Quality Assurance Procedure

Cathodic Protection System Testing

Anode Output Measurements Using Swain™ AutoMer Meter

CP - 3

Updated 3/16/2006

Written and Prepared by :
Thomas M. Dennison

This document is not intended to be used *in lieu of* a prescribed course of study in corrosion , corrosion protection systems , and the testing thereof. It is to be used as a guide by those persons having been properly qualified in the various techniques of inspecting , measuring and troubleshooting cathodic protection systems.

CATHODIC PROTECTION CURRENT MEASUREMENTS

INTRODUCTION :

The following recommended procedures are designed to ensure accuracy in the *performance* of the survey, and to provide a minimum standard for the recording format ... to assure that a thorough report can be developed upon completion.

Typically, the performance of a *cathodic protection system* is measured by sampling the *cathodic potential* at various points throughout the structure being protected. This electrical potential is quantified as a *voltage* measurement, and is easily taken using a (high accuracy / high input-impedance) multimeter, referencing a highly stable 'laboratory-grade' reference electrode.. Another means of gauging the performance of such a system is to measure how "*hard*" the sacrificial anodes are actually working; i.e., how much current they are delivering. DC current measurements are relatively easy to make when the measuring device (meter) can be placed *in series with* the circuit under measurement. However, due to the nature of anode installations on offshore facilities, this method of measurement is not feasible. Current measurements must be ascertained via an 'indirect' method. The Swain Meters™ accomplish this task by measuring the strength of the magnetic field surrounding a conductor … the strength of which is directly proportional to the current density (one of numerous physical laws which relates to a variety of nondestructive test methods). Several difficulties present themselves when employing this "tactic", with DC. The first problem is that the *"sensor"* is going to exhibit some degree of sensitivity to the earth's magnetic field itself [Swain™ meters are "rated", per each clip diameter, as to the amount of influence (i.e., ±"X"ma) that the earth's magnetic field will exert upon them]. Another problem is that, since there is no *reversal* of the magnetic field (as there is with an *AC* current), we cannot measure the field strength *directly* … but, rather, must rely on measuring the effect which the magnetic field exerts upon the sensor as a component in an electrical circuit (i.e., how much the magnetic field changes the magnetic state of our (meter coil's) core). See Figs. 1 & 2

See Appendix 2 for further information about operation of the Swain™ meters, and Troubleshooting.

EQUIPMENT :

METER :	This procedure covers only use of the Swain™ AutoMer DC Amp Clip meter.
LEAD WIRE :	The only acceptable wire for connecting the clips to the meter will be the cabling provided by the manufacturer; 16 gauge, water resistant SO type. Hold-back line (*poly rope*) must be utilized to insure that strain is relieved from any underwater connections, as well as to insure safe retrieval of the clip.
CLIPS :	This procedure covers only use of the Swain™ 5 inch clips, specifically for underwater use on sacrificial anode standoffs. These clips exhibit an H_e (effect from earth's magnetic field) of approximately 0 ± 40 milliamps.

