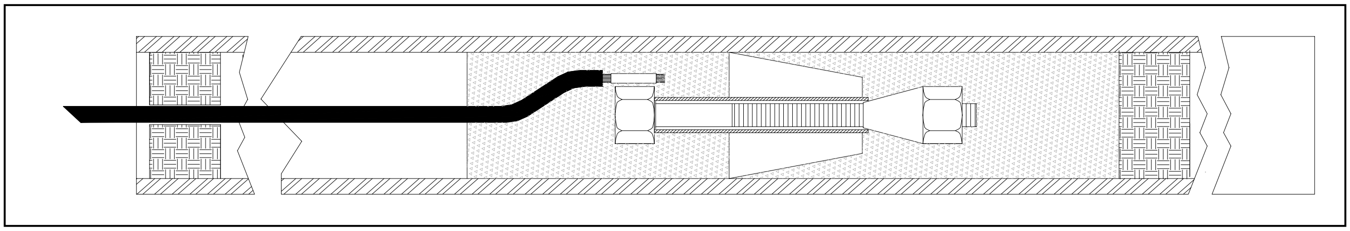
The quality of cable connection and its encapsulation is critical to full utilization of an anode.

Typical encapsulated cable connections are shown in Figures 1, 2, and 3.

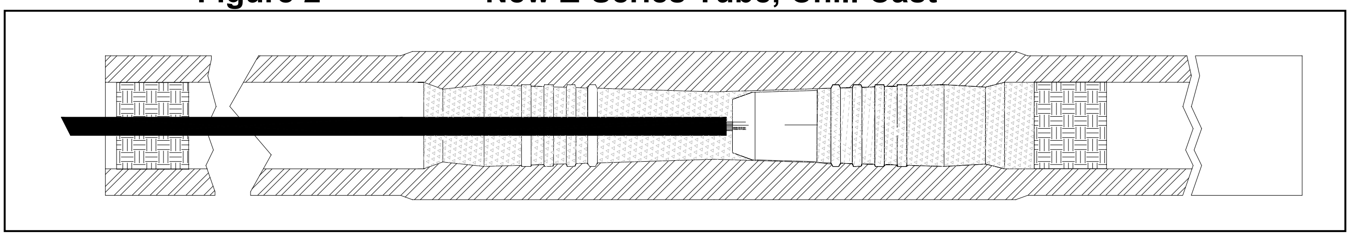
Figure 1 Traditional Hollow Tube, Centrifugal - Spun Cast

Note the absence of retention features or connection seat in the inner diameter of this typical



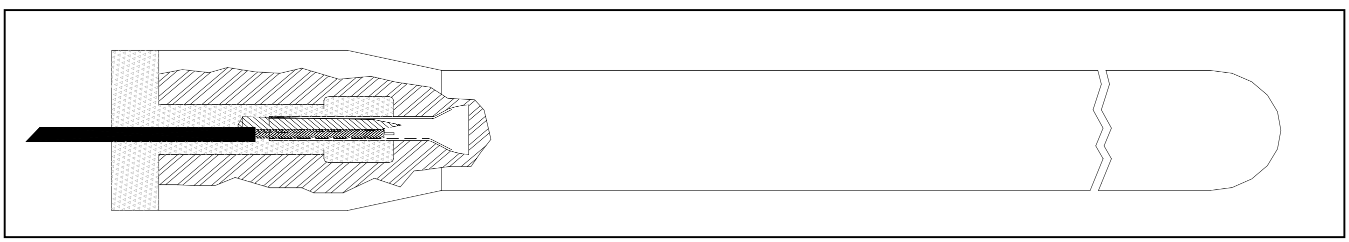
Centrifugally Cast tubular anode.

