THE UTILITY OF HORIZONTAL COMPONENT MEASUREMENTS IN RANDOM-WALK TEM SURVEYS

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Abstract

Laboratory tests and field examples of the horizontal field component measurements in shallow transient electromagnetic (TEM) surveys show the utility of these data in target characterization in reconnaissance, random-walk surveys for unexploded ordnance (UXO) and underground utilities. For example, prior work has shown that the Hx component (which we define as the horizontal field component in the direction of travel of the measurement system) is often useful in distinguishing small 3-D targets from linear features (such as buried pipelines or power lines). The current work expands on this capability, which is particularly important in UXO projects in which random transects are evaluated to determine a statistical estimate of density and distribution of potential ordnance and explosives. Anomalies from pipelines or power lines can skew the statistical evaluation toward over-estimating the number of potential UXO in a given area. The current research provides examples of the additional information that is available in the horizontal components of TEM surveys, particularly in the early time after transmitter turnoff. For example, the Hy component data are useful in estimating the orientation of linear features such as pipes and power lines with respect to the survey lines.

Introduction

The TEM method, using relatively small loops (a few square meters in area and less) mounted on wheeled carts is one of the most commonly-used techniques applied currently to UXO, underground storage tanks (UST), and utilities detection. In most cases, the vertical component (Hz) is measured at one or more heights above the ground after the system and background earth responses have decayed to near-zero levels, allowing detection of subsurface conductors. Hz-component cart-mounted measurement systems, such as the Geonics EM-61, have been extremely successful tools in UXO, underground storage tank, and utility detection.

Characterization of targets is becoming increasingly important, however, particularly in UXO projects. Advance knowledge of the type of UXO, or the simple distinction between UXO and non-UXO metallic debris, can have important economic impact on excavation and removal procedures. Although characterization is somewhat less important in projects in which 100% of anomalies are to be excavated and removed regardless of the nature of the target, it is very important during random-walk, reconnaissance surveys, such as an Engineering Evaluation / Cost Analysis (EE/CA) project. These projects are intended to provide a statistical estimate of UXO targets in given areas for detection and removal cost estimates.

One avenue of research into the characterization problem includes the use of the horizontal component, in addition to the vertical component, of TEM data. Also of interest is the use of more measurements along the decay curve, in order to make use of the time constant information. The directional dependence of the horizontal component measurement and its use is intuitive, and has been commented on in shallow TEM surveys (Mayerle, et.al., 1998 for example), but full 3-D, multi-component modeling has apparently not been done for this problem.

In this paper, we discuss field results that illustrate the use of horizontal measurements, with particular emphasis on random-walk surveys, i.e., surveys in which a dense grid of measurements is not available for interpretation. For example, anomalies from a pipeline are reasonably interpreted as a pipeline (or some other long linear object) in a dense survey grid because of the linear alignment of anomalies and line-to-line correlation. However, in a random walk TEM survey, a pipeline in the project area may be crossed multiple times, producing an anomaly each time, but if only the Hz component is measured, these anomalies are not distinguishable from any other anomalous targets (UXO, metallic debris, etc.). In this paper, we discuss physical tests and field projects that show the use of the horizontal component data to delineate, from random-walk surveys, not only the linear nature of a pipeline or power line, but its relative orientation to the survey path.

Equipment System

The multi-component TEM data discussed here were acquired using a non-conductive cart-mounted 3-component loop system, with orientations as shown in Figure 1. The transmitter loop measures 1 meter by 1 meter, utilizing only four turns of wire to enable fast turn-off, early time measurements. All three receiver loops were 0.5 meters by 0.5 meters, also with 4 turns each. In all of our work, we have defined the Hx component to be the field component oriented along the direction of the path of the cart, and the Hy to be the field component oriented perpendicular to the path of travel. The receiver/transmitter was a Zonge NT-32 (called "NanoTEM"), carried by backpack to provide separation from the loops. In this system, the three components of data are acquired simultaneously on three separate 16-bit analog cards. Locations are determined using a Trimble Pathfinder RTK GPS unit, with the antenna mounted above the center of the transmitter loop.