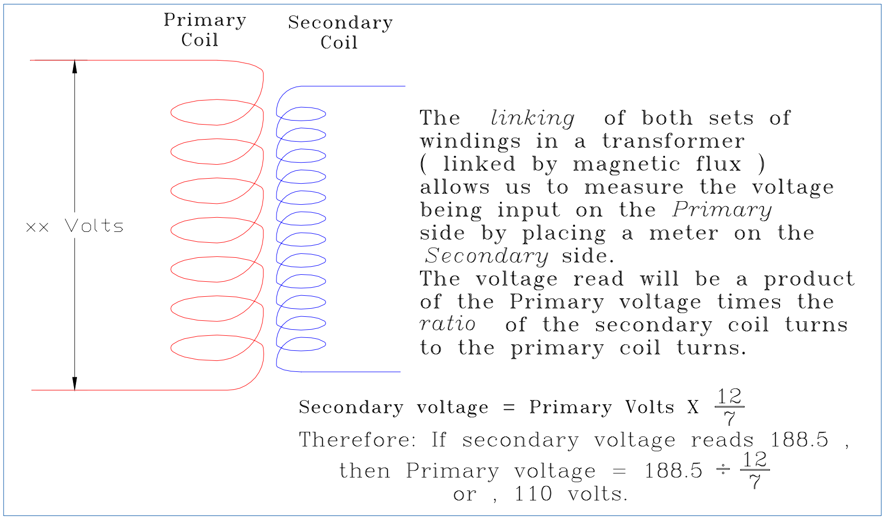


Fig.1

When dealing with AC currents, there exists a very clear and distinct relationship between the voltages in adjoining coils (linked by magnetic flux), such as in a transformer.

However, with *DC* currents, there is no repetitive “*collapsing*” of the magnetic field followed by regeneration of same. Therefore, there is no *induced voltage* to be read in an adjoining coil.

We must rely on utilization of an “active” circuit … with a known (“zero”) calibration … introducing that circuit into the magnetic field associated with our (*current-carrying*) conductor … and measure the effect which the magnetic field exerts on our circuit.

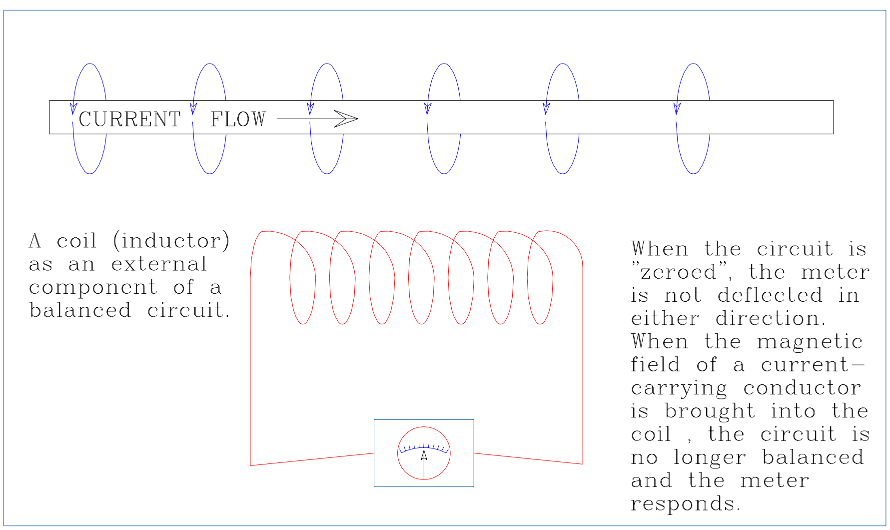


Fig.2

As Fig.2 states, when a magnetic field is placed in proximity to our circuit (*or vice-versa*), the circuit is no longer in balance, due to the change in the magnetic state of our (meter coil’s) core. With the Swain™ meters, even the earth’s magnetic field will influence the meter’s reading (noticeably) … as will any other magnetic influence. [Note: It bears mention that numerous other qualities of the circuit, beyond simply the core’s magnetic state, are likewise affected by the introduction of an outside source of magnetic flux.] Only through proper calibration, and knowing what factors will influence the response of such a system, can completely accurate and reliable readings be obtained.

CALIBRATION PROCEDURE

In order to properly assess the demand placed upon a structure's cathodic protection system, any measurements taken must be thoughtfully, carefully, and meticulously analyzed and verified before being recorded. This includes a conscientious effort to calibrate the meter and clip assembly.

As already mentioned, many factors (including orientation with respect to the earth's magnetic field) will affect the output of the sensor / clip. Therefore, while performing the calibration check, it is imperative to accumulate and record numerous data, taken at several points and in several orientations (including with the clip reversed, in order to verify polarity).