Figure 2 New Z-Series Tube, Chill Cast



Note the retention grooves and taper seat on the anode ID; proprietary to Chill Cast Tubulars from Anotec

Figure 3 Traditional Solid Rod Stick Anode, Sand or Chill Cast



Critical functional requirements for all cable connections are:

- **Low resistance**
- **Strength**
- **Reliability of Encapsulation (waterproofing)**

Connection Resistance

Customer specifications usually require that the resistance of the cable connection be less than, for example, 0.003 ohms. This criterion can be easily and reliably met by virtually all connection methods. In Anotec's experience, measurements always achieve less than 0.001ohms resistance. On extremely rare occasions where a connection exceeds this criterion, it is either rectified or segregated for disposal.

Of practical concern is the tact that some customers specify that connection resistance Rc be calculated rather than measured directly. For example, where:

R1 = Resistance of Bare Cable, and R2 = Total Resistance of Cable-Anchor-Anode, then

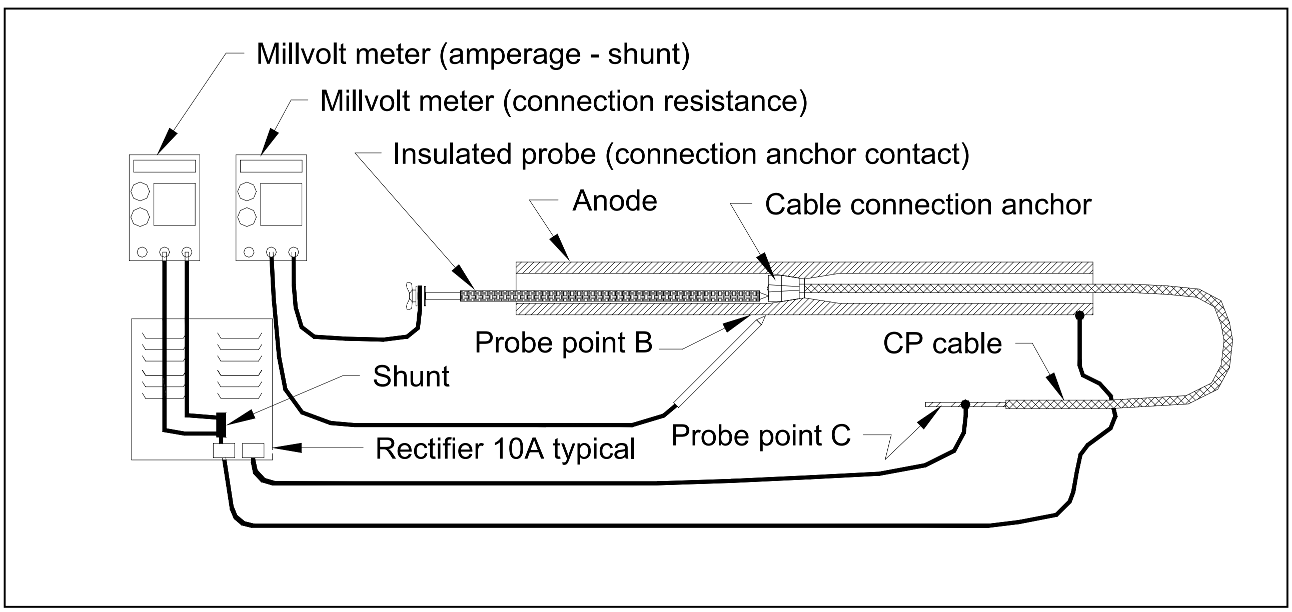
Rc = R2 - R1.

If R1 and R2 are measured accurately without being affected by temperature change, this approach is reasonably reliable. But if the cables are relatively long, and the temperature change is large, the validity of Rc can be significantly compromised, because the magnitude of the resistance change can greatly exceed the magnitude of the connection resistance criterion.

Peabody's 2nd Edition [(1)] page 137 Table 7.1, lists correction factors to adjust copper conductor resistance according to temperature variations. For example, if 300 ft of bare #8 conductor presents 0.179 ohms resistance when measured at 50F; then total resistance cable-to-anode measured later at 60F will be affected by a resistance increase of 0.004 ohms due to the 10F increase. In this case, assuming an actual connection resistance of 0.001 ohms, the calculated cable connection resistance will exceed the criterion of 0.003ohms. ie. if $R2_2$ = 0.179 + 0.004 +0.001 = 0.184 ohms, and R1 = 0.179 ohms, then Rc = 0.184- 0.179 = 0.005 ohms. Without factoring in temperature change, a perfectly good anode would be rejected. On the other hand, in the event of a corresponding temperature drop, a poor connection could be inadvertently accepted.