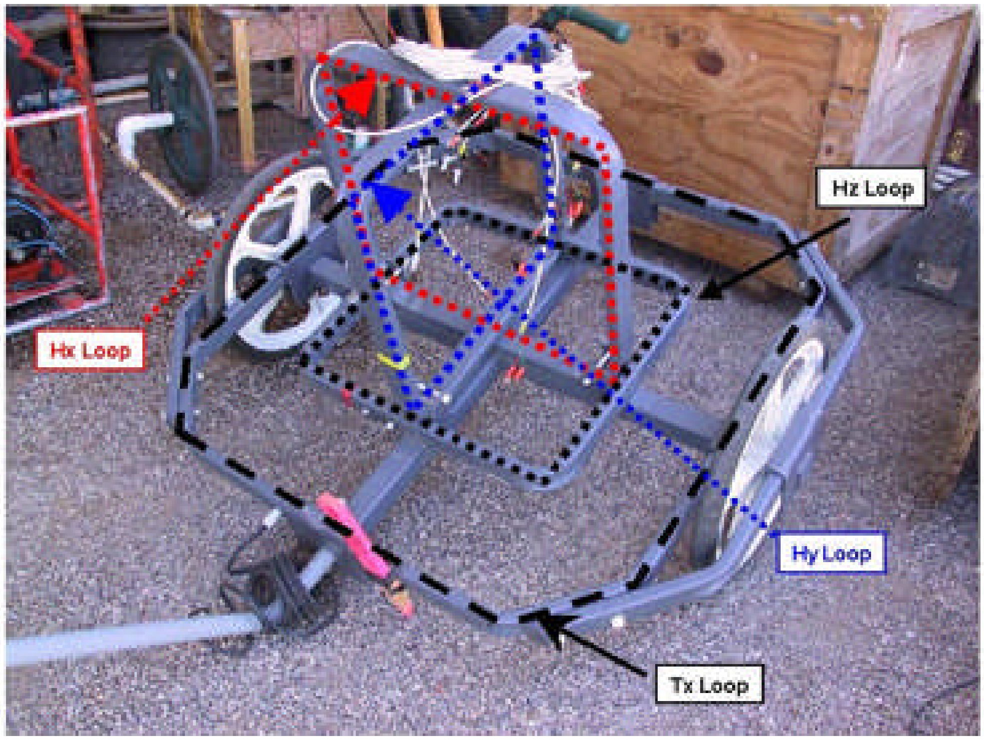

Figure 1: Loop orientations on the non-conductive cart for the multi-component TEM measurements.

The testing was deliberately done in a manner to simulate normal field operations, rather than on a fixed laboratory bench for example, or using an automated system to carefully control speed and data density. The "laboratory" tests were run manually, at a slow walking pace, in a moderately noisy environment within 300 feet of overhead power lines. As a target, we used a 20-foot (6.1 meter) length of 1-inch diameter iron water pipe, lying on a gravel surface. In each case, the pipe was oriented for the test and surveyed with GPS. The data were acquired at a repetition rate of 64 Hz, stacking and averaging 32 cycles to constitute one data block, although an alternative method often used with this system is to record each individual cycle as a separate data block, followed by decimation in data processing at a later time.

One very important factor is that the measurements discussed here are made much sooner after transmitter turn-off than is the case for most currently available systems that measure only the Hz component. These early time measurements are important for several reasons: First, some non-ferrous targets, such as buried power lines, have a very short time constant, and their signal has decayed to near-zero levels (even in the Hz component) by the time most normal Hz systems begin reading (Carlson and Zonge, 2002). Second, the horizontal field components are often substantially weaker than the vertical field, thus measurements that are made several hundred microseconds after turn-off are often too noisy for use. The system we use is capable of turning off the transmitter in approximately 1.5 microseconds in a 1-meter square transmitter loop, and data acquisition begins less than a microsecond later. To achieve this fast turn-off, it is necessary to limit the number of turns on the transmitter loop, as well as the current levels. By comparison, typical Hz-only systems turn off very slowly (many tens of microseconds) and data acquisition does not occur until several hundred microseconds after turn-off, to allow both the earth response and system response to decay to near-zero levels.

In the profile plots of the data included here, unless otherwise noted, the y-axis of the plots show a composite-window value, in microvolts/amp-meter^2, of the five earliest windows of the given component. Windows 1 through 5 are at 0.32, 1.52, 2.73, 3.93, 5.14, and 6.34 microseconds after transmitter turnoff, respectively, and each window is 1.205 microseconds wide.

Linear Target Features

Linear vs. 3-D Features

The distinction between linear features and 3-dimensional features in the horizontal component data is evident from numerous field examples. An example from an earlier paper (Carlson and Zonge, 2002) is shown in Figure 2. This example shows the difference in the Hx component data along a single line of data that crossed a buried pipeline and buried septic tank (with a metallic cover), both of which were excavated for verification. Although both targets created similar late-time Hz anomalies, the anomalies in Hx are distinctly different. As the cart moved along the survey path (from left to right in this plot), the pipeline created a positive anomaly as it approached the pipeline, near-zero crossover readings directly over the pipeline, and a negative anomaly as the cart receded. The septic tank cover, however, created an anomaly of the opposite polarity: a negative-crossover-positive sequence. This distinction was evident on numerous lines of data, repeatedly on this pipeline as well as on other pipelines and buried power lines. This particular characteristic remains empirical, until we can confirm it with full 3-D, multi-component, early-time mathematical modeling, although polarity reversals in general of transient decays due to pipeline-type features have been discussed in the literature (for example, Tsubota and Wait, 1980).

