How to Get Better Accuracy with a Clamp-on Direct Current Ammeter

Introduction

Clamp-on direct current ammeters are tools for solving cathodic protection problems. They can measure interference in a gas pipe or support column, measure anode current on a subsea structure, or find lost CP current due to bad pipeline insulation, defective anode leads, or poor structural electrical contact.

This abbreviated paper discusses how much lost current can you find? What is the resolution? Accuracy? The answer depends on:

- **The equipment**. This paper reports on results using our technology. [Patent 3,768,011 and others pending describe the concepts we use to build our clamp-on ammeters.]
- **The application**. Accuracy is different with a ¾" cable or a 48" oil pipe.
- **The method**. A "pig" may leave spots having considerable magnetic intensity. Proper use of the Floating Zero Procedure can reduce the error by ten to one.

The Equipment

Sensors

MER2™ Meters come with ¾" to 82 inch diameter aperture sensors. The 6 inch and smaller are clips for one hand use. The 8" to 82" are clamps having two "C" sections which mate at the "lips" to form a closed ring. These are secured with brass finger nuts on captive studs. A clamp is shown in Fig. 1.

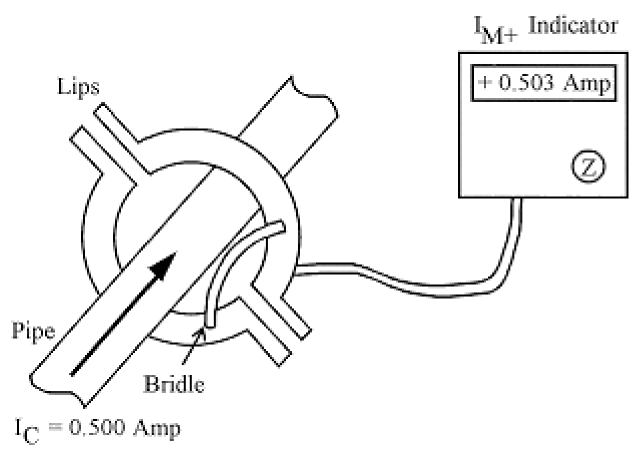

Figure 1

The sensor of a clamp-on DC ammeter is secured around a pipe carrying 0.500 A CP current. This is the signal input to the ammeter.

The clamp is said to be placed in the positive polarity sense because the bridle is nearer the source of positive return current from the earth.

The zero control (Z) on the indicator was set so I read 0.0 when all current in the pipe was temporarily cut off. When the current came back on, the meter reading was 0.503 A. This is acceptably close to the true current of 0.500 A.

It is better to use a clamp which is big enough to fit comfortably around the pipe, but not more than twice as big. This is because the zero offset due to the Earth's magnetic field H_e increases with the size of the sensor, and so also does the sensitivity to nearby magnets. H_e is measured by rotating the clamp in a vertical North - South plane. The equivalent input current change in zero offset, H_e, is less than 0 ± 3 mA for a ¾" clip; 0 ± 100 mA for a 13" clamp, and 0 ± .75 A (750 mA) for a 48" diameter aperture clamp.

Resolution

One mA resolution is available for clamps up to 13" diameter on the 2 A range. A 1.9 A current in a 13" pipe, or in the rail of an electric train can be measured with 1 mA resolution. From 14 to 82 inch diameter aperture, the resolution is 10 mA on the 20 A range, or 100 mA on the 200 A range. The recorder jack overrange capability on the 2 A and 20 A range is about 3 times full scale, i.e., 60 A on the 20 A range.

Current Reading -- Precision and Linearity

The panel meter reading and the output of the recorder connector are proportional to the direct current flowing through the aperture of the sensor to within 0 ± 1% of reading, ± 3 least significant decimal counts.

In other words, a meter reading of 0.500 A interrupted current is good to ± .005 A, except that the last digit may be off as much as .003 A.

So 0.500 A interrupted current will read 0.500 A ± .005 A ± .003A; or 0.500 A within ± .008 A.

Measuring by Changing the Current with an Interrupter

The simplest way to get 1% accuracy is to interrupt the current. This cancels out the zero offset. In Fig. 1 for example, if the 0.500 A current flowing in the pipe is entirely due to a rectifier and this rectifier is disconnected, the current changes - 0.500 A.

When the rectifier is reconnected, 0.500 A flows. The indicator's meter shows I_M = 0.503 A. So the indicated change in current magnitude was +0.503 A.

This is an example of the change in current method of measurement.

It is not necessary to set the panel meter to read zero when the rectifier is disconnected. Instead, when the current is zero, we note the meter reading. Then, when the rectifier is reconnected again, note the meter reading. The measured current IM is the algebraic difference.

