressible. It envisages placing the electronics in a watertight enclosure displacing the air inside with a pressure-compensating fluid, normally oil. The internal fluid perfectly resists the ambient pressures pushing against the sides of the enclosure.

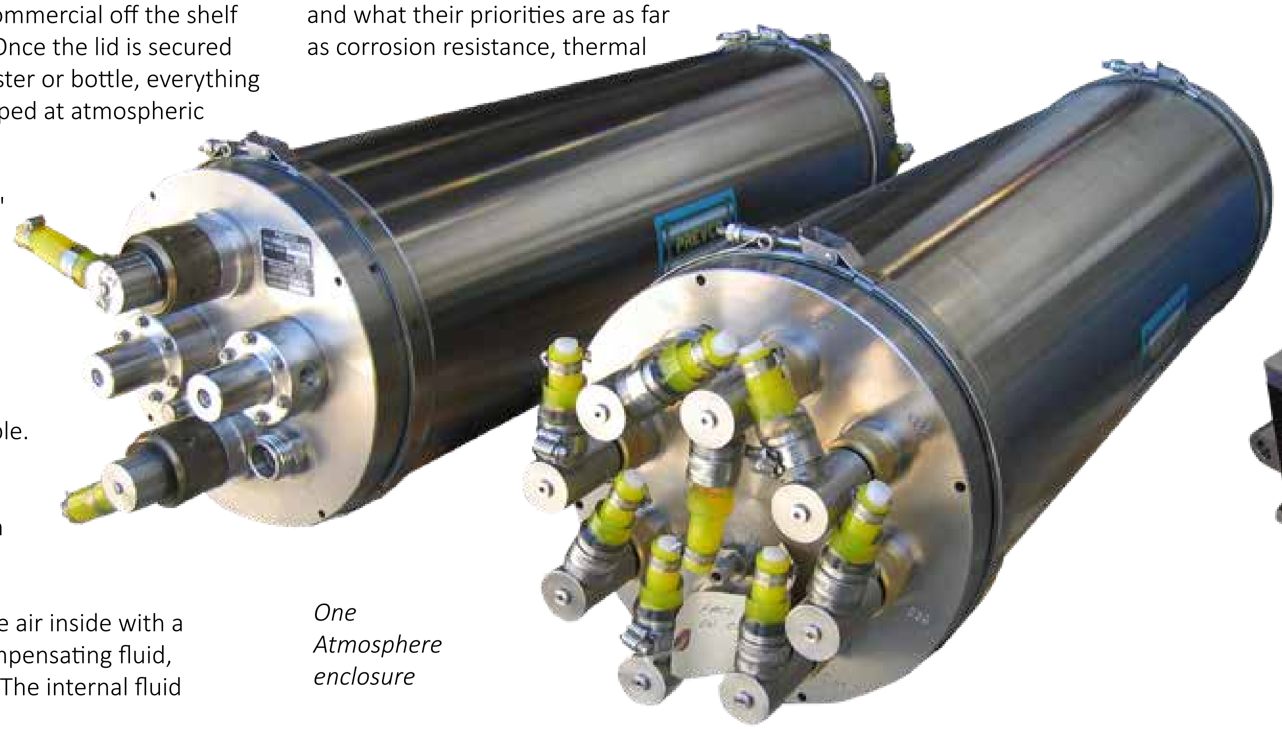
ONE ATMOSPHERE

"Numerically, most of the pressure vessels used on underwater vehicles are the one-atmosphere air-filled variety because a majority of electronics are incompatible with working in a liquid, high pressure environment," said Stephen Ashley, Technical Sales Manager at Prevco. "While some military electronics behave perfectly well in oil , most commercial units are not designed to be immersed this medium.

"When designing a one-atmosphere pressure vessel, the choice of material is paramount. We would always ask a customer for as much information about the deployment as possible, including depth or pressure rating, time at depth 'continuously' and what their priorities are as far as corrosion resistance, thermal conductivity, weight and of course, cost.