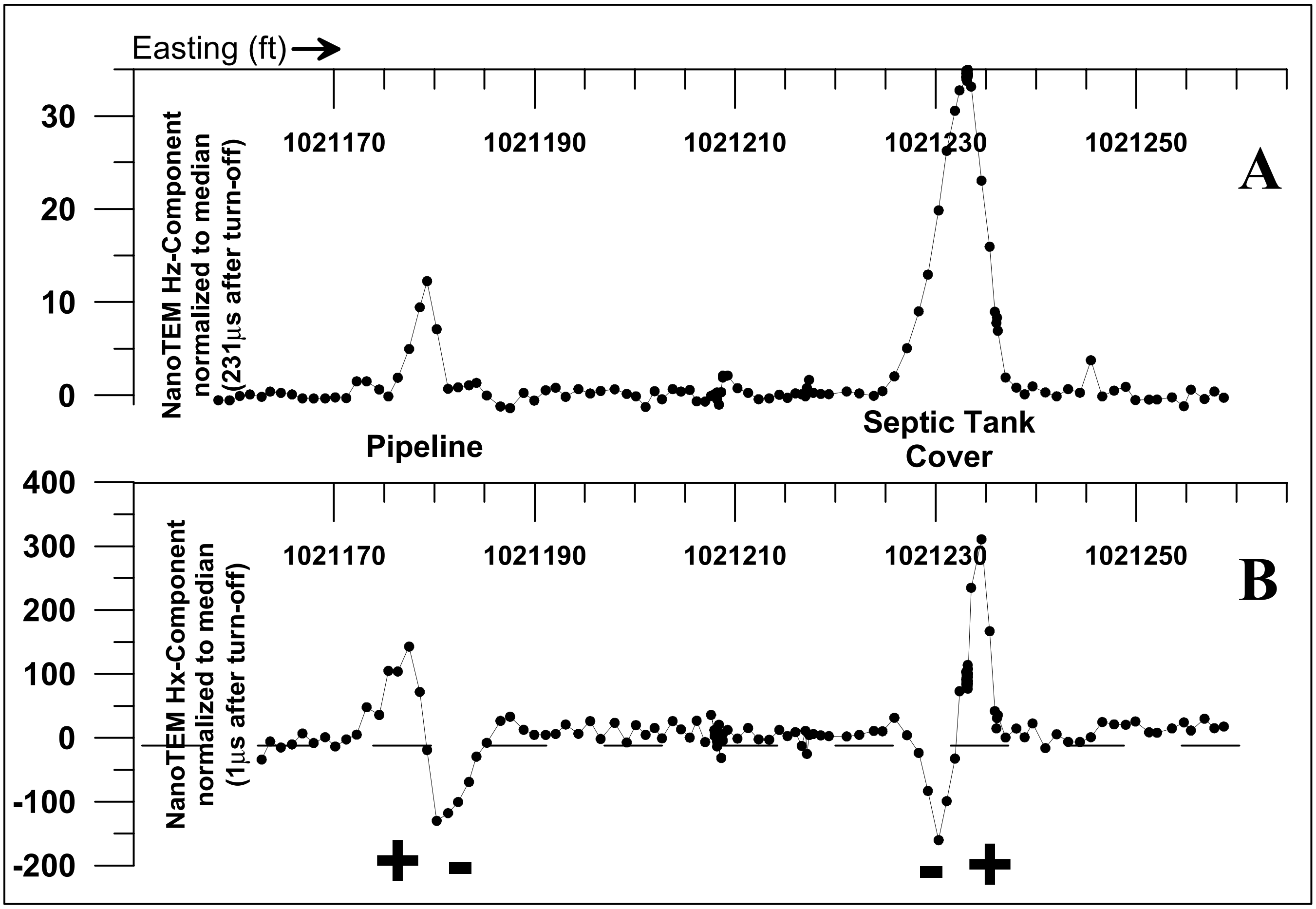

Figure 2: Comparison of typical late-time Hz component data (A) and early-time Hx component data (B) in profile form along a survey line crossing a pipeline and then a metallic septic tank cover. The pipeline causes a positive-crossover-negative anomaly, while the septic tank cover (a 3-D object) causes a negative-crossover-positive anomaly. (From Carlson and Zonge, 2002)

Orientation of Linear Features

In addition to simply distinguishing between linear features and 3-D features, the horizontal component data are also useful in determining orientation of linear features. For example, Figure 3 shows the distinction in the horizontal component data between two pipes that are both oriented at a 45° angle to the survey line; one, however, is approached such that the pipe is first on the port side of the cart (A), and the other is approached such that the pipe is first on the starboard side (B). Both pipes create similar Hx anomalies (positive-crossover-negative in the direction of travel) which are shown as black profiles in (A) and (B). Both also create similar Hz anomalies (not shown here), thus these two pipes would be indistinguishable in a typical Hz-only system. The two pipes are distinctly different in the Hy measurements, however. In the orientation used for this test, approaching the pipe such that the pipe is first on the port side (A) the Hy anomaly is negative-crossover-positive, but the starboard approach is the opposite, positive-crossover-negative.

