SPHERICAL GLASS INSTRUMENT HOUSINGS FOR DEEP OCEAN USE - THEIR DEVELOPMENT AND APPLICATION

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ABSTRACT

This paper takes the reader from the birth of the small, deep ocean, spherical glass instrument housing using unreliable greasy rubber gaskets to today's sophisticated, precision, large volume reliable unit. Glass housing penetrators for electricity, vacuum, water pressure, fiber optics, and optics are also described. Implosions and an explosion are covered in this overview of the subject.

INTRODUCTION

Understanding the modern day glass sphere, such as is produced by Benthos, will help to overcome the fear of using a breakable material as a deep sea flotation sphere or electronic instrument housing. Analysis and extensive experimentation have proved that properly designed, manufactured and maintained glass spheres are indeed very effective and reliable products for use in the deep ocean.

We all think of glass as a very weak material. It is, in tension. It is also a very strong material, in compression. The ratio of its compressive strength to its tensile strength as a hollow sphere is about 100:1.

A hollow glass sphere has several characteristics that make it a very useful deep ocean instrument housing.

1. The spherical shape takes advantage of the great compressive strength of glass since a hollow sphere is in pure compression when deep in the ocean. Actually, the deeper the sphere goes, the stronger it gets. To damage it while it is under pressure you have to first overcome the large compressive stress it is experiencing.

2. Glass is extremely corrosion resistant, ranking with titanium.

3. Glass is lighter than most metals. The net buoyancy of our glass housings is greater than their weight in air. They float more than half way out of the water.

4. Deep spherical glass housings are considerably less expensive than deep spherical metal housings.

5. Glass is transparent.

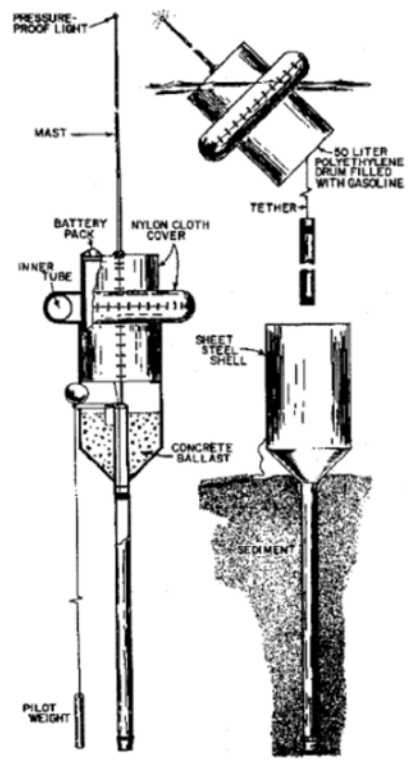


Figure 1
The original heavy and bulky free-fall Corer using gasoline for buoyancy and concrete for ballast.