"From a point of view of corrosion resistance, an Anodised Aluminium housing should usually be brought to the surface on a 3–6-month basis to check for any scratches to the anodise and to replace Zinc Anodes as necessary. On the other end of the scale, materials such as Super Duplex Stainless Steel, Titanium and Copper Beryllium can remain underwater or even on the seabed for 10, 15 or 20yrs with no maintenance.

"From a point of view of thermal conductivity, Aluminium, Stainless Steel and Copper Beryllium are much better than plastic enclosures or Titanium – a bit like putting a blanket over something. The enclosure might need some method of heat sinking to get component-generated heat out of the enclosure and into the sea.



One Atmosphere enclosure

Radial fins, thermal heat sink pipes and internal cooling pipes could all be considered.

"Because of necessity for thicker walls to withstand the pressure, this can translate into quite large, often custom-made cylinders or spheres. In smaller vehicles, the relative weight of these larger containers may sometimes require inclusion as part of the vehicle's total buoyancy calculations.

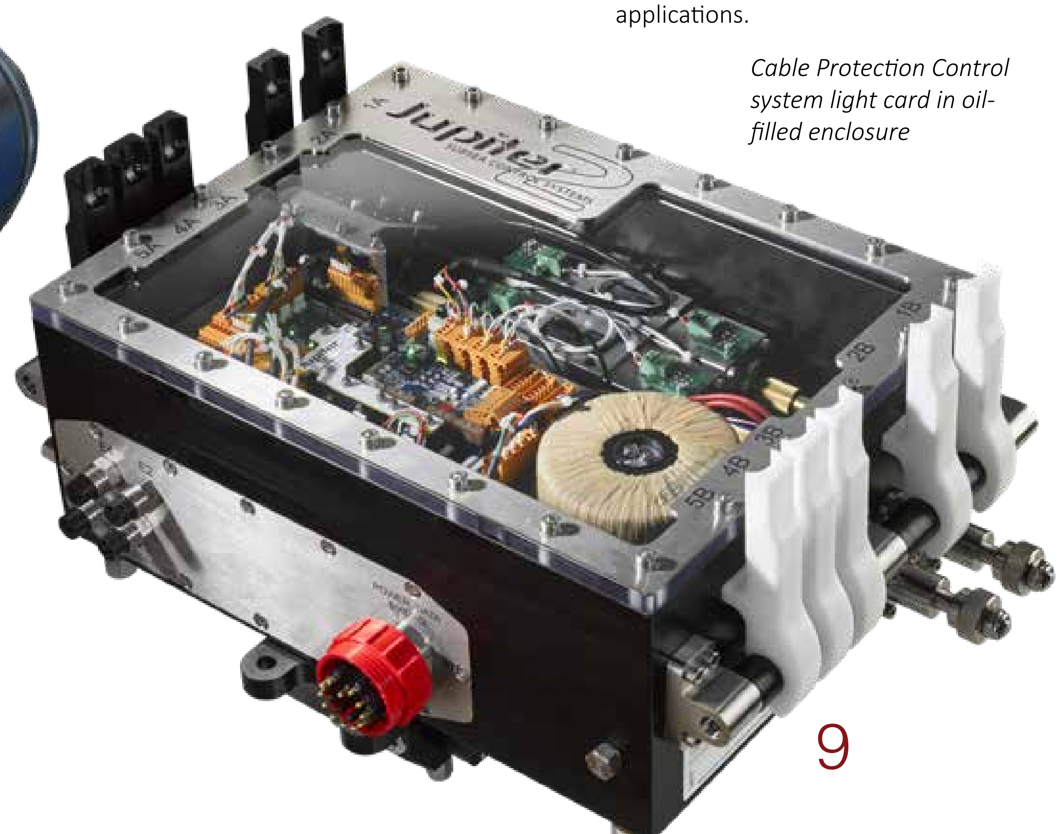
"As such, lighter/stronger metals are often preferred (ie, Titanium) to cheaper stainless steel, Aluminium or plastics. The main thing to keep in mind is to always choose the right material for the deployment, regardless of cost, as failures in the field can be extremely expensive.