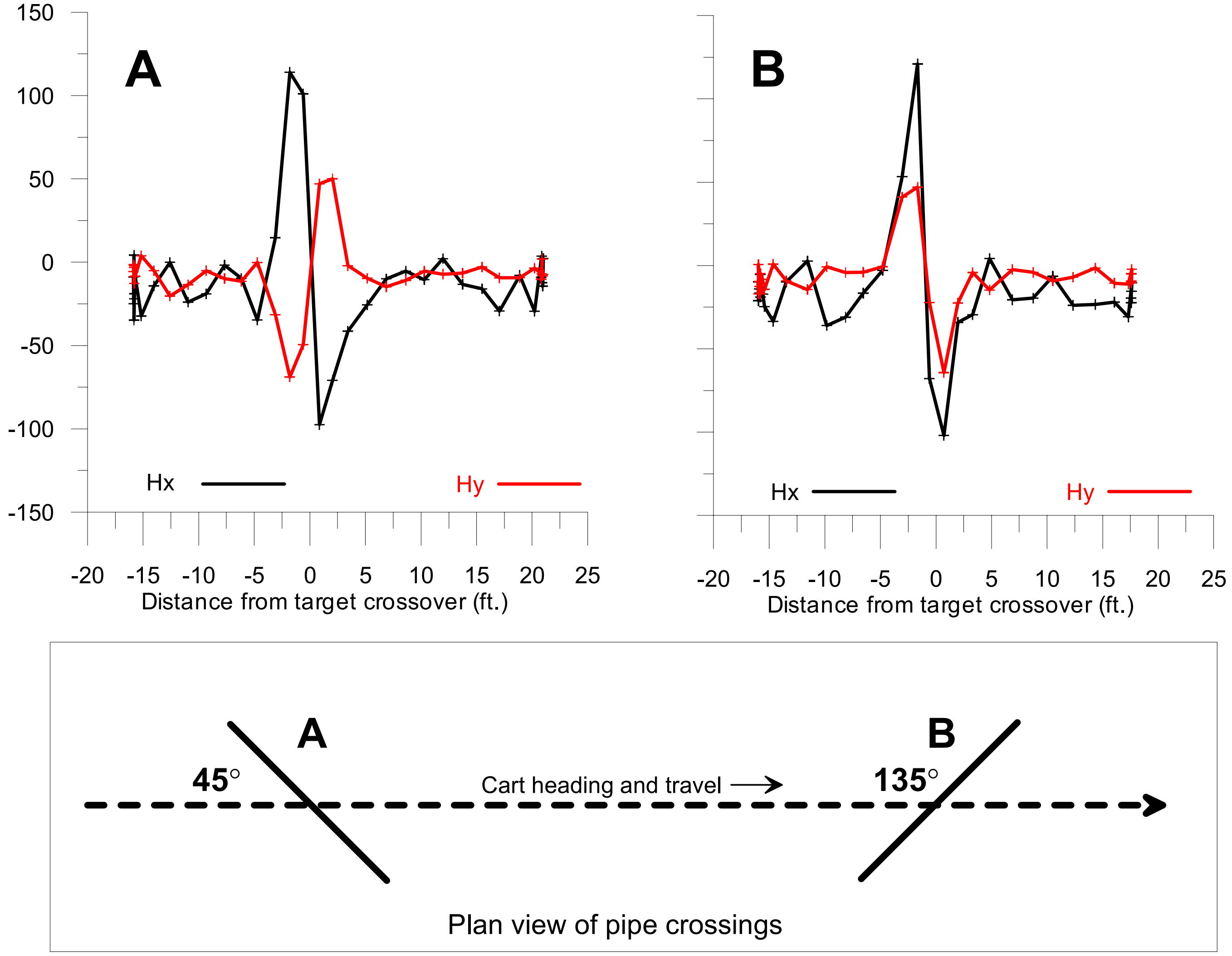

Figure 3: Comparison of Hx and Hy component data in profile form, crossing the test pipe at an angle of 45°. In (A), the pipe approach is on the port side of the cart path, but in (B) the pipe approach is on the starboard side. Note that the Hx anomaly in each case is similar, but the Hy anomaly is negative-crossover-positive in (A) and postive-crossover-negative in (B).

Similarly, smaller changes in orientation of the target pipe are also evident. Figure 4 shows the horizontal component data acquired when the pipe is oriented at 90°, 45°, and 30° to the survey path (approach on the port side). In the Hx component data, the anomaly is positive-crossover-negative for all three orientations, but strongest for the 90° intersection, decreasing for 45°, and smaller still for 30°. In the Hy measurements, however, the anomaly is almost undetectable for the 90° crossing, and increases for the 45° and 30° crossings.

Thus if the Hx data in a random-walk survey indicate that an anomaly is due to a linear target such as a pipe, the Hy data can be used to determine whether the pipe approach is from the port or starboard (such as in Figure 3). Further, if an anomaly appears to be a pipeline on the basis of the Hx data, but is absent in Hy, the linear feature is most likely perpendicular to the survey path (such as in Figure 4).

