HISTORY OF WALKOVER LOCATING TECHNOLOGY

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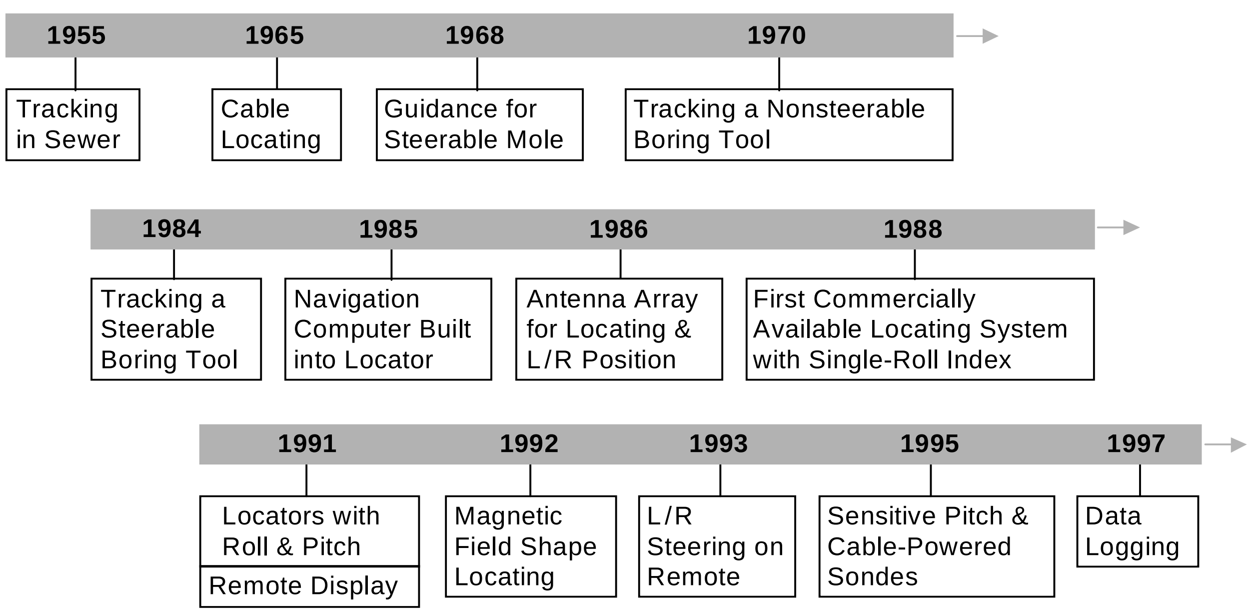
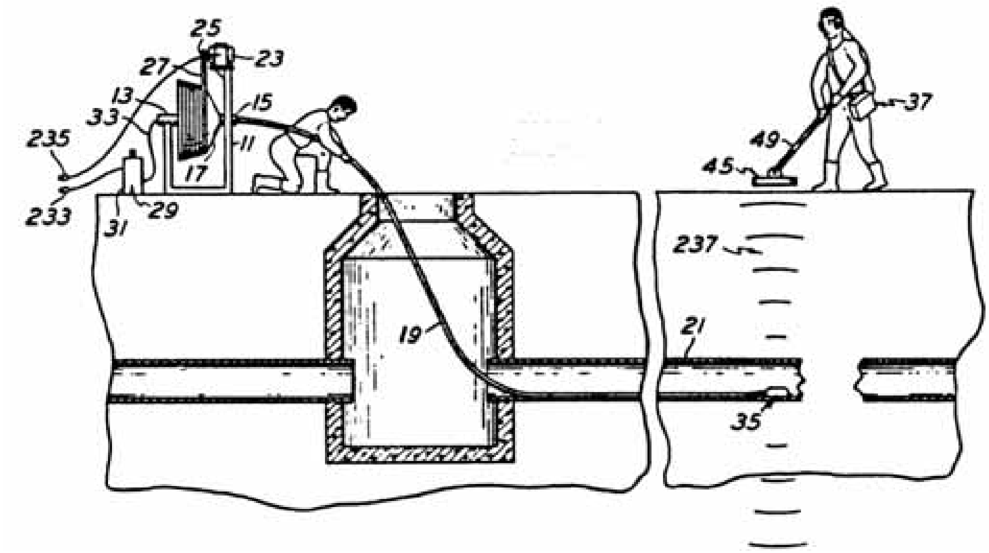
Modern walkover locating systems for tracking the drillhead in horizontal directional drilling (HDD) operations have evolved over many decades from several different applications. This review highlights the major achievements in this evolution. The historical information presented here was obtained from published patents, brochures and other literature available to the public, as well as the author's personal experience. Some specialized refinements are not mentioned because their basic function existed in prior equipment, and to include them would turn this paper into a book. The author apologizes to anyone whose effort has not been recognized.