STEPS FOR CALIBRATION

1. Set-up the "Anode stand-off calibration sample", as shown in Fig.3. Insure that all connections to the pipe and power supply are *clean and tight*.
2. Set-up the Swain™ meter , using the length of cable which will be used on the job. Be sure to install hold-back lines *at this stage* (before calibration) … making certain that absolutely no strain will be placed on underwater connectors! Make sure, too, that the batteries (alkaline "C" cells only!) are fresh. See Appendix 1.
3. Turn the Swain™ meter to "Auto"; allow brief warm-up period (watch for "Ready" light). The clip should be *humming* … like a loud mosquito … when held to your ear.
4. Turn the power supply On, and adjust the current control until exactly 1.00 amp is shown by the in-line meter (this represents the *exact* current *anywhere* in the circuit … specifically, through the 2 inch pipe … which now closely approximates the flux distribution characteristics of the anode standoffs to be tested). If the power supply is a digital unit itself, then no separate "in-line" meter is needed.
5. Following the procedure for proper clip manipulation (see Survey Procedures, pg.6), take numerous readings in both polarity-orientations, until confidence is achieved in the values being displayed. Again, check the results in both polarity-orientations; the Swain™ meter must read very close to the in-line meter. Document the *highest-confidence* readings for both polarities on the test coupon (pipe) as your calibration. The *difference* between the power supply and Swain readings can then be taken into consideration during calculation of each anode's actual output. (Be certain to record the deviation [H_e] for the inclination of the clip during calibration … as with readings while testing.)
6. The factory calibration statement states that the meter can read approx. 1–2% different than the actual calibration current (using the *primary* clip. Readings may be up to 5% different than actual when using the secondary clip). If a significant variation is experienced, try turning the meter off … check all points in appendix 2, and retry. If necessary, change clips.
7. Repeat Step # 5 above at 2.50 amps (250% of first test value), and note the degree of difference (error value) given by the Swain™ meter, if any, on the data form. Insure that both polarities are checked, and that the +/- value gets recorded correctly.

The unit is now ready for accurate data acquisition. *Extraordinary* care is now called-for, to insure that no changes occur to the system, prior to taking readings.

- DO NOT touch the zero knob, or calibration *must* be re-performed.
- Allow *NO* strain to cause any connections to come apart, *even slightly*!
- Be VERY careful feeding - out the cable assembly. [Holdback lines must have already been secured, before performing calibration … see Step 2, above.]

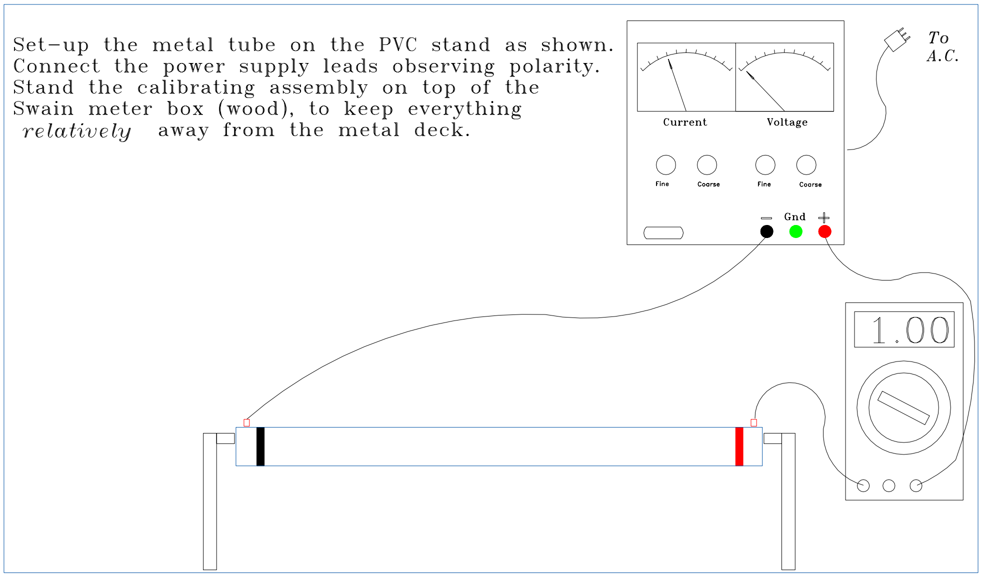


Fig.3
Calibration Set-Up

[If power supply is a digital unit itself, the external in-line meter is unnecessary… (red-to-red)]

Neither the power supply, the inline amp meter, nor the Swain™ meter are water / weatherproof !