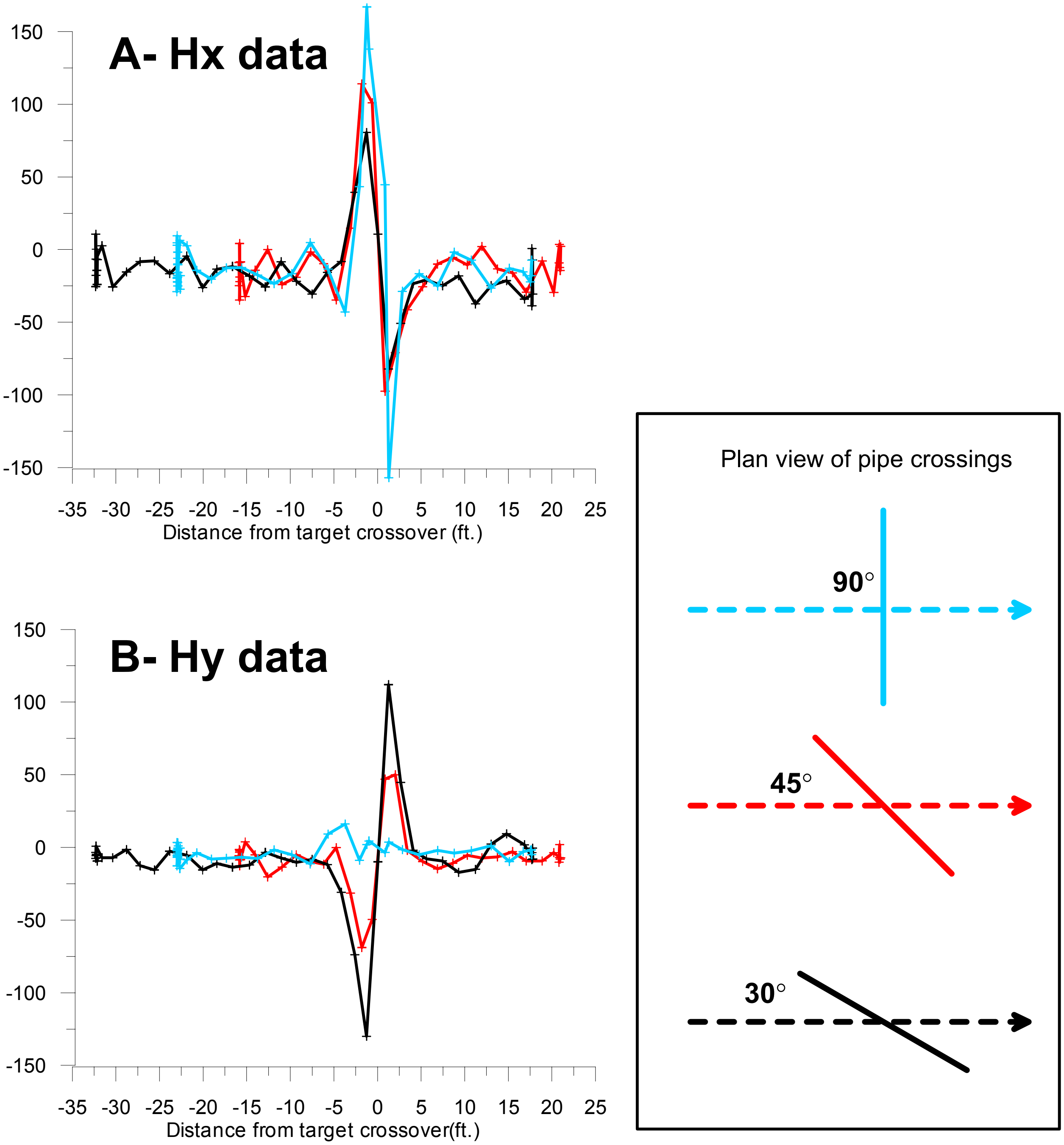

Figure 4: Comparison of Hx and Hy component data in profile form crossing the test pipe at varying angles. The Hx data show a decrease in anomaly amplitude as the angle to the pipe shallows. The Hy data show no anomaly when perpendicular to the pipe, and an increasing anomaly as the angle relative to the pipe becomes more shallow.

It is also noticeable in Figure 4(B) that the width of the Hy anomaly increases as the angle of the pipe crossing becomes shallower, as is expected intuitively. This would suggest that if the survey path approaches a linear target at a very shallow angle, the Hy anomaly should be relatively broad. A good field example of this is seen in a survey of a baseball field described by us in a previous paper (Carlson and Zonge, 2002). Figure 5 shows a plan view of that survey data, showing the horizontal vectors (calculated from the early-time Hx and Hy data), and Figure 6 shows the profile plots of the Hy data for three of the baseball field survey lines. Also on Figure 6, plotted at the same scale, is the equivalent data from one of the pipe tests for comparison. All three sample lines from the baseball field survey show a very broad anomaly relative to the pipe anomaly, and examination of the plan view plot (Figure 5) shows that the survey lines crossed the anomaly at a very shallow angle. Relative target depths of the test pipe and the baseball field anomaly are also certainly influencing the width of the anomalies.