Research in the patent literature shows inventive efforts as far back as 1933 related to tracking and locating. The closest reference to current technology seems to be attributed to Robert Neff, who filed for a patent in 1955. Neff disclosed a locating system for finding blockages in sewer lines. The concept bares resemblance to current tracking systems in that a dipole transmitting antenna was fed into the sewer line and a walkover surface receiver was used



Timeline of Major Developments in Walkover Locating Technology



1955 Neff Electronic Locator System

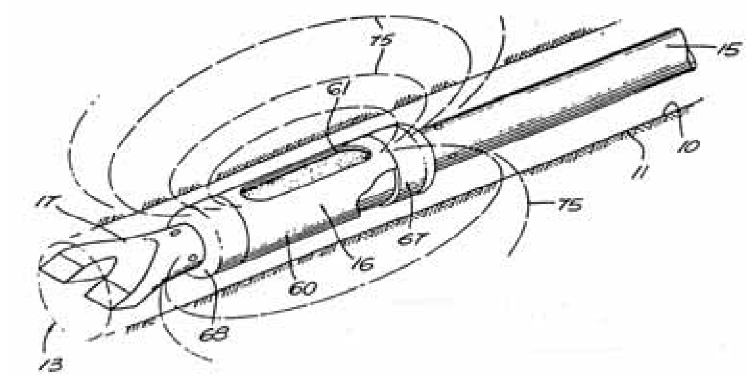
to locate the antenna. The dipole antenna was oriented perpendicular to the surface rather than parallel, as in current locator transmitters. The receiver used a simple volume control and headphones to direct the operator. This system guided the operator to a position above the antenna, but could not determine depth. Because high-power transistors were not available at that time, vacuum tubes were used for both the receiver and the transmitter. The confined space available for the downhole device precluded having the transmitter there. Instead the transmitter was above ground and only the antenna went downhole. This allowed the transmitter to be connected to 110-volt power.

1965 Bell Laboratories Depthometer

In 1965 C. A. Young of Bell Laboratories wrote an article in the *Bell Laboratories Record* describing a cable locator that used the ratio of signal strengths measured by two horizontal antennas at two heights off the ground to determine the depth of a cable. This method assumes that the field strength variation of the magnetic field emanating from the cable is known. For long, straight cables the signal strength variation is inversely proportional to the distance from the cable, i.e., double the distance, halve the signal strength. If the cable has bends or terminates close to the locator, then the signal strength relation is not known. Most current boring tool locators use this twin horizontal antenna arrangement to determine depth.

In the late 1960's Bell Telephone Laboratories built a guided impact tool or mole. Although the guidance system did not fall into the category of a walkover tracking system, it was the first time that a small-diameter boring device was outfitted with guidance. A patent filed in 1968 by James Coyne of Bell

Labs describes a complex arrangement of receiving and transmitting antennas that provided a steering signal used to control the mole. The system was never commercialized and no one picked up the effort to develop a steerable system at that time. Interest in tracking nonsteerable tools did continue, however.



The Goldak Co. Transistorized Dipole Transmitter (1970 McCullough and Ladine)

By the late 1960’s the transistor reigned in electronics. It could handle the speed and the power demanded by transmitters. In 1970 Lester McCullough and Duane Ladine of The Goldak Co. developed a transistorized dipole transmitter that was potted into a section of an unguided boring tool. One or two receivers were used to find the nulls in the magnetic field in front of and behind the boring tool. McCullough and Ladine state that the distance between the two nulls can be related to the depth by calibrating. This procedure used the shape of the magnetic field to determine depth. They did not provide a description of how to find the nulls except to move the receiver longitudinally along the transmitter axis (assuming that it was known). Their description was one of the first documented references to the use of the magnetic field shape for gathering locating information.