It is highly recommended to have all these units carefully set-up inside the dive shack or other *controlled environment*. The storage box and calibration set-up can be set-up outside, but apply common sense to minimize damage to same.

*While setting-up the Swain™ meter, inspect the " *lips* " of the clip, and use an *alcohol pad* as needed to insure that the bare metal *core* contact areas are thoroughly clean.*

They should also be free of any rust. *Do not use sandpaper on these "fine nickel-finish" areas*. If any rust *is* present, the windings in the clip have probably been compromised, and will exhibit difficulties in calibrating and reading. When finished with testing, spray these areas with a light coat of LPS-3 (for a waxy protective coat).

For calibrating, set the Swain™ meter on a Pelican case, or other such object to keep it off the deck.
If radio frequency interference is causing difficulties, refer to troubleshooting section, appendix 2.

Have copies of report / data forms ready before setting-up to perform calibration. Be sure to record all pertinent information pertaining to the job, setup, and test parameters.

Have the boat captain (if applicable) verify as close as possible the alignment of both the vessel and the platform or rig [these parameters can and do influence deflection / concentration of the earth's magnetic field!]. Be sure to document these criteria on the report form.

Remember *before beginning*, to insure that the meter contains 8 fresh alkaline type "C" cells.
A fresh set of batteries, under normal circumstances, can be expected to give somewhere between 40 and 50 hours of service. However, for offshore work (considering both the *cost of*, and sometimes *limited* bottom time) batteries should be changed-out after each two days of use.

Refer to Appendix 1 [Page 10] for changing-out batteries.

SURVEY PROCEDURES

After the anodes to be tested have been designated, and depicted on a sketch, the diver will retrieve current readings from ***Both*** ends of each anode … with ***Each*** reading being checked in ***Both*** polarities. Any agreeable method can be used between diver & topside to insure correct documentation of reading polarity. Saying …"Cable (Handle) Up / Down", or *color-coding* clip handles with tape will work.

Remembering that *many* things affect the displayed reading on the Swain™ meter, care must be exercised to insure the validity of each reading recorded.

One *very important* consideration which bears mention is that the diver's grip on the clip handle can have a *profound* impact on the readings obtained, as his grasp changes ever so slightly. Each diver must pay strict attention to maintaining a consistent grip on *one side only* (of the clip), while 'scanning' each test point. Here, also, the diver must develop a knack for keeping the standoff tube aligned within the center of the clip … and not "skewed " through it. The diver should be involved in the calibration procedure, and receive "first-hand"/ "eyeballed" knowledge of the effect which his manipulation will have upon the readings.

The need for clear, understandable communications between the diver and the data recorder will be at an "all-time-high" during anode current measurements. As the diver approaches each anode (as directed by topside), he must indicate which standoff he will be starting on. Next, he must get "comfortable" for being able to remain steady while scanning each "leg". When he is ready to scan, he must direct topside to "Begin Reading" … (This *means*, "Out loud"!).

Topside then must read-out the (changing) readings as the diver does a *relatively* slow scan of the standoff. The diver must then *reverse* the clip, and repeat the process, until that point is determined where there is the least difference between the two (different polarity) readings. [Instead of an actual 'scan', since the distance is relatively small along each standoff, the diver may choose to test the "low, mid, and high" points on each one, prompting topside to *read* "Here", "Here", and "Here" (or "Member" / "Middle" / "Anode") as he locates the clip at each spot.] With a minimum of practice, a team should be able to achieve adequate speed in testing with such a 'standardized' method. *Do Not* forget to do readings in reversed polarity, finding the average of the *pair of readings* with the *smallest* difference (averages are calculated using the *absolute* values … see page 13).

The diver must sample each standoff at several points, finding *that point* at which the *least difference* occurs between readings when the clip polarity is reversed. These are the two readings which will be recorded for that particular standoff (marking each value in the appropriate column on the report form).

For the final report, the actual value for *each standoff* will be the average of the two (polarity) readings for that point. The actual (total) current value for *each anode* checked will be the sum of the two (averaged) standoff readings for that anode … see page 13.