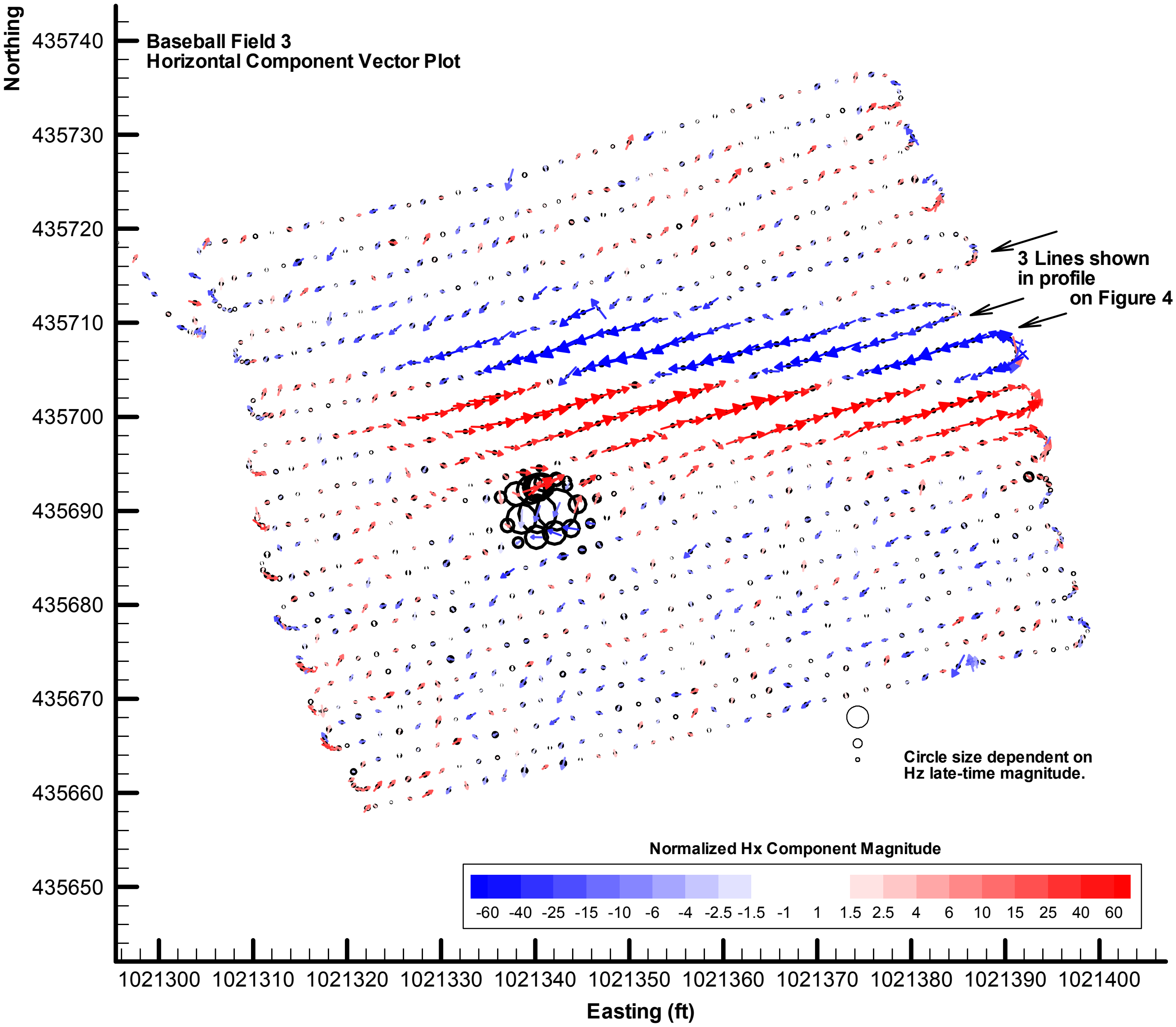

Figure 5: Plan view of the horizontal vectors from a field project to locate buried metallic debris under a baseball field. The vector length is correlated to vector magnitude, and the vector color is correlated to the Hx component magnitude. The late-time Hz measurement at each station is shown as an open circle, scaled to Hz magnitude.