"We often use Titanium due to its high strength and low weight. The maximum water depth we are normally asked to work to is 6000m, although we have had enquiries from Chile from a company that wanted to put an ROV and camera into a trench to film sea creatures in 8000m of water. We simply fed the details into our design software and produced a suitable specification.

"The larger one-atmosphere units are more likely to be cylindrical metal designs in which the flange is fabricated as part of the original piece of material (as opposed to being welded on which would be a potential source for cracks corrosion or weaknesses)."

OIL FILLED

Because the walls do not need to be so thick while seal loading is lower, oil-filled systems are often considerably smaller than one-atmosphere systems, to the point where relatively modest PVC containers have been used for some applications.



Cable Protection Control system light card in oil-filled enclosure

Typical applications are the use in junction boxes that house control systems although they have also been specified in housings for subsea video, multiplexers, transceivers and light control systems.

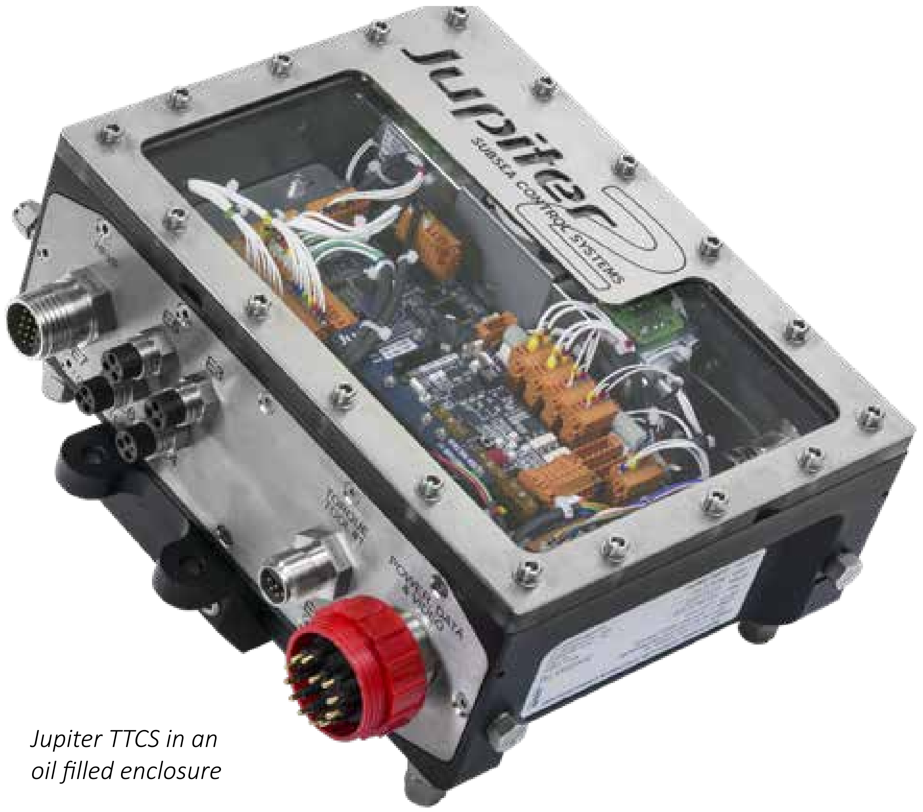
The downside of oil-filled systems is that the electronics inside have to be considerably more robust as they are subject to full ambient pressure. This translates as purpose-designed specialist circuitry using high-strength components. These have to be tested rigorously before being put in the enclosures.