For example, if the zero offset is -0.2 A, this will be the meter reading when the current is off. When the 0.500 A current comes back on, the meter still reads 0.2 A less than true, so it reads +0.3 A. The true current is the difference:

$$
\begin{aligned}
IC &= 0.3\text{ A} - (-.2\text{A}) \\
&= 0.5\text{ A}
\end{aligned}
$$

Unmeasured Current

A disadvantage of the change in current method is that an important current in the pipe may be missed. For example, a serious interference current will not be noticed if it is steady. The change in current method ignores zero offset, but it also ignores a constant signal input current.

Constant Current

When the signal input current is not interrupted, the zero offset IZ adds to the input current IC so that the meter reading IM can be in error. It represents an error because it is unknown. The cause of zero offset can be a magnet near the sensor (magnetized pipe, rebar, etc.), or the Earth's magnetic field. And it can be due to the indicator's zero control. If this is well off-center, the zero offset IZ can be big.

To see the effect of zero offset, suppose that the 0.500 A current IC flowing in the pipe in Figure 1 is constant. This could be interference current. Or sacrificial anodes hard wired to the pipe. Then the indicator's panel meter IM and recorder output voltage show the algebraic sum of the pipe current I_C plus the input current equivalent of the unknown zero offset IZ. Restated:

$$IM = IC + IZ.$$

If, at the same time IZ were -0.2 A; and the true IC were 0.50 A, then the meter would read:

$$
\begin{aligned}
IM &= 0.5 - 0.2\text{ A} \\
&= 0.3\text{ A.}
\end{aligned}
$$

This reading is not good. Zero offset IZ needs to be canceled.

Canceling IZ by "Changing the Sensor"

To delete zero offset IZ when the input current is constant, we change the sensor instead of changing the current. Changing the clip or clamp's position on the pipe can pretty well cancel out IZ.

Canceling Zero Offset Using a 2 Step Floating Zero Procedure.

Generally the simplest way to find the true value of an unchanging input current, I_C in Fig. 1, is to cancel out zero offset IZ. I think of this process as "changing the sensor."

The usual way to "change the sensor" is to move it. First read the current with the sensor placed on the pipe in a positive sense, as shown in Fig. 1. In this example, the meter reads I_M = 0.503 A. Then turn it over to a negative sense as shown in Fig. 2. Ideally, the effect is to exactly reverse the current reading to I_M = -0.503 A.

However the zero offset may have changed somewhat when the clamp was moved. Magnetic effect is the likely cause.

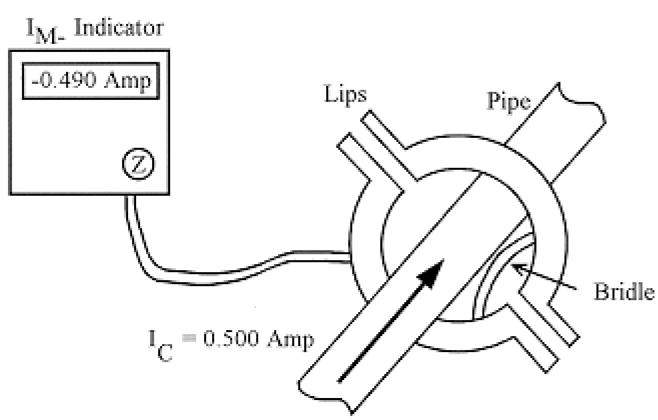

Figure 2

Here the sensor is placed in the negative polarity sense.

This illustrates "changing the sensor". The sensor in Fig. 1 has been turned over so that now the bridle is farther away from the source of positive pipe current IC = 0.500 A. This current flows through the aperture of the clamp in the opposite direction from that in Fig. 1, so the polarity of the meter reading is reversed.

Instead of positive, IM reads -0.490 A. The ideal reading is IM = -.503 A, exactly the reverse of Fig. 1, but it is likely that the Earth's magnetic field and nearby magnet will cause the reading IM to deviate from the ideal. A reasonable reading is IM = -.490 A.

The 2 Step Floating Zero (FZ) Procedure is an example of the "change the sensor" method for canceling zero offset. It is usually quite accurate, and easy to do. The most likely magnitude of I_C is:

$$IC = \frac{IM+ - IM-}{2}$$

For example, in Figure 1, I_{M+} = 0.503 A. In Figure 2, I_{M-} = -0.490 A. Then the most likely magnitude of I_C is:

$$IC = \frac{0.503 - (-0.490)}{2}$$

$$= 0.497 \text{ A.}$$

The error, i.e., the deviation from the true IC = 0.500 A is -.003 A.

The 2 step FZ can work just fine. However, there is an element of chance. If the pipe or manhole is strongly magnetized, it can be a lot less accurate than the 8 or 16 step FZ procedure.