It is also important to note that even though the Baseball Field 3 east-west linear anomaly is strongly evident in the early-time horizontal component data, both in profiles as well as in the plan view vector plot, it is not present at all in the Hz component data. The Hz component data, which is included on Figure 5 as open circles at each station (with the size of the circles dependent on late-time Hz magnitude), give no indication of an anomalous feature in that area. (A well-constrained anomalous area in the Hz data is seen centered approximately at grid location 1021341E, 435690N, in good agreement with an EM-61 MKII survey performed by another contractor on the same baseball field.) Neither the EM-61 data, nor the late-time NanoTEM Hz data detected the east-west linear anomaly that is obvious in the Hx and Hy data sets, however, indicating that it has a very short time constant. The Hz anomaly that is located at 1021341E, 435690N has since been excavated and verified, but the east-west linear anomaly (which is not detectable in late-time Hz-only systems) is interpreted to be an old buried power line, does not appear to pose a safety threat, and therefore has not been excavated to date.

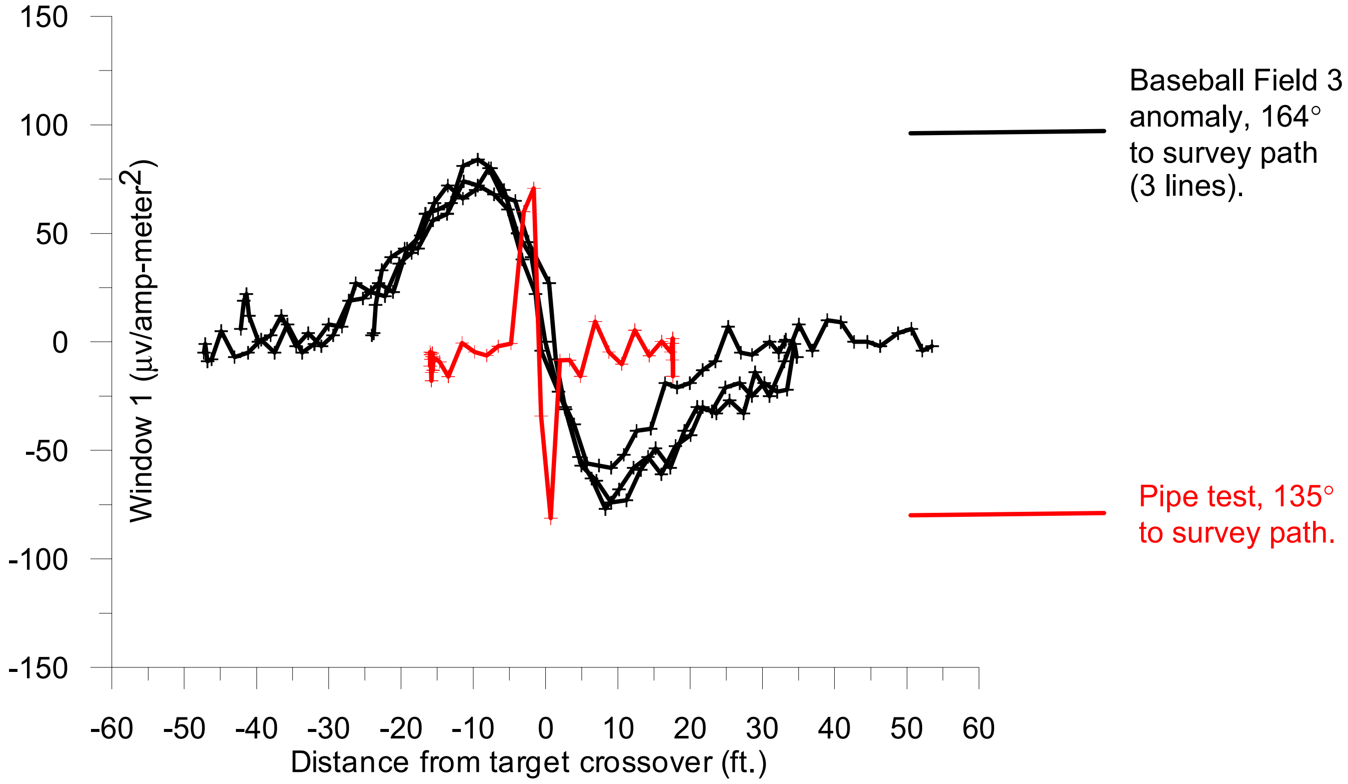

Figure 6: Profile plots of the Hy component data from the baseball field survey shown in Figure 5 and from one of the pipe tests, showing the broad anomaly resulting from the shallow angle of approach to the baseball field anomaly.

In the event that the TEM survey path crosses over the end of a pipeline or similar feature, the horizontal component data are also distinctive. Figure 7 shows the results for two test surveys over the end of a pipe; in one case (A), the pipe is located to the port side of the survey line, and in the other case (B), the pipe is located to the starboard side of the line. Once again, the Hx component shows similar positive-crossover-negative anomalies in both cases. The Hy data, however, show a simple negative anomaly when crossing the end of the pipe with the pipe on the port side, and a simple positive anomaly when the pipe is on the starboard side. These Hy results are distinctly different, in addition to being clearly distinguishable from the scenarios described above in Figures 3 and 4.