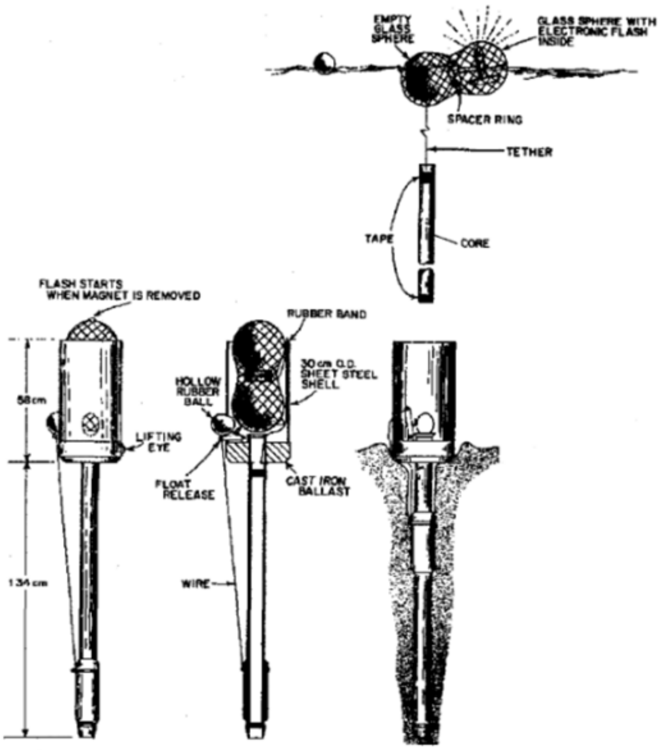


Figure 2

The compact Boomerang Corer using glass spheres for buoyancy and steel ballast. Note the flash unit inside one of the glass spheres which is used for float recovery.

THE DEVELOPMENT OF SPHERICAL GLASS INSTRUMENT HOUSINGS

In 1964, Benthos developed a free-fall, free-rising, deep ocean sediment coring device with Woods Hole Oceanographic Institution (WHOI). The flotation unit we originally used was a bulky, heavy and dangerous barrel of gasoline (see Figure 1). Then suddenly, deep sea glass flotation spheres became available from Corning Glass Works. The spheres were 25 cm (10 inches) in diameter and two of them together (weighing 9 Kg (20 pounds)), replaced our 41 Kg (90 pound) gasoline float. It was a significant change to our corer and made it practical (see Figure 2). The new corer became known as the "Boomerang Corer."

Spherical glass floats have been used for many years on fishing nets. These "fishing" floats are blown by hand, are irregular in shape, and therefore, have an unpredictable depth capability. The Corning floats would go deep and were made of two molded glass hemispheres fused together.

In order to be able to find the float of the corer when it came to the surface at night, we wanted to put a brilliant electronic flash inside one of the glass spheres. This would be a simple, reliable and inexpensive recovery system. However, there was a problem. How could we put the flash inside the fused glass sphere? We ordered two glass hemispheres from Corning and worked on ways to put them together to form a deep sphere that we could open for maintenance.

First, we ground the molded edges of the hemispheres flat. Then we installed a thin, firm (90 durometer) rubber gasket between the hemis. The assembled "sphere flash" is shown in Figure 3. This design worked for moderate depths. However, when we tried to go deeper, the rubber gasket flowed inward, dragging glass with it causing spalling all around the inside of both hemis. This type of failure is a dramatic illustration of one of the most fundamental characteristics to be considered when working with glass under pressure: Tension must be avoided. So, we did away with the rubber gasket and replaced it with silicone grease. Now the spheres could be subjected to the water pressure found at 6700 meters depth without encountering spalling or leaking.

Figure 3
Our first spherical glass housing. Note rubber gasket between hemis.

So, in addition to being in the Boomerang Corer business, Benthos was now in the deep sea glass housing business. However, we still had a problem. Occasionally we would see barely visible cracks mid-wall in the glass hemis, as shown in Figure 4. We eventually concluded that this was caused by the highly pressured grease being forced into the glass. (The grease pressure is about 8 times greater than the water pressure.) This phenomenon is similar to the "hydraulic fracturing" of the rock in oil wells. (It is purposefully

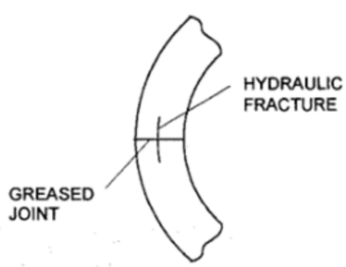


Figure 4
Grease in the joint between the glass hemis will develop high pressure and be driven into the wall of the sphere by "hydraulic fracturing".

done to recover more oil.) To overcome this problem, we eliminated the grease which eliminated the hydraulic fracturing and assembled the glass hemis with their flat edges clean and dry. We added a soft butyl rubber sealant to keep water out of the joint between the hemis, as shown in Figure 5. This is the method of sealing we still use today.