Since the relative orientation ("rotation") of the clip within the earth's magnetic field affects the readings … (as much as 40 - to - 50 milliamps, using the 5 inch diameter clips) … the exact amount of this deviation must be documented somewhere in the report materials. *IF* all anodes selected are chosen so as to be in the same "attitude" of alignment (N/S - E/W), and at identical *inclination* (all on horizontals, or on VD's angled the same direction), recording this parameter will be a simple task. However … as this technology *is* a science … the deviation of the clip must be documented *for each different attitude* at which readings are taken.

The drawings will assist in the final interpretation of the report, by indicating "visually" the attitude of each anode tested.

Per Mfr's spec : every 20 minutes, reset the "Auto" function . . . Turn "Off", then back on to "Auto".
NOTE : Don't forget to verify the calibration both *before* and *after* taking readings!

Company Address and ZipCode
Phone (###) ###-####   Fax (###) ###-###   Email XYZ@Tester.com

ANODE INSPECTION REPORT

CUSTOMER:________________________________ LOCATION:______________
ADDRESS: ________________________________ M./V. : ________________
JOB # : ________________________________ DATE : ________________

JOB SPECIFICATIONS : Perform anode current measurements on selected anodes , together with a general anode survey.

PERTINENT ENVIRONMENTAL CONDITIONS : (Water depth , Seas , Temp., Vis.)
Depth to N/B = 184 ft. Seas ; Calm, building to 2-3 ft. ; Water temperature remained cool ; visibility approx. 50 ft (throughout) ; current : mild

VESSEL & PLATFORM ORIENTATION :
See sketch accompanying this report (pg. 8).

PERSONNEL :
Topside Technician : John Q. Operator
Diver - Technician : John Q. Diver
Job / Dive Supervisor(s) : Allan A. Organizer
Customer Representative(s) : John D. Representative

EQUIPMENT USED :
Meter - Swain AutoMer s/n 2614
Cabling/Length - 500 ft. 16/2 SOOW-A w/ underwater SeaCon connectors
Clips - 5 inch MER Sea Clip - WPC
Cal. Std. - 2" pipe w/ adjustable-current power supply (see pg. 5 in procedure).
Power Supply - Tenma Laboratory DC power supply Model 72-2010 / Certified.
Diver-Videoed ?(y/n) - Yes

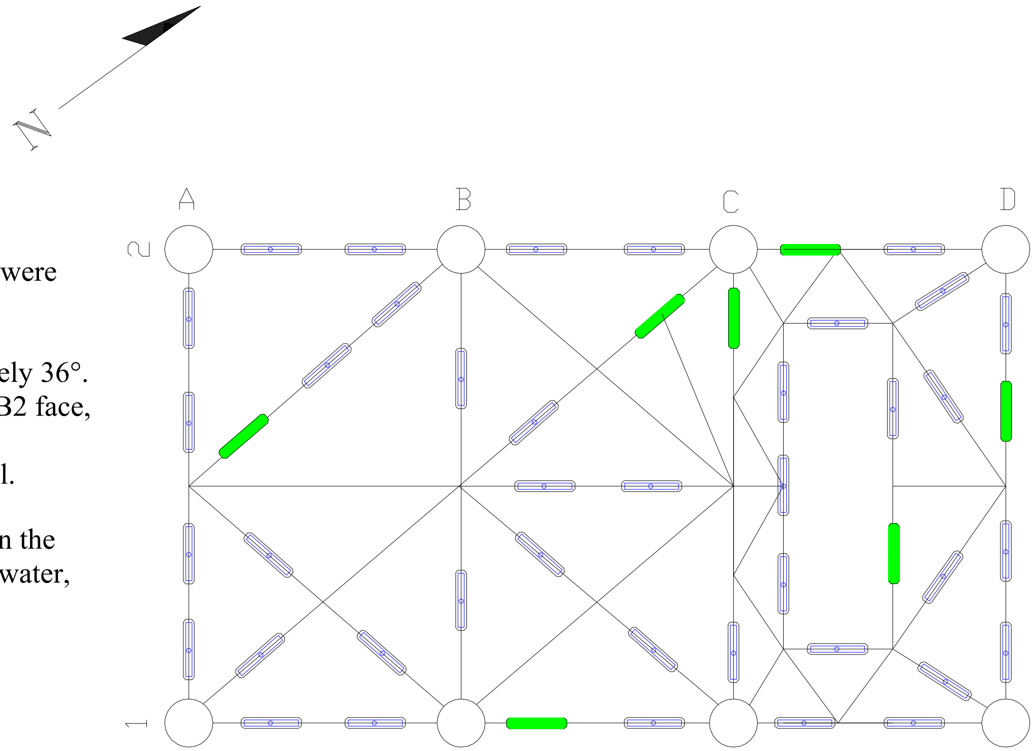
Calibration - ________ @ 1.00 amp ; ________ @ 2.50 amp
Deviation (H_e) - _____ ma _______ ma