Recognizing these concerns, Anotec measures connection resistance directly. Figure 4 shows how a long insulated probe can be used to measure connection resistance in centrally connected tubular anodes independently from cable resistance variability. It is recommended that this procedure be adapted into resistance testing clauses in specifications.

Figure 4: Connection Resistance Test Apparatus



Note that unless the cable is continuous, conductor-to-anode resistance cannot be measured this way.

Particularly for measurement of very small voltages, meters should be regularly and appropriately calibrated. A simple calibration device based upon the reliably constant voltage of a typical dry cell battery is useful for checking multi-meters. Anotec Work Instruction documents defining procedures for inspection, testing and, as well calibration of meters, may be requested. Contact Anotec.

Cable Connection Strength: One criterion for connection strength is 1.5 times (or greater multiple) of the cable breaking strength. Refer to Table 1:

Table 1: Nominal Breaking Strength of Copper Strands (ASTM B3, B8)

Size	Ohms per 1000ft	Copper Area sq. in.	Breaking Strength, lbs.
8	0.654	0.013	480
6	0.410	0.0206	763
4	0.259	0.033	1210
2	0.162	0.052	1932

Figure 5 shows one example of practical apparatus used by Anotec for testing: (a) conductor-to-anchor connection strength, and (b) anchor-to-anode connection strength.

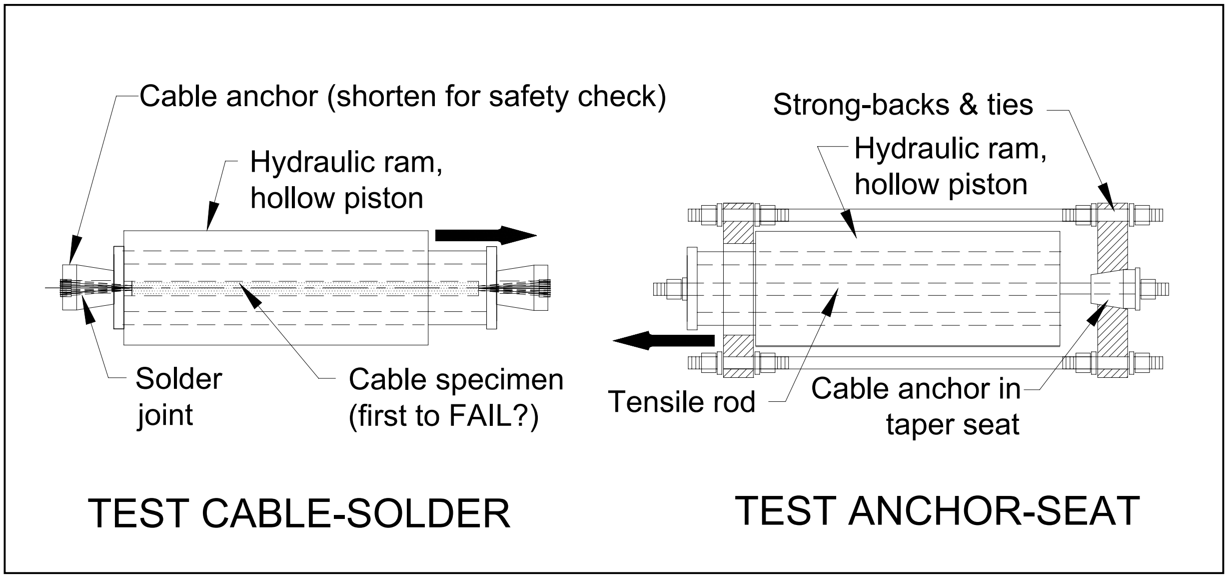


Figure 5: Cable-Connection Strength Test Apparatus

No matter how well connected is the cable to anode; all is for naught if the connection does not have a reliable waterproof seal.