Lab Trial of the 2 Step using a 4" Clip on Copper

I used a 4 inch diameter aperture MER™ Meter to measure the current in a #16 wire strung north-south. The actual (true) current was 0.500 A from a lab current source. The zero knob on the indicator was set so that IM (Fig. 1) read zero when the clip pointed due east. There was no significant magnetism except the Earth Field. The real He of this clip was 0 ± 13 mA peak. The specification requires that the He of a 4" MER™Clip be less than ± 30 mA peak equivalent input current. I use this as the normalizer in checking to see if a result is reasonable.

With the clip around the wire in the positive sense (Fig. 1), still pointing east, the meter read I_{M+} = +.498 A.

With the clip turned over in the negative sense (Fig. 2), but still pointing east the meter read I_{M-} = -.491 A.

Then the most likely value of I_C is:

$$I_C = \frac{I_{M+} - I_{M-}}{2}$$

$$= \frac{0.498 - (-0.491)}{2}$$

$$= 0.495 \text{ A}$$

The error was -.005 A. The error is -0.2 He. A good result.

Lab Trial of the 2 Step using the same 4" Clip on a Steel Pipe

Copper, aluminum, lead, etc., conductors do not have internal magnetization, but steel pipe may. I repeated the 2 step, this time on a 3" diameter, .2" wall steel pipe having some internal magnetism. In a relatively "cool" sector, the East pointing 2 step FZ gave:

IM+ = .502 A
IM- = -.492 A
Average: IC = .497 A

Since the true pipe current was still 0.5 A, the error was -.003. A good result.

The Element of Chance

When I did a full 8 step FZ using the same setup in the same location, I found that the up pointing 2 step gave I_C = .471 A. I could have chosen this worst orientation in the first place and been -.029 A in error. Not good. This was 1 H_e off the mark.

The 8 Step is more reliably accurate than the 2 Step FZ procedure.

Lab Trial of the 8 Step in the same "Cool" Sector

The result was twice as accurate as the up pointing 2 step. To be sure, it was less accurate than the East pointing 2 Step, but it is more dependable.

General Floating Zero Procedure (FZ)

This section describes the 8 Step Floating Zero Procedure for measuring a constant current. It describes how to largely cancel zero offset error, even in a magnetized pipe or near other magnets. It is an outline for the 16 step procedure which is basically the same, but more reliably accurate in a tough spot.

When the CP current IC in the pipe in Fig. 1 is constant, the method of measurement is to change the position of the sensor. This largely cancels zero offset. Meter readings corresponding to several sensor clamp positions are averaged. The result is closer to the true pipe current.

The next examples are taken from data measured on a lab pipe having a calibrated continuous IC = 0.50 A true current. [AutoMER™™ SN 2517 and 4" MER™Clip #563. The measured H_e is 0 ± 14 mA peak to peak. The specified maximum He is 0 ± 30 mA peak. The lab pipe is 3.3" OD; has 0.22 wall and is 45" long. It was spot magnetized at various times in connection with the design of Magnetic Error Reduction clips.]

The lab pipe is locally magnetized -- some places more than others. In the "cool" sectors a two step Floating Zero (FZ) Procedure worked fine. In the very "hot" sectors having a lot of local magnetism, it was necessary to use a 16 step FZ. This utilized 8 different orientations of the clip on the pipe -- first in the positive sense and then again in the negative sense. I think 4 orientations, each read in both the positive and negative sense, will do for most pipes in the field. However, the "Hot" sector shown in Table 1 was more accurately measured with the 16 step FZ.

The 4 inch diameter aperture MER™ Clip is represented as a clamp in Figures 1 and 2. The clamp is oriented nose up and to the left on the pipe. The actual pipe current I_C is 0.5 A.

Figure 1 shows the clamp in the positive sense, i.e., the bridle is in front of the clamp. The 0.5 A true current is shown flowing into the bridle, so the meter reads positive. In my experiment the meter reading was IM+ = +0.479 A when the nose pointed down.

To position the clamp symmetrically around the pipe I used a 9/16" foam belt, loose on the pipe. Wood or plastic shims have been used, but a foam belt works better.

Like Figure 1, Figure 2 shows the clamp on the pipe in the nose up and to the left orientation. However, in Fig. 2 the clamp is in the negative sense; i.e., the bridle is behind the clamp. The 0.5 A pipe current flows through the clamp's aperture and out into the bridle. This is the reverse of the positive sense, so the meter on the indicator reads negative. I measured I_{M-} = -0.461 A when the nose pointed down.

The zero control (Z) in Figs. 1 and 2 should be set when the FZ procedure is started, and then not touched. Straight up is a good guess. In my experiment the meter read zero when the clip was held in a magnet free sector (except for the Earth's magnetism), in a vertical plane, pointing east. Since the lab pipe was horizontal, running north-south, this was a good start. But it is not essential. The FZ cancels out zero offset error due to indicator miss-adjustment as well as zero offset error due to magnets -- both local and Earth.