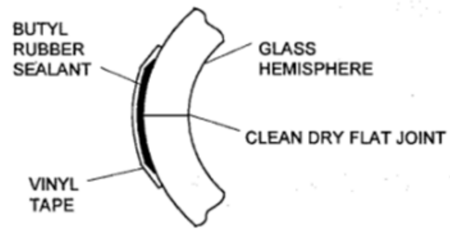


Figure 5
The final design with a clean dry glass joint and sealant outside to keep water out.

After manufacturing 24.5 cm (10 inch) glass housings for a number of years, we found there was a need for much larger spheres and came out with our 43 cm (17 inch) diameter housings and floats. These spheres have the following characteristics:

- Wall thickness: 14 mm (.56 inch)
- Weight in air: 17.7 Kg (39 pounds)
- Net buoyancy: 25.4 Kg (56 pounds)
- Depth rating: 6700 M (22,000 feet)
- Theoretical collapse depth: 10,000 M (32,810 feet)

The spheres are made from annealed low expansion borosilicate glass with the following properties:

- Specific Gravity: 2.22
- Young's Modulus: 62 GPa (9×10^{6} p.s.i.)
- Poisson's Ratio: 0.20
- Refractive Index 1.48
- Thermal Coefficient of expansion: 38×10^{-7}/°C
- Specific Heat: 0.18 calories/gm°C

As the spheres descend in the ocean they become smaller by an amount Δd.

$$\Delta d = 1.16 \times 10^{-6} Dd$$

where D = the depth to which sphere is submerged in meters and d = the diameter of the sphere.

A 43 cm sphere shrinks approximately 3.3 mm at 6,700 meters.

The approximate decrease in volume ΔV of a sphere with depth is given by the formula:

$$\Delta \varsigma = (2.64 \times 10\text{-}6)\ Dd3.$$

The change in the diameter of a sphere with temperature can be calculated using the following equation:

$\Delta\delta = (3.8 \times 10\text{-}6)\ (DT)\ d$

where ΔT is the change in temperature in centigrade degrees.

COMMUNICATING THROUGH THE GLASS WALL

Magnetic Switch

To turn electrical devices inside glass housings on or off, we use a magnetic reed switch mounted inside the sphere, controlled by a permanent magnet on the outside of the sphere, as shown in Figure 6.

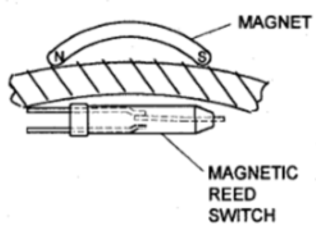


Figure 6
A magnet on the outside of a glass housing can be used to operate a magnetic reed switch inside.

Electrical Penetrations

In order to run electrical power and electrical signals through the wall of a glass housing, we developed the single conductor tangential electrical penetrator shown in Figures 7. Stock tangential deep ocean electrical bulkhead connectors can also be installed in glass

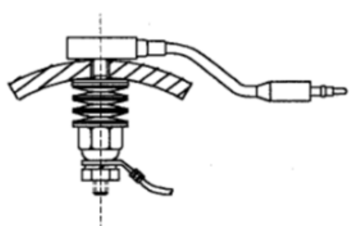


Figure 7
Benthos single conductor tangential penetrator.

housings. Several types are shown in Figure 8. Radial bulkhead connectors such as are shown in Figure 9 can also be used. The Benthos tangential penetrators should be used whenever possible rather than a bulkhead connector for a number of reasons shown in Table 1.

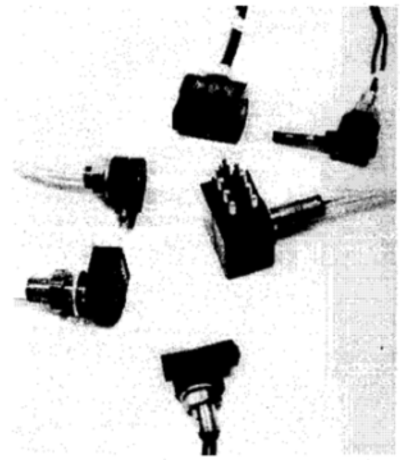


Figure 8
Several types of tangential bulkhead connectors.