Sealing the Cable Connection The objective is to prevent premature failure of the cable to anode connection due to corrosion by moisture infiltration, which for anodes is usually highly acidic.

Hydraulic pressure testing of various cable-to-anode encapsulations indicates that not all seals are completely water tight at high pressures. Nevertheless, of the hundreds of thousands of traditional HSCI anodes in service very few have failed. Anode seal failure is therefore a concern, but not a crisis. Excavation of anodes for examination is usually a costly exercise, so relatively little is known about the actual root causes of premature failures in the field.

Two long-established approaches to sealing cable-connections in HSCI anodes are:

- Mastic sealant with epoxy cap
- Full epoxy or urethane seal

Simply specifying the materials for encapsulation is insufficient. Encapsulation involves a process requiring technical control. The following paragraphs relate *anode design* to *sealing process performance*. Conventional wisdom holds that sealing requires bonding. In fact, epoxy and urethane do not bond well to polyethylene or PVC, which are the most commonly used cable insulation materials. Furthermore, epoxy and polyurethane potting compounds shrink a small amount during their conversion from liquid to solid due to: *cure reaction* and *thermal contraction*. Why then have so many anode installations survived for so long? One theory is that the relatively fine seams that may develop between both the resin and the surfaces of anode and cable, eventually block with products of corrosion that prevent ingress of fresh electrolyte. In the absence of fresh electrolyte, further corrosion ceases. Obviously, in the absence of perfect bonding, *seam-width reduction*, and *seam-length extension*, are appropriate objectives.

In this regard, it is important to appreciate how *seal diameter reduction* and *seal length extension* work together to minimize the effects of *cure reaction* and *post cure thermal contraction*.

Because the cure reaction is exothermic, heat released raises the temperature of the resin. Because the rate of cure increases with temperature, the heart of the resin will cure more quickly than the edges, which are cooled by metal and cable. Therefore, as the epoxy heart solidifies it will draw uncured liquid resin away from the metal and cable surfaces. As the cure cycle ends, absence of liquid resin "feeder" will mean that a gap (seam) may be created as resin is pulled away from anode or cable surfaces. Afterwards, as the resin mass cools to ambient, any solid shrinkage will amplifies seam width.

For seal effectiveness, anode designs should, in principle:

A. Minimize *Internal Diameter*, in order to minimize seam-width between cured resin and the surface to be sealed, and

B. Maximize *Seal Length*, in order to maximize resistance to infiltration, by increasing the potential for both:

a) *Bonding* and
b) *Blocking* by products of corrosion.

With this in mind,

Figure 6 contrasts seal diameters for:

1. Conventional centrifugally cast tubular anodes and
2. *New Z-Series* chill cast tubular anodes from Anotec.

Clearly, 1.85L of epoxy in the straight-walled 3" ID traditional tubes will not seal as well as 0.42L in the 1.6" ID Z-Series Tube even though the seal-lengths are equal.