"The electronics not only have to cope with the full depth pressure but also the fact that the printed circuit board (PCB) is immersed in oil. It is very important to always ensure that there is a small pressure differential between the inside and the outside," said Paul Fletcher, Operations Manager at Zetechtics.

"This means that at 4000m depth, we need the electronics to withstand 440bar (400 bar plus 10%).The selection of components is therefore critical. If there is something with a void, a tantalum capacitor with an air bubble inside for example, the component will crush and fail.

"You have to think differently when designing the circuits for inside the oil filled enclosure . We specify the high-grade components that we want the board to contain and how we want it laid out, and pass this to our specialist suppliers for manufacturing.

"After some basic tests on the completed board , we receive the



Jupiter TTCS in an oil filled enclosure

unit in-house for inspection and run it through our it environmental chambers for temperature cycling. It then goes for bench testing and ultimately pressure testing. This is done for every subsea PCB as standard before it is allowed to be used or sold.

"The environmental chamber cycles the temperature between-20^{o}C to +80^{o}C, stressing the board to identify any weak or bad solder joints. We then put it onto our automatic testing equipment (ATE) and run a series of 1000 tests in two hours." If, for any reason we need to change any components, we then put it back through the ATE process and pressure testing.

"The Jupiter software is designed so that the hardware channels are software selectable. If part of the system fails such as a valve isn't working, it is possible to re-map it to a different channel. This provides diversity of redundancy for the operators

"We have standard enclosure dimensions for all of our control system variants which are scalable and modular but with removable side plates so that the customer can upgrade or add sensors or pressure transducers. We then build it accordingly.

Before installation offshore, it is important that the system is filled with oil, bled of all air and compensated for the depth of operation and temperature range from on-deck to subsea.

OIL

"There are a number of different types of oil on the market. We insist that enclosures are filled with transformer oil or equivalent This is very high grade and a very strictly controlled water content. We can also recommend the use of some friendly oils inside the enclosures. Some of the operators use hydraulic oil and run it through a CJC filter first to remove the water from the oil before filling the enclosure.

"Filling the enclosure with oil can be messy, but it is vital to ensure any voids or air gaps are removed as this could crush the lid and destroy the electronics. The preferred way of filling the unit is to use the four connections, one at each corner.

When mounted vertically, oil is injected in through the bottom port and bled out of one at the top. Once it is full of oil and compensated, it is important that any leak results in oil coming out rather than seawater pushing in.

"At the surface it is pressurised to 0.7 Bar above ambient pressure and as the enclosure dives down, it maintains maintain this small pressure differential between the inside and the outside of the box.

"Even though the oil is incompressible, the volume can change as the enclosure submerges," continued Fletcher. "To maintain the pressure differential, the volume changes need to be accommodated for by compensator. This is like a back-up reservoir with a large spring that provides the energy to feed more oil form from the reservoir into the system , maintaining the positive pressure and preventing water ingress.

