TrueGyde Steer supports the microcoil as an alternate magnetic source to the standard coil. This document describes how to build and use a microcoil as well as its advantages and disadvantages relative to the standard coil. The microcoil is a low cost add-on feature in the TrueGyde Steer license.

**Construction**

A microcoil consists of multiple turns of wire wrapped around in a cylindrical pattern. Microcoils can be organized into two categories, permanent microcoils and temporary microcoils. A permanent microcoil is built on a solid frame made out of a non-magnetic material such as aluminum, wood or plastic. This frame has a cylindrical shape with multiple wraps of wire. A permanent microcoil will typically have a diameter from 4 to 10 feet although one customer builds a 16ft. diameter folding microcoil. The number of wire wraps will typically be from 10 to 100. This type of microcoil is trucked to the job and can be carried around on the job site.

The picture below shows a permanent microcoil built by a TrueGyde customer being taken to a job on the back of a pickup truck. The frame for this microcoil was built with wood. The microcoil has a 7.75 foot diameter, a 1 foot thickness (from bottom to top) and 62 wraps of #6 copper wire. It weighs about 175 pounds.
A temporary microcoil is wire laid out on the ground or slightly above the ground in a horizontal circular pattern with multiple wraps. It is typically held in place by stakes pounded into the ground. This type of microcoil is built to use in one location and only that location. It must be dismantled and rebuilt, possibly with a different geometry to use in a different location. The picture below shows a microcoil built in the middle of an interstate highway. It has a 30 foot diameter and 11 wraps of copper wire and held together using electrical tape. The microcoil has been placed higher on some stakes in order to allow it to be level. It could be constructed with #14 gauge wire and powered with two 40 volt rechargeable lithium battery.

Advantages

The microcoil has distinct advantages over a standard coil. If it is a permanent microcoil, then its setup time is minimal. A temporary microcoil takes longer to set up, but its setup time would generally be less than a rectangular standard coil. This is particularly true when setting up in dense bush. In addition, a microcoil is quite small and can fit into places where a standard coil would not be practical as seen in the pictures above.

The first tracking advantage of the microcoil is that it does not have the end of the coil effect like a standard coil. With a standard coil it becomes difficult to track near the end of the coil and almost impossible to track beyond the end of the coil. On the other hand, a microcoil can project backwards or forwards beyond its ends to determine the steering tool location. It can also project left or right.
This point is shown in the diagram above. The steering tool does not have to be directly below the microcoil for successful tracking. The only restriction on locating with the microcoil is the distance between the microcoil and the steering tool. If the coil is too far away from the steering tool the magnetic field will be too weak. For the permanent microcoil shown previously in this document next to interstate (figure 3), the tracking range behind or in front of the microcoil was about 55 feet for a tool depth of 30 feet. This was based on a total current of 30 Amps that was generated by two 40 volt lithium batteries. A larger temporary microcoil would have a larger tracking range, the effective range will be described in more detail later. A greater distance can be achieved by using multiple batteries.

The second tracking advantage of the microcoil is that it provides a 3-D tracking location. The standard coil receives an away value based on the directional data calculation or user input and then calculates the optimal tool lateral and elevation co-ordinates based on that away value. The tool location algorithm indicates a potential error in the away value via the axial mismatch but has no ability to correct any error in the away value. The microcoil will correct any error in the away value and provide an exact 3-D tool location for the measured magnetic field. This will be extremely helpful if a significant away error has occurred. It should be noted that tool azimuth relative to line azimuth errors can result significant errors when working outside the coil.

A third tracking advantage is that the tool location is extremely accurate when the tool is reasonably close to the microcoil relative to the maximum tracking range (less than half the maximum tracking range). In this scenario, the tool can be positioned to within a few inches.

**Limitations**

The main disadvantage of the microcoil is its limited tracking range. Even a fairly large temporary microcoil with a strong current will have a range on the order of 200 feet with a high res tool. However, the microcoil was not intended to be used exclusively for a typical long job. Note however that a permanent microcoil could be used with reasonable efficiency on a job with a length of several thousand feet. In this scenario, the microcoil could be used to track 4 or 5 joints of pipe and then moved to its next location. If the operator was willing to steer the bore without tracking for a few joints, then the microcoil would be advanced about 200 – 400 feet at a time. This scenario is definitely the exception but could apply to jobs where the standard coil is not practical.
The microcoil was primarily intended for use in tight spaces, over water and in situations where projection beyond the coil ends is helpful. This includes placing a microcoil at the side of a freeway or on the bank of a river and using it to project into the freeway or river. As stated earlier, the microcoil can also be used to confirm the away value if there is some doubt regarding its accuracy. It is important to note that like the coil the microcoil should not be too close to steel objects.