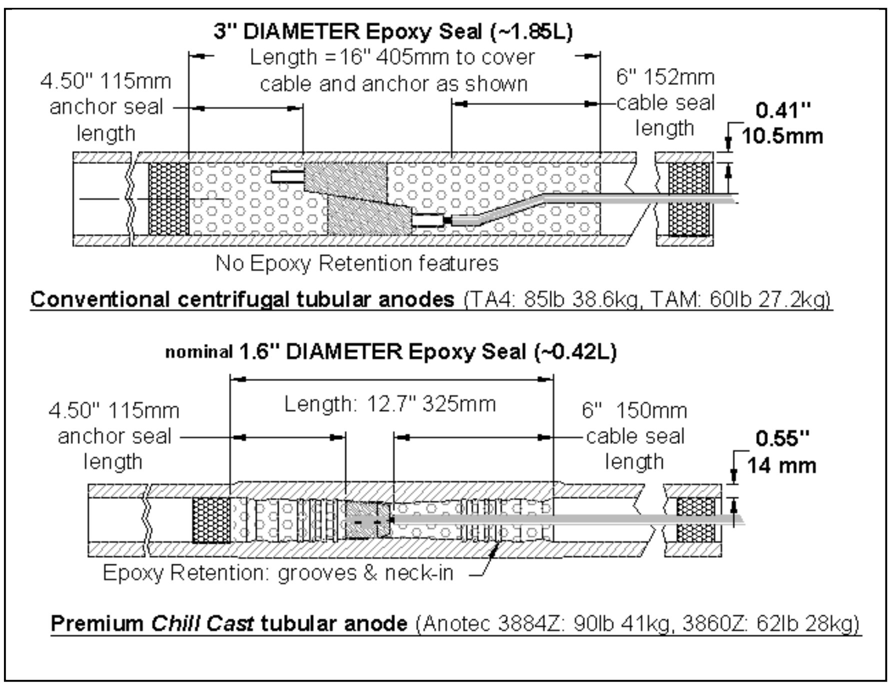
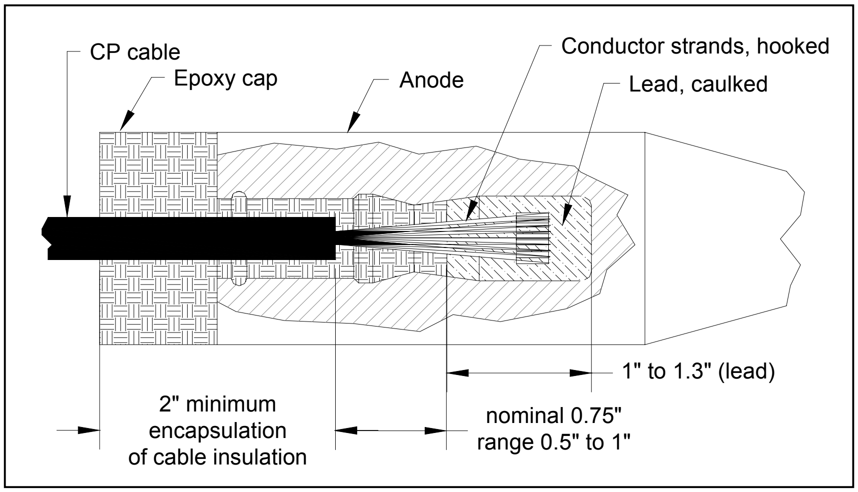