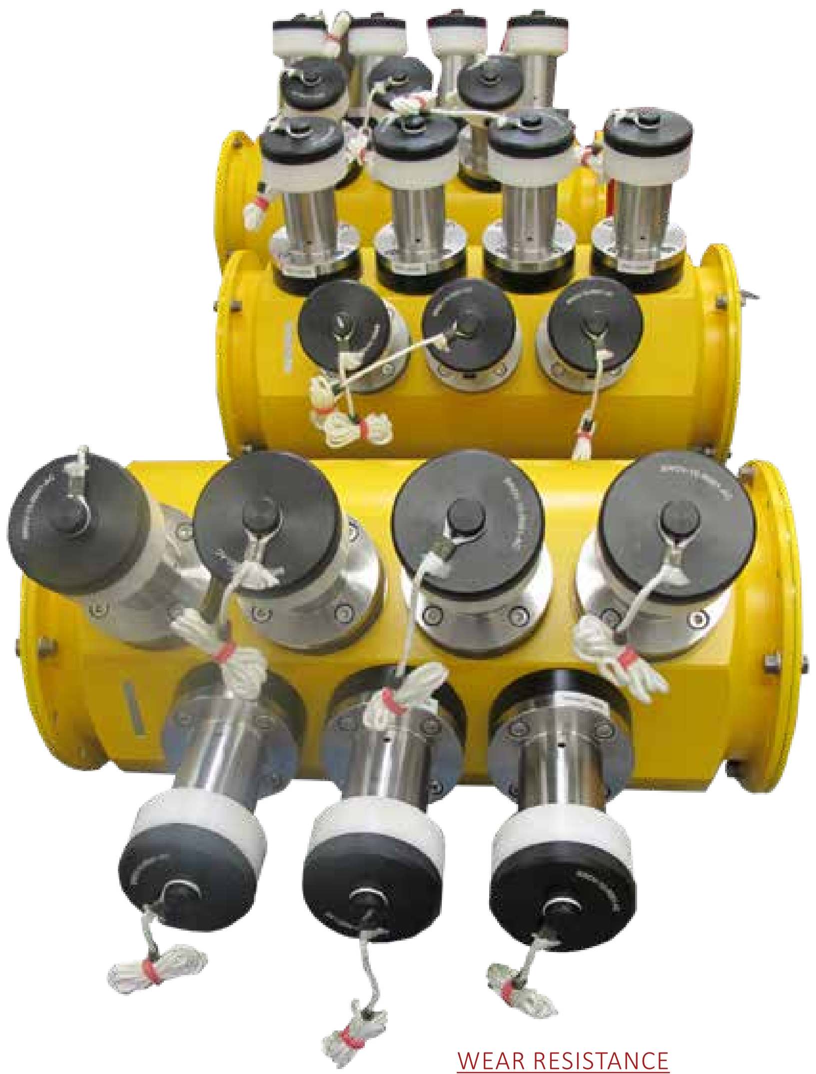
"Compensator levels are often monitored with electronic sensors and alarms to show the rate at which levels dropping. If these sensors show the level decreasing, this buys the pilots time and gives an indication of when the vehicle needs to resurface.

"The operator might want to fill the compensator 100% full, but there is another consideration. When running through motors or if it is used in a hot climate, the oil will get hotter, and the oil can expand with heat.
The operator, therefore, may decide not to fully fill the compensator because it may blow the compensator's relief valve, the safety mechanism designed to ensure that the box does not crack.

ANODISING

One very cost effective material for all underwater enclosures is anodised aluminium

“Hard anodising is a surface treatment that turns a relatively soft aluminium surface into a material almost as hard-as-diamond," said Dr Anne Deacon Juhl of Aluconsult. "Elsewhere anodising is used to make helicopter blades that can withstand sandstorms.



"The main purpose of anodising is to form a thick and dense oxide layer over the softer aluminium to provide high wear and corrosion resistance .

There two main types- Type II and Type III (often referred to as hard anodising).

"Type II anodising is the most often used process to achieve this protective anodic layer," said Juhl. However, some product applications require an even thicker oxide layer – with more aluminium oxide above 25 µm. This is when hard anodising or Type III anodising becomes interesting. On a structural level, hard coat anodising is denser, with narrow pores and very thick cell walls.

"For hard anodising, it is important to use higher current density so that the coating has to be formed by current-controlled processes, not voltage-controlled. Furthermore, using electrolytes with low oxide dissolving power at low electrolyte temperature ensures a limited amount of oxide dissolution. By varying the process parameters, the characteristics of the hard coat can be *tuned* to meet specific design requirements.

"Structural deviations in the hard coating can be related to microstructural features in the aluminium alloy. The best results for hard anodising can be seen on low alloyed aluminium with less than 5% copper and less than 8% silicon.