Toward the end of the 1970’s the Electric Power Research Institute (EPRI) became aware that the practical life of buried distribution cable was about 20 years. Reviewing cable placement records made EPRI aware of a real problem they were about to face. Many of the locations where cables had been placed were now developed, and replacement would be a major disruption. Consequently they sponsored development of tools to replace electric power cables without disruption. As an outcome of this sponsorship FlowMole® Corporation was formed (now UTILX). In 1984 the author headed an intense development of directional drilling tools resulting in the production of the GuideDril System. Key to the development was the ability to locate the boring tool head. By this time cable locating tools had been well established, so direct use of a cable locator (Metrotech® 810) in the GuideDril System was attempted. A signal was induced on the drill pipe, and the cable locator was used in the normal

Metrotech® 810
Radio Frequency Line Tracer

fashion. The locator failed to perform because the drilled hole was not straight and the drill pipe ended at the tool head being located. Attention was then turned to developing a dipole transmitter that could be fitted into the boring tool head. This proved to be the solution, although the locator had to be rotated 90 degrees relative to how it was designed to be used in order to capture the dipole flux lines. Also a table had to be constructed to relate the depth readings from the Metrotech 810, which was calibrated for cables, to the depth of the dipole transmitter in the drillhead.

By this time, the mid 80's, microprocessors were capable of performing complex calculations, and their low cost made them attractive to incorporate into electronic designs. In 1985 a navigational computer was added to the locators used by UTILX. The operators could type in the located coordinates of the drillhead, and the computer would return a steering command. However, the operators did not like the extra work involved, so the computer was removed from the locator. Still, the requirements of locating a boring tool were sufficiently different from locating a cable, so the development of a new locator was required. In 1986 the author and Albert Chau developed the FlowCator®. This locator used an array of antennas to determine the position of the tool head. Arrows directed the operator fore and aft along the intended path. Adjacent to the tool head the operator would press a button and the FlowCator would take measurements from the different antennas in the array and compute the depth and lateral offset from the intended path. The instrument also had the capability of providing a steering command, but that feature was never used because the operators felt it added too much time to the locating process.

FlowMole® FlowCator®

Several problems were encountered in locating with walkover systems during their development to this stage. The first was the ghost or phantom locate points. These points represent peaks in the signal strength fore and aft of the tool head. They are produced by the receiver's antenna arrangement. Although these ghost peaks are not as strong as the peak over the head, they can and still do fool many operators. The result is the operator can mislocate the tool head and the computed depth is not correct. Even the FlowCator with its arrows for directing the operator could be fooled unless it was in the vicinity of the tool head.

The second challenge of walkover systems was in training operators to control the depth of the drillhead. Left/right steering was easy by comparison, because the operator could mark the locate points on the ground surface and see trends from these marks. Depth, on the other hand, had no such cues, and novice operators would often find themselves pushing in drill pipe with a depth oscillation that resulted in the tool breaking the surface. A knowledge of the pitch orientation of the head would have eliminated this problem. UTILX discussed pitch sensing in several of its patents and had some prototype guidance systems with this feature, but had not implemented pitch sensing in its walkover locators.

The third challenge was finding a tool after an extended bore where locating was impossible, such as under a busy highway or a river crossing. No systematic means to locate a dipole transmitter could be found that would work with the detection arrangement of the FlowCator or any cable locator system. If the direction of the boring tool is not known as well as its position, then the location effort becomes monumental. For example, an 8-foot by 8-foot (2.4-m by 2.4-m) platform was built by UTILX for use in training operators to locate a lost tool head, and with a transmitter placed under the platform at an unknown location and orientation, a well-trained operator would take several minutes to find it.

After just a couple of years of operation a fourth challenge arose. By this time it was becoming routine to drill horizontally over several hundred feet. The drill pipe was keyed so that the steering surface of the tool head was fixed to a drill chuck index. As the drilling distance increased, the drill pipe would twist and the tool head orientation would no longer correspond to the chuck index. The operators compensated for this by noting the signal strength as the drill rotated slowly. Since the transmitter window in the drillhead was oriented upward when the drill was in the 12:00 position, the peak signal strength was at 12:00. This gave the operators a rudimentary means to correct for drill string wrap-up, assuming the wrap-up would not change with rotation.

Until 1988 there were no HDD tracking systems commercially available, since UTILX's equipment was not for sale. In that year Radiodetection® offered a system (RD300) that was a derivative of a sewer locating system they had developed. The transmitter (sonde) introduced in this system solved one of the challenges recognized by UTILX's experience, that of accounting for drill string wrap-up. Radiodetection solved this problem by incorporating a gravitational switch in the sonde. Normally the sonde would send a pulsed signal, but in the 12:00 position the signal would be ON continuously. This provided a more accurate means to correct for the wrap-up, assuming that the wrap-up would not change as the drill string was rotated past 12:00 to the desired steering orientation.