Figure 6: Epoxy Seal Diameters Compared

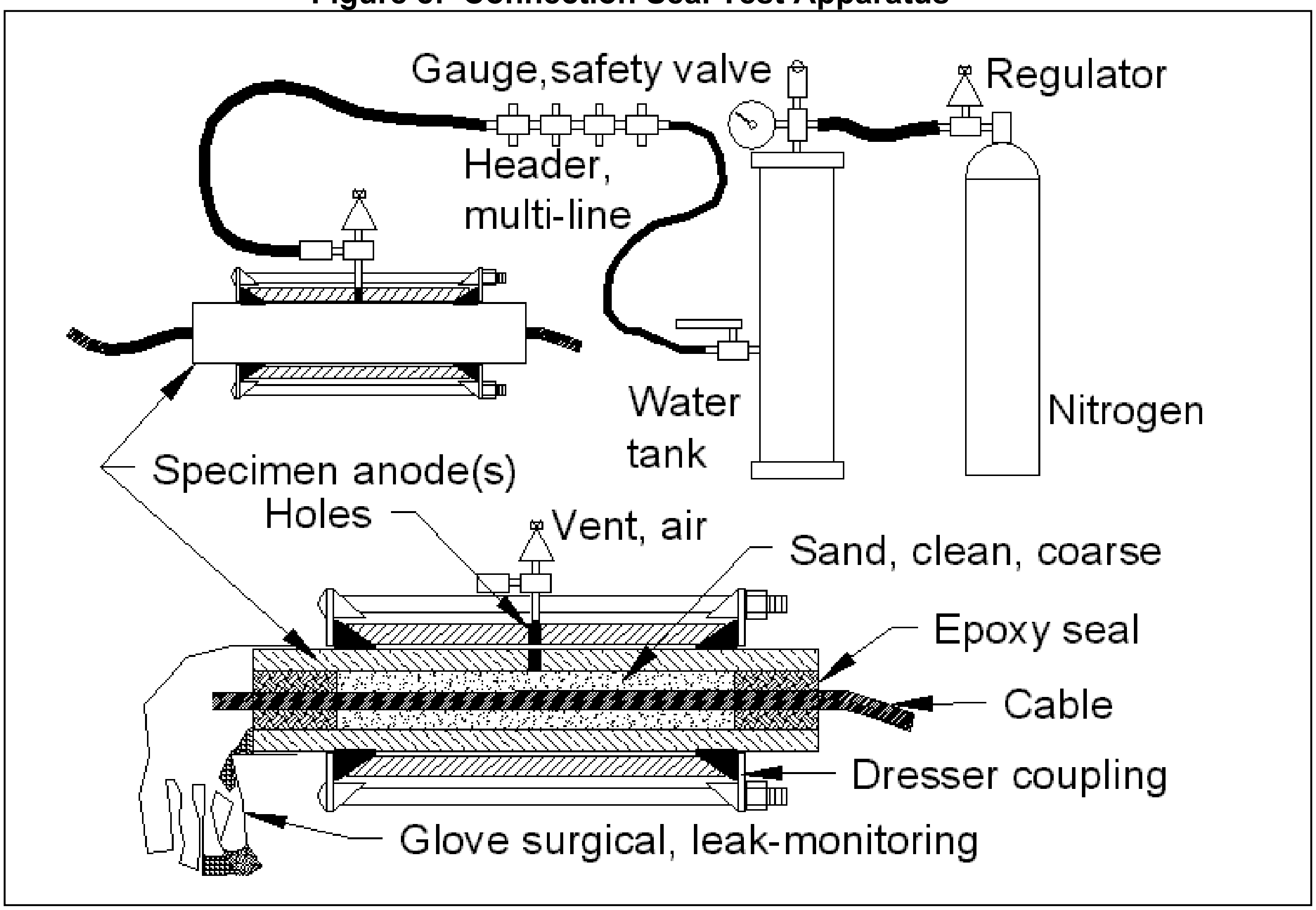
Turning to a more mundane concern, it is important to realize that if excess insulation is stripped from a cable's copper conductor, the seal length along the cable insulation may be unwittingly shortened and compromised, particularly when epoxy seal space is limited by the design. This concern is applicable to both Sticks and Tubes. With this in mind, Figure 7 shows recommended conductor exposure for a stick connection, with the intention of controlling insulation seal length.

Figure 7: Epoxy Seal Path, Stick Anode



The Hydraulic Pressure Test apparatus shown in Figure 8 can be adapted to test leakage relationships between seal diameters and seal lengths for anode and cable insulation surfaces. The test can be adapted to stick anode connections and can be used to evaluate and qualify alternative encapsulation materials and surface preparations.

Figure 8: Connection Seal Test Apparatus



Quality Control of Cable Connection Encapsulation:

Epoxy for encapsulation should not shrink appreciably during cure. (Dry, clean sand may be added to reduce shrinkage). Components must be properly stored, mixed, and placed. Epoxies age and are temperature sensitive. Mixing must be complete, without contamination by air or other impurities. Sealant cure should be verified by scratch test. Surfaces in contact with sealant must be clean and may require preparation. If mastics such as Ozite are used, they must be placed in a controlled manner to prevent contamination of surfaces that are intended to mate to epoxy. In the hot sun, even thin films of mastic may warm enough to flow, leaving an open path for electrolyte to eventually pass between the anode wall and the epoxy seal.

References:

1. Peabody's Control of Pipeline Corrosion, NACE 2nd Edition 2001.