Apart from the high corrosion resistance, the hard anodised oxide layer has other valuable properties, such as low friction and a non-stick surface.
Tests have shown it can withstand 3000 hours in a Neutral Salt Spray testing (NSS). In comparison, Type II anodising needs only 1000hrs to pass the NSS test.

Anodising confers a number of useful properties.

HARDNESS
The anodic coating has a hardness of more than 500 Vickers Hardness (HV) compared to tooling stainless steel with 950 HV. However, this pertains to a very thin hard coat layer on a very soft aluminium body.

WEAR RESISTANCE
Hard coating with 450 HV has the same wear resistance as tooling stainless steel with 950 HV even though the latter has almost twice the HV.

The aluminium copper alloys (the 2000 series) with 2% or higher copper content have a lower wear resistance than all other alloys.

DIELECTRIC
50 µm hard anodised coating will fail around 1.5-2.0 kV, sometimes higher.

HIGH-TEMPERATURE RESISTANCE
The hard coat withstands 2000°C for a short period of time.

ADHESION FOR CHEMICALS AND DYE:
Because of the pore structure, any chemicals will stay well on the hard coat layer without flaking off – even with high mechanical wear.

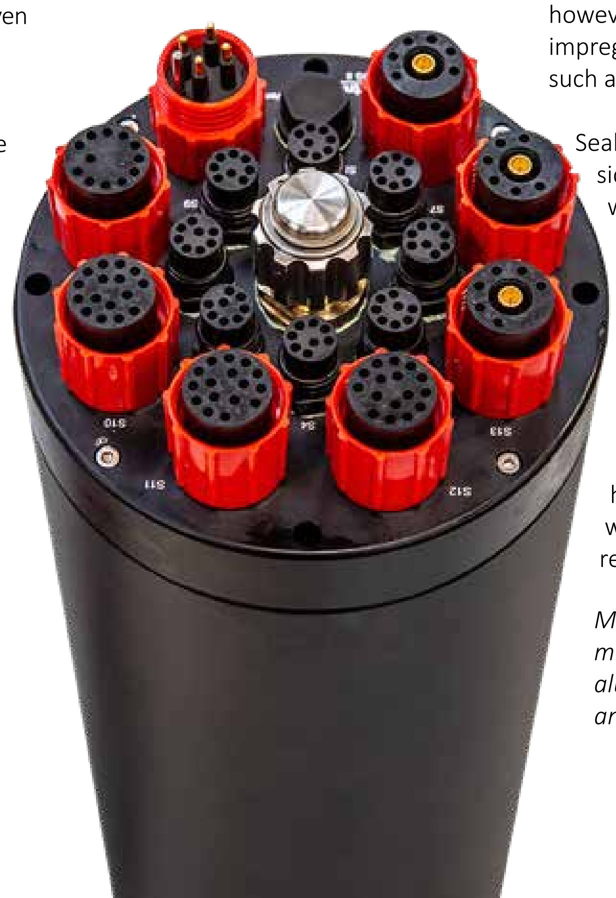
The hard coat can also be dyed, although it is difficult because the hard anodised layer has narrow pores and dye often consists of big dye pigments. In addition, the hard anodising layer has a colour of its own, ranging from dark grey (aluminium-silicon alloys) or brown to silvery aluminium (6000 series) appearance depending on the alloy.

A darker hard coat is usually dyed black while a lighter hard coat can be dyed with any colour.

"Hard coatings are usually unsealed to maintain a high wear resistance" said Juhl. "They can, however, be conventionally sealed or impregnated with different materials such as Teflon, waxes, and silicone.

Sealing seal the hard coat has the side effect that wear resistance will decrease by 20 to 50% depending on the sealing process used.

"If corrosion resistance is the most important property of the surface, sealing will enhance this property. The sealing will normally be in hot water or dichromate, which increases the corrosion resistance remarkably."



MacArtney NEXUS 8 multiplexer with anodised aluminium housing and anodised SubConn connectors