Radiodetection® RD300 Locator

In 1989 Peter Flowerdew at Radiodetection filed a patent for a locator that could provide both roll and pitch orientation. The system was based on two rotating and one nonrotating magnetic fields. This system did not provide an absolute orientation but rather a relative one that depended on where the operator was standing relative to the drillhead and would change as the locating receiver was moved. The ability to get roll information would eliminate the wrap-up problem, and the ability to determine pitch would greatly reduce the operator training. Although the intent was on the mark, the implementation was not practical, so it did not become commercialized.

Ditch Witch® Subsite™ 80^R

In 1991 competition grew with new manufacturers entering the industry. Several significant advancements were made to walkover tracking systems. Both Ditch Witch® and Digital Control introduced new systems. The Ditch Witch Subsite™ system was a combined cable locator and tracking system. This system was based on digital signal processing and could operate on several frequencies. It also included a gravitational roll sensor that provided an absolute roll orientation, which completely eliminated wrap-up steering errors. At the same time Digital Control introduced the DigiTrak™ System. The DigiTrak System was designed from the beginning to be a boring tool locator and departed from the conventional cable locator technology. It used a pair of orthogonal antennas to measure the total magnetic field in the plane of the locator. This technique eliminated one of the locating challenges mentioned above, that of ghosts. There are no ghosts with this method. Also, the unit departed from the cable locator scheme of determining depth. Instead it employed a calibration procedure based on the fact that the transmitter in the drillhead housing is designed to produce a uniform, constant signal. The depth was displayed continuously, unlike prior systems which required the operator to push a button and wait a few seconds. When not over the transmitter, the display showed the approximate slant distance to the tool head. The compact design employed internal ultrasonic measurement of the locator height above the ground surface to accommodate operators of different heights. This feature additionally provided separation of the locator's antennas from the ground to greatly reduce the adverse influence of rebar in streets.

Digital Control DigiTrak™ Receiver

At its introduction, the DigiTrak was the first walkover system to display both the roll and pitch orientation of the tool head as well as the first to provide a warning for a weak battery condition in the transmitter. The pitch orientation covered a range of -100% to +100% grade in 1% grade increments and was not influenced by roll orientation. The roll and pitch orientation for the DigiTrak were based on gravity and therefore independent of where the operator was standing relative to the tool head. Knowledge of the pitch orientation greatly increased the speed of drilling since fewer locate points were needed to control depth. Also, this knowledge improved drilling accuracy particularly on uneven terrain. At its introduction, DigiTrak extended the operating depth to 20 feet—almost double that of prior available systems.

In late 1991, Cogent Technology in the U.K., an independent newcomer to the drilling industry, introduced a roll accessory system for the RD300 that included a new transmitter with a roll sensor and a remote display for the roll orientation. The remote display provided the operator at the drill rig with a means to orient the tool without continuous feedback from the locating operator. At the time there was some controversy as to what effect the remote display might have on the allocation of responsibilities between the two drilling operators and, in turn, what effect this might have on the efficiency of the drilling operation. It turned out to have a positive effect and became an important contribution to the industry.

Cogent Technology MoleMonitor

In 1992 Digital Control introduced new firmware in their locator that allowed for a new locating technique. The new technique was based on the magnetic field shape rather than the signal strength. This technique overcame difficulties associated with locating a tool head when both the position and direction were unknown, as discussed above. For the first time it provided a systematic procedure to accomplish this task. The new technique provided an accurate indication of when the operator was over the drillhead as well as additional locating points ahead of and behind the tool head. These locating guidance points provided a very accurate mechanism for sighting the bore path heading. The technique also provided a way to track the tool while the drillhead was actually moving, thereby reducing locating time. Finally, it allowed the operator to locate the drillhead from a position off to the side, which is useful when drilling under obstructions. Both McLaughlin, marketing the Japanese-built Takachiho locator, and Digital Control recognized the advantage of the remote display to their products and developed remote displays that included roll, pitch, battery status, and temperature. Digital Control also included a left/right steering indicator to guide the drillhead when the operator could not physically locate over the tool, such as encountered when crossing under busy streets.