GENERAL ANODE CONDITION :
All anodes inspected appeared to be active , and all exhibited approx. 25-to-40% depletion. Volume loss appears to be even throughout all anodes surveyed , with only about 10% pitting on most . Pits range up to approximately 1 inch diameter and 3/4 inch depth.
See page 9 of report for table of current readings obtained.

PROCEDURE USED :
CP-3 QA Procedure for Anode Output Measurements Using Swain™ AutoMer Meter.

SAMPLE REPORT DATA

ANODES SURVEYED AT -78 FT LEVEL



The sketch at right depicts those anodes from which current readings were obtained (highlighted / green).

The centerline of the platform is oriented on a heading of approximately 36°. The vessel was tied-up alongside the boat landing located at the A2-B2 face, with the stern facing "North" (bow at 'A' row, stern at 'B' row). All calibrations were performed ' *at-or-near* ' centerline of the vessel.

Clip offset (deviation) values for the various anode angles are given in the the table of current readings. Values were obtained with diver in the water, *at the level* at which readings were taken . . . (*NOT* during calibration on the vessel).

Anodes oriented ≈ "East-West"… such as the one on the D1 HZ → D2 , are designated as (oriented) E-W. Measurements on these are taken with the diver (and clip) on the '*southernmost*' side of the anode (leftmost side of drawing).

Anodes oriented ≈ "North-South"… such as the one on the B1 HZ → C1 , are designated as (oriented) N-S. Measurements on these are taken with the diver (and clip) on the '*westernmost*' side of the anode (topmost side of drawing).

Anodes oriented on the diagonals … such as the one on the B2 HD → MidPoint A-row , (although they actually lie *closest to true* N-S) are designated as (oriented) "Diag.". Measurements on these are taken with the diver (and clip) also on the '*westernmost*' side of the anode (top-left-most side).

SAMPLE REPORT DATA

ANODE CURRENT MEASUREMENTS

ANODE LOCATION	Standoff 1			Standoff 2			Oriented:	Deviation (H_e):	Total I_A
	+ Polarity	- Polarity	Average*	+ Polarity	- Polarity	Average*			

Calibration: + **Polarity** ____________ **Deviation** __________ ma

* Remember to average the *absolute* values.

- Polarity ____________ **Deviation** __________ ma

Diver / Technician: ______________________________ **Data Recorder:** ______________________________

APPENDIX 1

BATTERY REPLACEMENT FOR SWAIN™ AUTOMER METER

WARNING !!!

The older units have <u>*NO*</u> protection for the meter against improper polarity of the batteries !

If the batteries are installed incorrectly in one of these units , and the meter is turned on, it will make someone a very nice $4000.^{00} paperweight !!!

The meter contains numerous delicate, *logic circuit* IC's (*integrated circuits*).
These are '*somewhat*' protected against damage (against a 'mild' drop, while meter is being used) by a foam pad inside the case. This pad *could* pull-out during the battery change-out (while opening the case). The manufacturer recommends extreme caution, and discretion, when separating the cover and case for this procedure. Note too, that fragile wires connect the front and back halves. These must be "replaced" into their <u>*correct location*</u> during the 'reassembly' process. The 4 gray cables between the logic components and the panel must be pushed <u>*well over*</u> to the side of the case. At the same time, while reassembling, care must be taken not to pinch any wires between the cover and the case / or batteries.