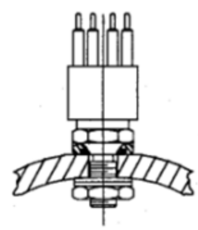


Figure 9
Multiple conductor radial connector penetration.

Vacuum Port

We install a titanium vacuum port in most glass housings, as shown in Figure 10. This allows the pressure inside the housing to be drawn down to less than 1 atmosphere, typically 0.3 atmosphere. The

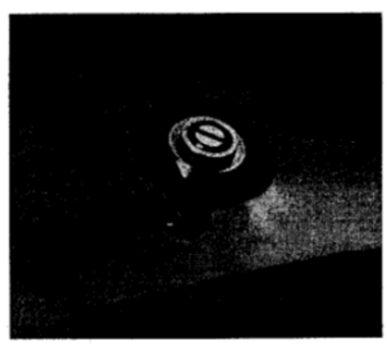


Figure 10.
A Benthos vacuum port installed in a housing.

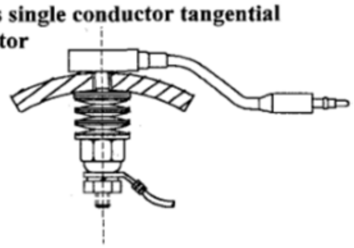
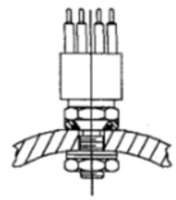
Benthos single conductor tangential penetrator 	**Multiple conductor radial connector - penetration** 
Simple - no "O" ring, no ground flat required.	More complex - uses "O" ring, requires a ground flat.
Small hole drilled through glass wall.	Larger hole required. The bigger the hole, the more the stress, the lower the safety factor.
Benign interface - rubber on molded glass.	Harsh interface - steel on ground glass. More chance for stress concentration.
Low profile tangential configuration.	High profile radial configuration. Lateral force on connector puts high force on glass.
Connector is remote from penetrator. No No stress on glass when mating connector.	Connector is integral with penetrator. Connector puts stress on glass during mating.

Table 1

Tangential Penetrators in glass compared with bulkhead penetrators in glass.

vacuum plus two external hose clamps hold the hemispheres together during air shipment and at other times. The force between such 43 cm (17 inch) diameter hemis is more than one ton at sea level. If too much vacuum is used, electrical components inside the housing can be damaged. The vacuum port allows the vacuum to be eliminated, thus permitting separation of the hemispheres for access inside the housing.

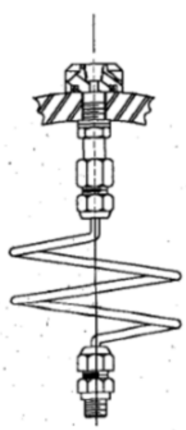


Figure 11

A pressure feed through installed in a glass housing allows sea water to reach a pressure transducer inside the housing.

Pressure Penetrators

We sometimes install pressure penetrators in housings such as is shown in Figure 11. These allow water to enter the housings to operate pressure transducers, recorders and switches.

Fiber Optic Penetrators

Fiber optic penetrators can also be installed in the glass. Those made by D.G. O'Brien of Seabrook, NH, U.S.A. can be installed in a glass sphere by use of an adapter. Diamond S.A. of Switzerland also makes a fiber optic penetrator.