Digital Control DigiTrak™ Receiver (side & top views) and Remote Display

Also in 1992, Metrotech decided to develop a boring tool locator. Although their cable locator was previously used on the first small-diameter HDD systems, they had not provided a locator calibrated to read dipole transmitter depth nor did they manufacture a transmitter for a boring tool. Bill Griffiths at Metrotech spearheaded the effort, which involved an alliance with Cogent. The resultant BoreHawk™ included a remote display and was designed as a low-cost system. Unfortunately they encountered technical development problems along with the untimely death of Bill, and their new product sales were halted.

Cogent/Metrotech BoreHawk™

During this period, Albert Chau and the technical staff at UTILX were also improving their equipment. They extended the range of the locator system and incorporated many of the features mentioned above, including an indication of ghost signal peaks. They also developed an instrument package that incorporated non-walkover guidance. One of their innovations was a means to correct position errors in a wireline system using a walkover locator. They also started selling some of their equipment overseas, but still refrained from domestic sales.

Increased depth range became an issue with contractors as drill rigs became more powerful, so in 1994 Digital Control offered a transmitter with a 50-foot (15-m) range. The transmitter is the same size as their shorter-range model.

In 1995 Digital Control opened up the opportunity to extend the HDD process to sewer lines by producing a transmitter with a 0.1% grade pitch sensitivity. In that same year they produced a cabled transmitter (Cable Sonde™) that extended the depth capability to over 100 feet (30 m). The single-wire connection provided the power required for the strong transmitter in the Cable Sonde and at the same time carried the roll, pitch, and status information back to the display on the operator's console. This means of carrying the information in the wire made it immune to local interference and also allowed application to some non-walkover situations.

DigiTrak™ 4-Cell Magenta Sonde (0.1% Pitch)

DigiTrak™ Green Cable Sonde™

In 1997 the manufacturers of locating equipment continued to improve their existing products and also introduced new advancements. Radiodetection introduced a new walkover locator with left/right steering and an array of antennas similar to the FlowCator. Both McLaughlin and Digital Control introduced bore logging capability. The McLaughlin Mole Map™ provides a display illustrating the bore hole profile including depth. The drilling data can also be uploaded to a computer for future reference and plotting. The Digital Control DataLog ™ system provides left/right path, depth and terrain plots that can be augmented with survey data for exact drill and terrain elevations. A data processing and plotting package is part of the system. The DataLog can also be used in conjunction with the remote steering feature or the Cable Sonde; a laptop computer can also be used to provide real-time plots of the bore, a feature useful for river crossings.

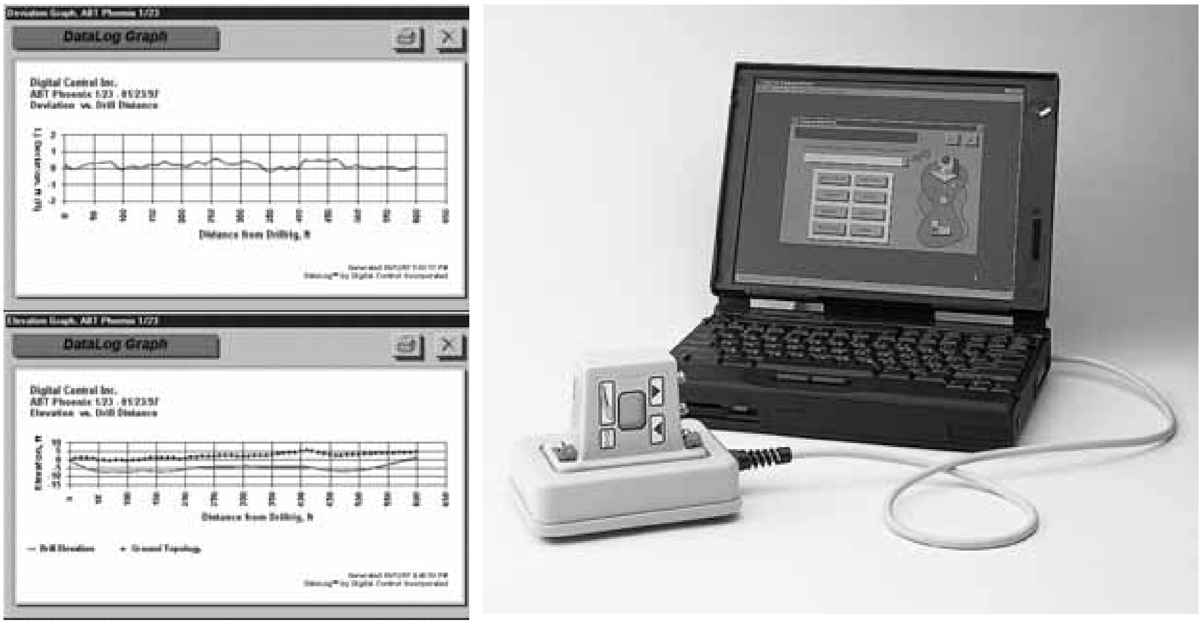
Recently Ditch Witch introduced a new system that is a hybrid of a wireline system and a walkover system. This new system employs a transmitter in the drill head, similar to a conventional walkover system. Besides the usual pitch and roll sensors, the Ditch Witch transmitter has a magnetometer as well. The signal from the transmitter is picked up by a receiver on the surface. That receiver is only required to be within range but does not need to be directly over the transmitter. The receiver uses telemetry to send the heading, pitch and roll data back to the remote unit at the drill. These signals are processed by the remote system to compute a position in a manner identical to conventional wireline guidance. The use of a magnetometer requires that the downhole tooling in the vicinity of the transmitter be nonmagnetic.