DO NOT *lean over* the meter during battery replacement if you are *dripping perspiration* .
Integrated circuits, as well as delicate meter movements, and salty / oily perspiration don't "mix".

Battery change-out will be most easily accomplished, without incurring any damage, if performed on a secure tabletop with either a pillow or a folded-over towel.

Step 1.) Remove the four stainless steel screws from the front panel.

Step 2.) Stand the meter on its *right* side (connector cable *UP*).

Step 3.) "Fold"- open the two halves of the meter, allowing the front panel to lay down.

Step 4.) *AFTER* making yourself 'aware' of the correct battery polarities, remove the eight "C" cell batteries. A diagram is included on the following page of this procedure.

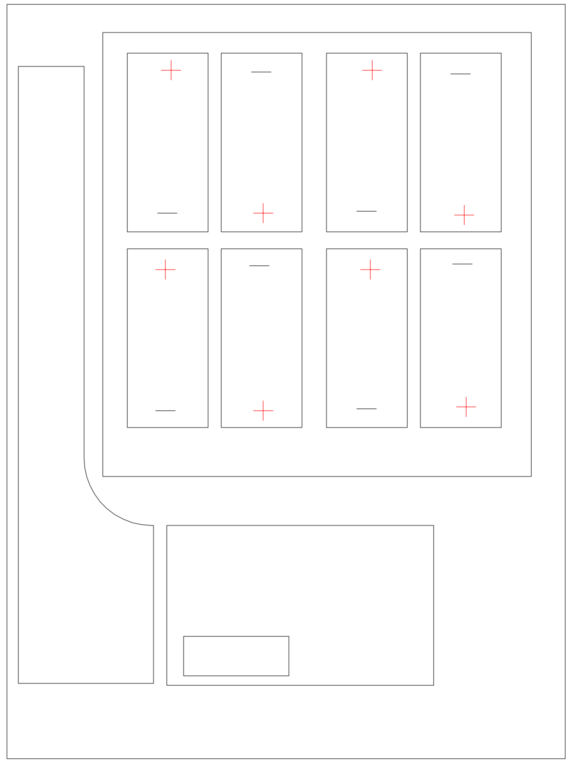
Step 5.) Install 8 new, fresh Alkaline "C" cells . . . one-at-a-time, carefully !
Do not drop any batteries onto any of the meter's internal components.

Step 6.) Carefully *re-fold* the two meter halves together, paying strict attention to the *lay* of the four gray sets of sheathed wires. An extra hand, here … just to help hold the bottom half of the case steady … would be a good idea. The fine wires inside are solid (not stranded) wire, and *will not* tolerate being pinched by the case, or between the batteries and the bottom half. (Be aware, there are *incredibly* delicate parts <u>potted</u>-<u>into</u> the bottom half. Some of these parts are actually slightly exposed above the top of the potting material.)

Step 7.) After replacing the 4 screws, perform a calibration check of the instrument.

Sketch of battery layout :

Swain™ AutoMer Meter



Again , in the older units , there is *no* 'diode' protection, against reverse polarity of batteries.

Double-check, and *triple-check* that each and every battery is installed correctly before closing the unit for use.

Be extremely careful that the four sets of (fragile) sheathed wires are laying properly, so as not to pinch them.

APPENDIX 2

ADDITIONAL OPERATIONAL INFORMATION FOR SWAIN™ AUTOMER METER

NOTICE :

The "AutoMer" portion of the meter's name / description does not signify that calibration, or the readings being taken, are automatically "*compensated*", or "adjusted" in any way.