Optical Windows

Some users have wanted to install a camera inside a glass housing and make photographs through the glass wall. We tried this. We ground and polished the outside and inside of a molded glass hemi to obtain spherical

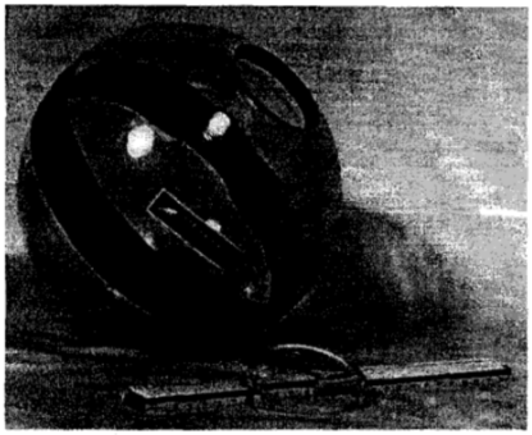


Figure 12
A ground and polished optical window for a glass housing.

optical surfaces. The results were not good. The glass of which the hemis are made is not optical quality, so striae of varying density, exist inside the glass causing wavy distortions. To overcome this, we put a conical hole in a hemi and installed a matching spherical-conical window of optical quality in the hemi as shown in Figure 12. It worked well to its rated depth of 6700 meters..

Glass-Metal Housings

We have made reliable deep housings consisting of two glass hemis separated by a metal cylinder. We developed this capsule configuration using aluminum alloy tubes for the Amanda Antarctic in-ice muon-neutrino telescope project which is a collaboration of the University of Wisconsin, University of California at Irvine, University of Sweden and DESY of Zeuthern,

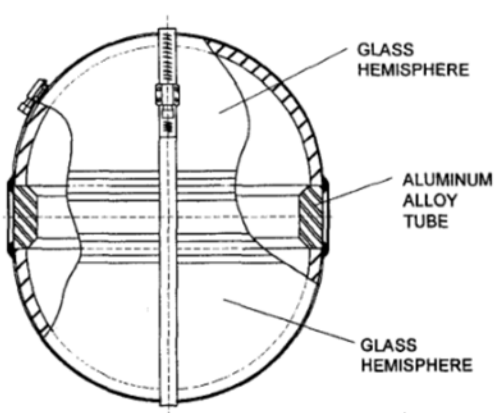


Figure 13
Glass-metal deep sea housing for 4000 meters depth.

Figure 14
A glass housing made to implode due to the large flat ground onto its wall. Implosion results in a mass of compacted glass powder.

Germany. See Figure 13 and Reference 7. These housings are depth limited by the strength of the cylinder rather than the glass hemis. The cylinders can be any length desired.

Glass Housings as Sound Sources

A glass housing can be used as an unusual sound source by making it implode while deep in the ocean. The amount of potential energy of a deep evacuated housing is approximately the pressure of the water at that depth times the internal volume of the sphere. To make a sphere implode at a predetermined depth, we grind a flat on the sphere as shown in Figure 14. The depth at which a sphere implodes is determined by the thickness of the glass at the center of the flat. When the sphere implodes, it does so in about .001 second (Reference 4). During this brief period the glass sphere is reduced to a compacted mass of very fine glass powder as shown in Figure 14. The details of the powerful acoustic signals radiated by such implosions are shown in Reference 3 and 4.

Explosion Potential of Glass Housings

While glass housings can withstand tremendous external pressure, they can take very little (less than 1%) internal pressure. This is because, as stated earlier, glass is very strong in compression and very weak in

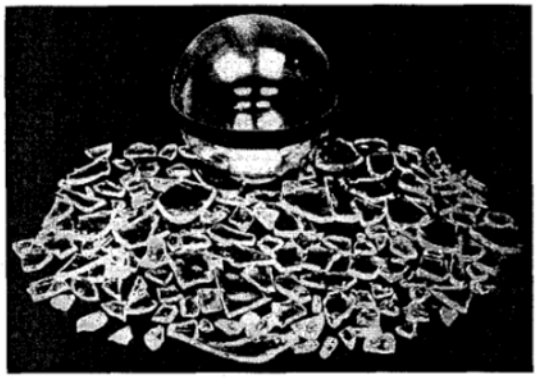


Figure 15
Illustration of the danger of an explosive gas mixture in a glass housing. Battery had emitted hydrogen and oxygen due to a short circuit. The mixture then ignited and the detonation shattered the 17" diameter housing into about one hundred pieces. Fortunately, no harm was done as the glass was retained by its plastic hard hat housing.