Late in the year Digital Control introduced a new system that uses 2 or more antenna cells placed anywhere in the vicinity of the intended drill path. There is a transmitter installed in the drill head which is identical to the walkover system. There is no magnetometer in this system so no special downhole tooling is required. The cells transmit received data from the inground transmitter back to a remote base station at the drill rig which computes the location of the transmitter and plots the bore path. The remote display also shows the intended path and provides a steering indication for the operator. The system allows the operator to drill past the antenna cells. This is particularly beneficial where access to the surface is not possible. Specific applications would be embankment stabilization, environmental installations or highway crossings to name a few.

Although the last 2 systems described are not walkover systems, many of their basics have evolved from the walkover concept. The transmitter sensors and data transmission techniques devised for the walkover systems are key to the new system developments.

In summary, modern HDD tracking systems have evolved from sewer line tracers and cable locators due in main part to the development of the transistor and microprocessor. From 1984, when the first small-diameter, guided drilling tools were developed, until today, the abilities of tracking systems have progressed substantially. The first systems would only provide a surface location, a rudimentary heading, and a depth range of less than 10 feet (3 m). Current locators provide the roll and pitch orientation, temperature, battery status, accurate heading, warnings for overheating, remote display of data, and even logs of the bore path at depths exceeding 140 feet (43 m). Transmitters that once could only run for a few hours can now run for over one week on batteries. In 1990 there was a clear distinction between the small-diameter

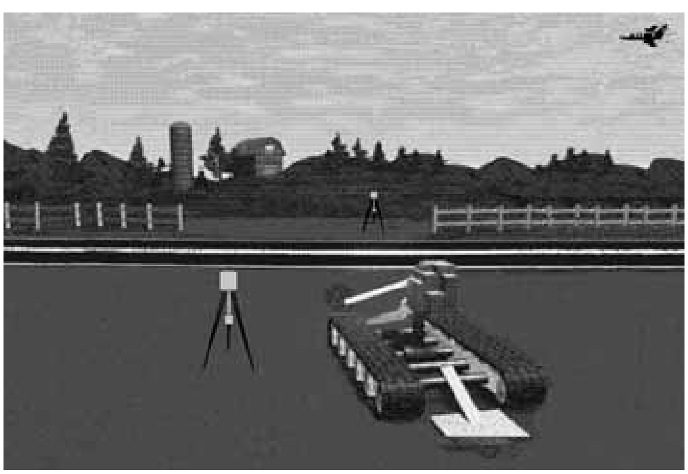
McLaughlin Spot D Tek™ Mole Map™ System



Digital Control DataLog™ System

utility installation equipment and the much more massive river crossing equipment. Today that distinction is less clear. In 1990 any bore deeper than 12 feet (3.6 m) required a wireline system, with few exceptions. Today drilling runs deeper than 70 feet (21 m) have been performed with tracking systems using battery-powered transmitters. Runs deeper than 100 feet (30 m) have been performed with the same receiving system using a transmitter with power supplied by a cable. Locating speed and accuracy have improved at a rapid pace and have allowed the HDD process to penetrate new markets because of reduced costs and increased capabilities.

Although walkover locators have almost always been used as autonomous systems, there is now a role for them in other guidance systems. Walkover systems can provide final guidance to wireline bores to eliminate accumulated errors and complete the bore precisely on target. Future guidance systems will undoubtedly build upon this technology and permit further automation of the drilling process.



Digital Control Inc.

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