Field Usage

When a microcoil is placed in the field, it must be horizontal (level). The microcoil center does not have to be along the job center line. The steering tool can pass to the left or right of the microcoil. The diagram on the right shows the microcoil when viewed from above. Like the standard coil, the operator energizes the microcoil with a forward current and then a reverse current. The forward current must flow through the microcoil in a clockwise direction when viewed from above. When using a welder to power a coil the welder should be located some distance away from the coil in order to not distort the magnetic field produced by the coil. However, the leads should be as close together as possible when leading to the power supply which is not indicated in this diagram.

Calibrating the Microcoil

As stated earlier, the ideal microcoil has wire wrapped on a cylinder or a polygon that approximates a cylinder. The operator then defines the microcoil to TG Steer using the dialog shown at the right. This dialog assumes the ideal cylindrical shape. The permanent microcoil shown earlier was carefully manufactured and came close to the ideal shape. Its parameters are shown in the dialog. The thickness is the height of the microcoil from top to bottom. It was 1 foot for the permanent microcoil shown previously. For a temporary microcoil consisting of wire laid out on the ground the thickness will be 0 or a very small amount such as 0.1 feet.
The microcoil position is its actual position in the field, these co-ordinates can only be meaningfully entered when the microcoil is used on a job. Note that the position specified is at the center of the microcoil, both in the horizontal and vertical co-ordinates. The permanent microcoil described earlier would have an elevation 6 inches above its base. If the microcoil is placed in several positions on a job, then Steer can record all of the positions and Profiler will display these positions.

If the microcoil is not a perfect cylinder, then the operator must define it in terms of an equivalent cylinder. For example, if the microcoil is an ellipse with a minimum diameter d₁ and a maximum diameter d₂ then the average diameter 0.5 * (d₁ + d₂) should be utilized.

A more common situation, particularly for temporary microcoils is that the wire will be connected to stakes in the ground and the microcoil will have the shape of a polygon rather than a circle.

The diagram on the right shows a regular hexagonal microcoil inscribed within a circle. Clearly the microcoil has a slightly smaller area than the circle. It also is obvious that as the number of sides in the polygon increases then the polygon will more closely approximate the circle. To express the “diameter” of a microcoil having the shape of a polygon, a circle with an equivalent diameter must be determined.

The table below shows the correction factor to use for a polygon with n sides inscribed in a circle. As an example, if the microcoil has 12 sides and is inscribed in a circle whose diameter is 20 feet, then the effective “diameter” of the polygonal microcoil is 0.977 * 20 feet = 19.54 ft.

<table>
<thead>
<tr>
<th>Polygon Name</th>
<th>Number of sides (n)</th>
<th>Correction Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Square</td>
<td>4</td>
<td>0.798</td>
</tr>
<tr>
<td>Hexagon</td>
<td>6</td>
<td>0.909</td>
</tr>
<tr>
<td>Octagon</td>
<td>8</td>
<td>0.949</td>
</tr>
<tr>
<td>Decagon</td>
<td>10</td>
<td>0.967</td>
</tr>
<tr>
<td>Dodecagon</td>
<td>12</td>
<td>0.977</td>
</tr>
</tbody>
</table>

An additional complication is that a microcoil in the shape of a polygon is not regular which means that the sides and angles are not all identical. To determine the effective “diameter” of an irregular polygon, the operator should apply both of the correction factors described previously. For example, consider an 8 sided microcoil. The operator first measures the distance between the 4 pairs of opposing corners and comes up with values of 19’8”, 20’1”, 19’10” and 20’5”. These 4 distances are averaged to arrive at an average diameter of 20’0” for the inscribing circle. The correction factor for an octagon (0.949) is then applied to determine an effective “diameter” of 0.949 * 20.0 feet = 18.98 feet.
Perhaps the most important issue in the microcoil is its tracking range. This is not an exact distance as the tracking accuracy decreases with increasing distance. A reasonable level of accuracy depends on the situation.