tension. If pressure builds up in a glass housing it can explode as shown in Figure 15. To caution users about this hazard, labels such as are shown below, are installed in all of our glass housings.

CAUTION

THIS IS A VACUUM PORT ONLY. NEVER APPLY PRESSURE AS THIS MAY CAUSE THE SPHERE TO LEAK OR EXPLODE

CAUTION

IF ANYTHING IS PUT IN THIS HOUSING THAT COULD EVOLVE HYDROGEN OR OTHER COMBUSTIBLE GAS, THERE IS DANGER THAT THE ENTIRE HOUSING COULD EXPLODE. NOTE: MOST BATTERIES EVOLVE HYDROGEN AND SOMETIMES BOTH HYDROGEN AND OXYGEN. CONSULT BATTERY MANUFACTURER AND USE SAFE ENGINEERING PRACTICES. DO NOT RECHARGE BATTERIES INSIDE HOUSING

BENTHOS, INC. NORTH FALMOUTH, MA., U.S.A.

Implosion of Spherical Glass Floats in the Ocean Due to Damage

Over the years there have been a small number of cases where Benthos spherical glass floats in plastic hard hats have imploded while deep in the ocean.

When used within their depth rating, the risk of implosion is very small for the following reasons:

1. The quality control used in the manufacture of Benthos glass floats is extremely high. The glass hemispheres are molded to close tolerances. The wall thickness and roundness of each hemisphere is checked before assembly. Any hemispheres with significant defects are rejected.

2. After assembly, each sphere is normally pressure tested to a depth of 6,700 meters (22,000 feet). Occasionally a small amount of spalling may occur. If this spalling is significant, the sphere is scrapped. Many years have gone by without an implosion in our pressure vessel. Of the past 50,000 spheres we have tested, about 4 have imploded for unknown reasons.

3. Theoretically, cycling will not weaken glass spheres. To prove this, we have tested one sphere to a depth of 6,700 meters 675 times with no degradation of the sphere.

4. Long term submersion of spheres to their rated depth should not cause failure. We tested a sphere in a pressure vessel in our laboratory for two years at a pressure equivalent to its rated depth of 6,700 meters with no problem.

Why then, have spheres imploded in the ocean? We believe that this is caused by the spheres having been damaged by mechanical impact while being lowered into the sea or during recovery on the previous deployment. A heavy blow to the sphere at the right place in the hard hat can cause the sphere to crack. At a symposium on glass at Benthos in March, 1976 with members of the Woods Hole Oceanographic Institution present, we purposely cracked a sphere in a hard hat by hitting it hard with a hammer in a region where the sphere was not protected by a rib in the hard hat. Next, the damaged sphere was put into our pressure vessel. At a depth of 2,974 meters, cracking sounds were heard through the hydrophone that we have mounted on our pressure vessel. Then the sphere imploded. We have repeated this experiment with similar results. Thus, there is no question that a sphere that has been cracked may implode when used in the ocean. We, therefore, recommend that before use each hard hat be opened and the sphere inspected to be certain that it has not been damaged.

CONCLUSION

In the 30 years we have been working with glass for applications in the deep sea, we have made great strides. Glass is now a commonly accepted material for flotation spheres and instrument housings. It has proven highly effective for its versatility and reliability. Our understanding of how glass spheres behave under pressure increases each year. We expect that glass spheres will continue to be used by oceanographers around the world for many years to come.

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