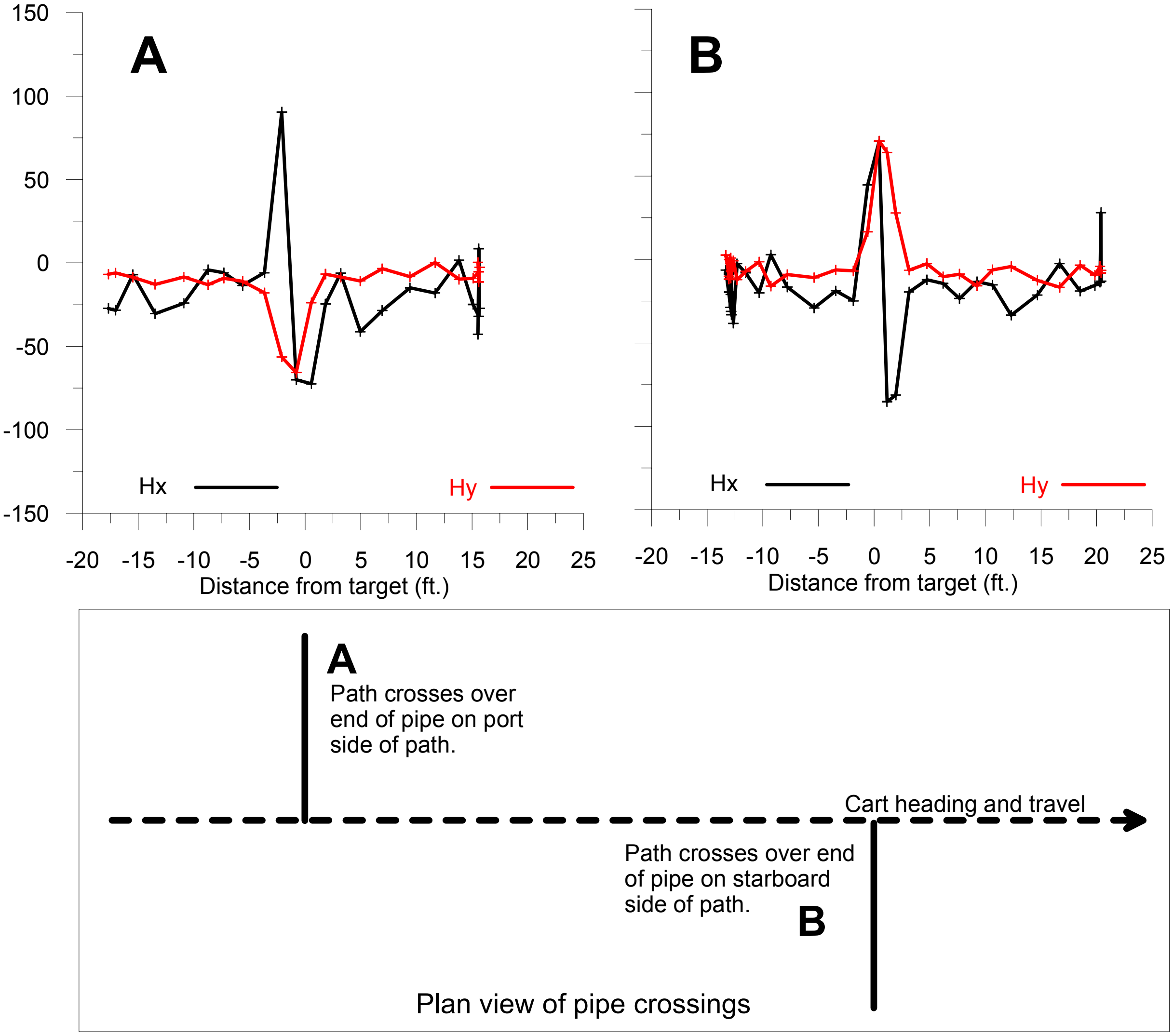

Figure 7: Comparison of Hx and Hy data in profile form when crossing over the end of the test pipe. In (A), the pipe is on the port side of the survey path, and in (B), the pipe is located on the starboard side. Note that the Hx data are similar, but the polarity of the Hy anomaly changes.

Conclusions and Caveats

There is clearly valuable information in the horizontal components of TEM survey data, as well as some detection capabilities in the early time data that are not present in typical late-time Hz component surveys, such as the example shown in Figure 5 above. Discrimination between linear and 3-D features is often possible, and it is also possible in some cases to estimate the orientation of linear features relative to the survey path without the need to acquire dense grids of data. As shown by the field examples and tests that were performed in a typical field environment at normal production speeds and densities, these useful results are currently achievable with commercially available equipment.

Much of the directional information, particularly of the Hy component (in our orientation scenario) seems intuitive, but 3-D, multi-component mathematical modeling of early time information, at these physical scales, is not yet available to our knowledge. The characteristic behavior of the Hx component data across linear features relative to 3-D features is not intuitively obvious, however, and mathematical modeling would be useful in verifying these results.

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