The "AutoMer" designation merely indicates that this particular unit (over previous models), … "substantially *reduces* zero offset error (due to non-uniform magnetic fields near the clip)." {Manufacturer quote. *Note*: "Reduces" does *not* mean "Eliminates". The "MER" stands for "Magnetic Error Reduction".}

RADIO FREQUENCY INTERFERENCE

It is possible for radiation from microwave transmitters , arc welders , etc. to cause "an erratic shift in zero" of the Swain™ meter.
If such interference is suspected , it may help to wrap the sides and bottom of the meter with 2 layers of aluminum foil.

IMPRESSED CURRENT SYSTEMS

Currents in cables for impressed current systems can be read directly with the Swain meter. However, in most cases, this calls for using a smaller clip than the 5". (A 3/4" one is recommended.)

SWAIN METERS ON ROV's

It is not feasible to utilize the smaller wires normally available in ROV umbilicals to operate the Swain Clips. However, units have been mounted in pressure-proof housings … mounted on the ROV, so as to allow a short cable from clip-to-meter … then using an 'Output/Recorder' jack from the meter to send the data topside through the umbilical wires.

" REASONABLENESS CHECKS "

The manufacturer offers suggestions on avoiding the reporting of inaccurate readings, by checking to see "if it seems reasonable, and if it was taken under reasonable conditions." Currently, the *manual's* suggestions are aimed at the analog-type of meters.

Compare readings to the system's specifications, if they are known. Or, use knowledge based on similar systems, and investigate what changes/differences exist in order to rationalize the discrepancy.

Test the meter's batteries, if in any doubt. And, look for any water / condensation in the meter.

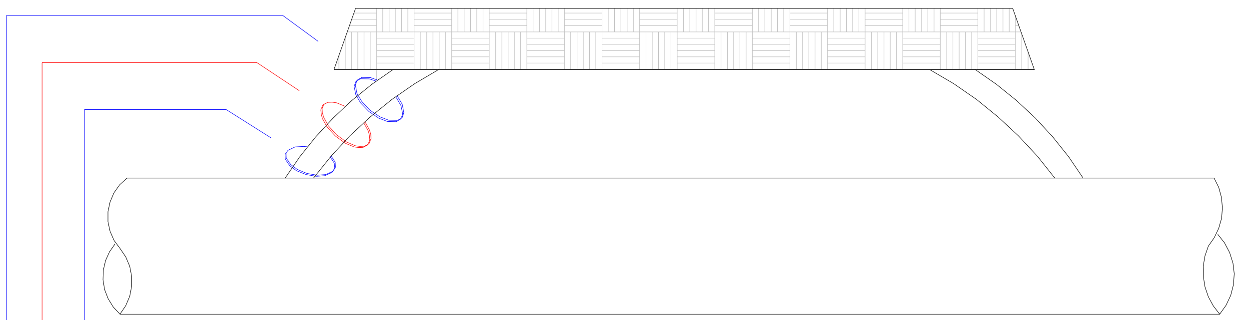
Verify the integrity of any connections. Clean with electrical contact cleaner or alcohol, if required.

Check the H_e (earth's field effect), and verify that it is within specification. If *high*, inspect the *lips* on the clip … insure they are clean and mate properly.

Shield the meter (indicator) with aluminum foil. Adding shielding will not change the (current) reading more than about 2%, unless there is a distinct problem with RFI.

Move. "Some problems are physically localized." Moving 1 ft. may properly distance the clip from an object containing an objectionable degree of magnetization.

If the diver " *scans* " *both* polarities at *each* of these three points . . .
and you read **:**



+ Polarity = 128
- Polarity = -157

+ Polarity = 136
- Polarity = -160

+ Polarity = 129
- Polarity = -118

The difference (*Absolute Value*) between the FIRST PAIR OF READINGS is :

157 - 128 = 29

The difference (*Absolute Value*) between the SECOND PAIR OF READINGS is :

160 - 136 = 24

The difference (*Absolute Value*) between the THIRD PAIR OF READINGS is :

128 - 118 = 11

SO : You will only record (for *that standoff* of *that anode*) :
129 and -118 . . . (these exhibit the " smallest difference ") . . .
Because the *MOST LIKELY* TRUE current at that standoff is

$$\frac{129+118}{2}$$ or . . . 123.5 ma . . . *minus* the H_e at that point.