What is *essential* is that the zero adjustment (Z) not be touched once a FZ run is started. Changing the zero control (Z) on the indicator during a FZ run invalidates the run. The data is likely bad.

Measurements Made During a Two Step FZ run

Combining Figures 1 and 2 using the data in my lab tests yields a two step FZ run.

In the setup of Fig. 1, I_{M+} = .479 A.

In the setup of Fig. 2, I_{M-} = -.461 A.

The scalar magnitude average is I_C = .470 A.

The error at this "Hot" sector, i.e., deviation from 0.5 A, is -.03 A.

This -30 mA error is equivalent to 1.0 times the He specification of the 4" clip used. It is more than we want to see, even in a "Hot" sector, but it is better than no FZ.

Measurements Made During an 8 Step FZ run in a Hot Magnetic Location

Table 1 is a chart of the type I use to organize the data for a FZ run. Clamp orientations are represented by arrows for nose up, down, east, and west. The four positive clamp sense readings IM+ are presented in the column to the right of orientation. This is done even if they are negative when read from the meter on the indicator. In such an event they are written as negative. The currents shown are what I measured at a magnetically speaking "Hot" location on the 3" lab pipe.

This can be seen in the data. For example, in the left hand column of Table 1, the west current reading was -.411 A. Its scalar magnitude is .05 A less than the average IC = .461 A on Table 1. Likewise the up reading is +.510 A; high by .049 A. These "standout" readings are 50 mA and 49 mA off the average I_C = .461 A; i.e., off by 1.7 He. Too much, if you need to know the current within a fraction of one He.

For a "Hot" pipe such as this, it is best to double the number of orientations, making a 16 step FZ run. Or better, if feasible move to a "cooler" spot on the pipe, at least several clamp diameters up or down the length of the pipe.

Assurance that the measurement is accurate enough can be had by deleting all lines of data wherein a measurement is more than 2 He from the average. This is best done on a 16 step FZ.

In the lab I made a 16 step FZ run in the same "Hot" sector. I got average IC = .490 A. This is He/3 shy of the true 0.5 A current. A good result. The added 8 steps increased the accuracy and confidence considerably.

Table 1

Summary of Eight Current Readings made at a "Hot" Pipe Location

Current Reading IM- Clamp in the Negative Sense	Clamp Orientation	Current Reading IM+ Clamp in the Positive Sense	Scalar Average for the Clamp Orientation
-.447 A	East	+.465 A	.456 A
-.411 A	West	+.450 A	.431 A
-.466 A	Up	+.510 A	.488 A
-.461 A	Down	+.479 A	.470 A
		Average: IC =	.461 A
		Known True IC =	.500 A
		Error =	-.039 A
		Error =	-1.3 He

In Table 1, the four readings IM- taken with the clamp in the negative sense, are presented in the left hand column, even if they are positive, and in such a case they are written as positive.

The error shown in Table 1 is more than is usually allowed. This is because the lab pipe was "Hot" in the sector measured, i.e., strongly magnetized in a spotty fashion.

Compare Several FZ Runs

Confidence in the practical accuracy -- say within ± 1 H_e -- is gained when the result of several FZ runs pretty well agree.

The 0.5 A true current IC has been measured four ways at the "Hot" lab pipe sector:

a. Two step FZ, Fig. 1 and 2: Result: IC = .470 A
b. Eight step FZ, Table 1: Result IC = .461 A
c. Sixteen step FZ: Result: IC = .490 A

d. Delete data rows having a deviation from average greater than 2 He; Result: IC = .471 A.

All four agree within 1 H_e , so we can have confidence that IC is likely between .461 and .490 A, or at least close thereto.

Is there a basis for selecting one of the four results? I think yes.

Criteria for Selecting the Result from One Process

I prefer to use the result obtained by averaging all the current readings available. This is the 16 step in c) above. The process is similar to that shown in Table 1. The average IC is .490 A, which is only He/3 less than the true 0.5 A.

However, some of the readings are "hot". Is it reasonably safe to rely on Table 1 or the 16 step? I think yes, on condition its result is within one He of the rest.

To see if this condition is satisfied, check the other three against the average IC = .490 A obtained from c) above, using the 16 step FZ.

In a), IC = .470 A. The deviation is -.02 A; i.e., -.7 He; This is acceptable.

In b), IC = .461 A. The deviation is -.029 A; i.e., -1 He. This is acceptable.

In d), IC = .471 A. The deviation is -.019 A; i.e., -0.6 He. This is acceptable.

Conclusion

We estimate we can rely on the 16 step FZ called c), and say:

"quite likely IC = .490 A, within ± H_e ."

If in doubt, or especially when the pipe is magnetically "hot":

- Use all 4 methods (a, b, c, and d, in the Summary, above).
- Pick 3 or 4 that agree within one He from these.

Use the result of the method having the most steps.