The table below shows the depth directly below the center of a microcoil at which the magnetic radial intensity is 300 nT for a high res tool. These two radial intensities are conservative values for reasonably good tracking results and indicates the maximum tool depth that should be easily measurable when the tool is directly below or almost directly below the microcoil.

<table>
<thead>
<tr>
<th>Diameter (ft)</th>
<th>Turns of wire</th>
<th>Total Current (Amps)</th>
<th>Depth (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>60</td>
<td>40</td>
<td>64</td>
</tr>
<tr>
<td>8</td>
<td>60</td>
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</tr>
<tr>
<td>50</td>
<td>20</td>
<td>40</td>
<td>149</td>
</tr>
</tbody>
</table>

Note: it is very important when tracking outside the coil that the line azimuth correlates with the tool AZ.

If the tool is not below the microcoil, but is projecting forwards or backwards significantly, then the distance from the microcoil center with the same field intensity is a bit smaller. It is reasonable to reduce the maximum distance by about 20% when the tool is mostly horizontal from the microcoil. Thus, for the microcoil parameters in the second row above, the maximum distance directly below the microcoil is 87 ft. The maximum distance when projecting forward or backward would be about 0.8 * 87 ft or about 70 ft. This roughly corresponds to a horizontal distance of 65 feet from the microcoil center when the steering tool is 30 feet below the microcoil.

To repeat the calculations in this table with any other parameters, the maximum depth in feet directly below the microcoil is roughly \(0.7 \times (D^2 \times N \times I)^{1/3}\) where \(D\) is the microcoil diameter in feet, \(N\) is the number of turns of wire and \(I\) is the total current in Amps. This maximum distance should be reduced by 20% when projecting forwards or backwards with the microcoil. The operator can use these principles to predict the tracking range for other microcoil scenarios. For operators working in metric units: 1 foot = 0.3048 meters, 1 meter = 3.281 feet.

A more thorough analysis of the microcoil tracking field can be obtained by entering the microcoil parameters into TG Steer and then using the “Tracking Accuracy” dialog. This dialog will show the field intensity or the anticipated tracking error based on an operator provided magnetic measurement error.
Q: I would like to build a permanent microcoil with several layers of wire wraps. Is this possible?
A. Yes, use the average diameter of the layers as the effective diameter. If there are three layers of wire and your inner layer has a diameter of 8.00 ft while the outer layer has a diameter of 8.06 ft then the average of the three layers is 8.03 ft.

Q: What is the best material to use for the frame of a permanent microcoil?
A. My preference is aluminum. This is primarily for strength and heat reasons. Note that when you pass a large current through your microcoil, the wire can generate significant heat. An aluminum frame will not easily melt like plastic or smoke like wood and it will draw away the heat from the wire more efficiently. On a related note, ensure that the wire insulation can withstand the expected temperatures. This last point is particularly important when there are several layers of wire wraps.

Q: Can I use aluminum wire instead of copper wire for the windings?
A. Yes. Aluminum wire has a higher resistance (about 68% higher) than an equivalent gauge copper wire. Thus, an aluminum wire must be about 2 gauges larger to have the same resistance. As an example, #8 aluminum has a resistance about 5% higher than #10 copper. However, aluminum weighs about 30% as much as copper for an equal wire gauge. Thus, #8 aluminum wire only weighs about half as much as #10 copper but with a similar resistance. Therefore, the wire of an aluminum wire microcoil would have half the weight of wire with the same current carrying capacity. The potential difficulty will be finding aluminum wire in a large enough gauge.

Q: I would like to track while I am under a river but quite far from either bank. Is this possible?
A. Yes, but it requires a bit of ingenuity and effort. You can use either a permanent or temporary microcoil on a non-magnetic raft. The microcoil could be powered by a portable source such as one or more car batteries. Clearly, with this power source, the current will be low compared to what is obtained with a welder.

Alternately, it is possible to have leads connected to a welder on the shore. In addition, the raft might toss around to some extent that is dependent on the current. If the raft is not level when the measurement is taken, this will introduce additional error into the measurement. However, even with these difficulties, the tracking information will probably add significantly to your knowledge of the tool position.