OPERATION AND MAINTENANCE OF A DEEP-WELL WATER-LEVEL MEASUREMENT DEVICE, "THE IRON HORSE

U.S. GEOLOGICAL SURVEY

WATER RESOURCES INVESTIGATIONS 76-27

Open-File Report

Prepared on behalf of the
U.S. Energy Research and Development Administration

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UNITED STATES DEPARTMENT OF THE INTERIOR

Thomas S. Kleppe, Secretary

GEOLOGICAL SURVEY

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Open-File Report

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CONVERSION FACTORS

The following report uses both the English and the metric system of units. In the text the English units are given first, and the equivalent measurement in metric units is given in parentheses. The units are frequently abbreviated, using the notations shown below. The English units can be converted to metric units by multiplying by the factors given in the following list.

English unit *To convert*	*Multiply by*	*Metric unit* *To obtain*
Feet (ft)	0.3048	Metres (m)
Inches (in)	25.4	Millimetres (mm)
Gallons	3.785	Litres (l)

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ABSTRACT

The deep-well investigative device, commonly called the Iron Horse, has been used primarily for measuring deep water levels in boreholes and wells. The device has proven useful in measurements during hydraulic testing of wells with water levels as deep as 2,600 feet (792.5 metres). The device may also be used for obtaining water samples, sounding depths, and determining vertical fluid velocity. Extensive use of the device at the U.S. Energy Research and Development Administration's Nevada Test Site has provided the necessary experience to refine methods for proper calibration and maintenance of the Iron Horse.

INTRODUCTION

The deep-well investigative device--commonly called the Iron Horse--has been used extensively at the U.S. Energy Research and Development Administration's Nevada Test Site. The Iron Horse is used primarily for lowering and raising electrical water-level-measuring probes into and out of deep boreholes and wells. It can also be used for obtaining water samples, sounding depths, and determining vertical fluid velocity in a borehole. The device has proven especially useful for making measurements during prolonged hydraulic tests in wells where depths to water have been as great as 2,600 feet (792.5 metres).

Although the basic idea for the Iron Horse was suggested and embellished by several people working in the ground-water discipline, Keith Essex and Art Frazier of the U.S. Geological Survey's equipment development laboratory in Columbus, Ohio, built the original device in about 1956. The original device was capable of holding about 3,000 feet (914 metres) of cable. The basic design has been very slightly modified from time to time, but in general the Iron Horse has remained the same in both appearance and function. The devices are now built in the machine shop of the U.S. Geological Survey, National Center, Reston, VA 22092.

The increasing use of the Iron Horse by others involved in water-resources investigations has shown the need for a maintenance manual. Young (1963, p. 90) briefly described the Iron Horse in a paper on drilling and well-testing problems at Nevada Test Site. Garber and Koopman (1968, p. 6-11) described the Iron Horse in considerable detail, exclusive of handling, care, and maintenance; unlike Young, they called the Iron Horse an "electric cable well-measuring device." Over the years, the device has been commonly referred to as the Iron Horse by those in the field because the instrumentation is mounted on a portable aluminum structure resembling a small blocky horse.

Acknowledgments

The authors gratefully acknowledge the efforts of the many individuals in the Geological Survey who have made this paper possible by their efforts involving constant reliance on the Iron Horse for data acquisition.

DESCRIPTION

The principal parts of the Iron Horse are: a 12-inch (305-millimetre) diameter reel with about 3,000 feet (914 metres) of preferably 0.10-inch (2.5-millimetre) diameter single-conductor armored cable, a measuring sheave geared to a depth indicator, a direct-current millivolt meter, and a flash-light-battery pack, all mounted on a portable aluminum structure (fig. 1). Attached to the lower end of the cable is a connector that can be threaded onto a water-level probe or adapted to other downhole investigative tools. The reel end of the cable is attached to the crank side of the device via a brass slip ring electrically insulated from the reel by a fiber plastic gasket. A spring-loaded, cylindrical, copper brush, behind an electrical terminal, drags on the brass slip ring; a wire connects the brush terminal to the negative (-) terminal on the millivolt meter. The stranded steel cladding on the cable provides the ground part of the electrical circuit. The positive (+) terminal of the millivolt meter is grounded to the boom by means of a short wire. Figure 1 shows the assembled Iron Horse ready for use.

ASSEMBLY AND GENERAL OPERATION

The Iron Horse is generally shipped in a box as shown in figure 2. In this form the legs, reel, and boom are tucked into the device as pictured. The reel is removed through the top by unscrewing the four wing nuts (fig. 1) and lifting the reel and its base upward by the crank. The crank is removed, then the reel is inverted to ultimately seat on top of the horse about where a saddle might be placed. For shipment purposes the front legs and boom fit into the body of the horse beneath the reel.

The boom with the measuring sheave and depth indicator fits on the front of the device (fig. 3) and is secured by two wing nuts threaded onto the stud bolts protruding from a block inside the angular end of the device. The front legs are secured to the bottom of the angular part of the body by slipping them into the lower studs and tightening the wing nuts on the upper nearby threaded studs (fig. 2). Then the rear of the device can be elevated, while removing the long bolt that fits transversely and holds the back legs up into the midsection. The back legs will drop down into the set-up position, and the long bolt is reinstalled through another pair of holes located farther toward the rear end to hold these legs in place.

The crank for manually manipulating the reel and its brake is at the top of the shipping-condition assembly (fig. 2). The crank is removed after lifting the reel and its mount from the shipping box and just prior to mounting the reel in the action or "saddle" position on the Iron Horse. When the reel is in place and anchored by four wing nuts, the crank is attached to the protruding shaft on the right side of the reel (fig. 1). A thumb set screw in the hub of the crank is tightened to keep the crank from slipping. A shallow conical recess in the shaft is for seating the inner

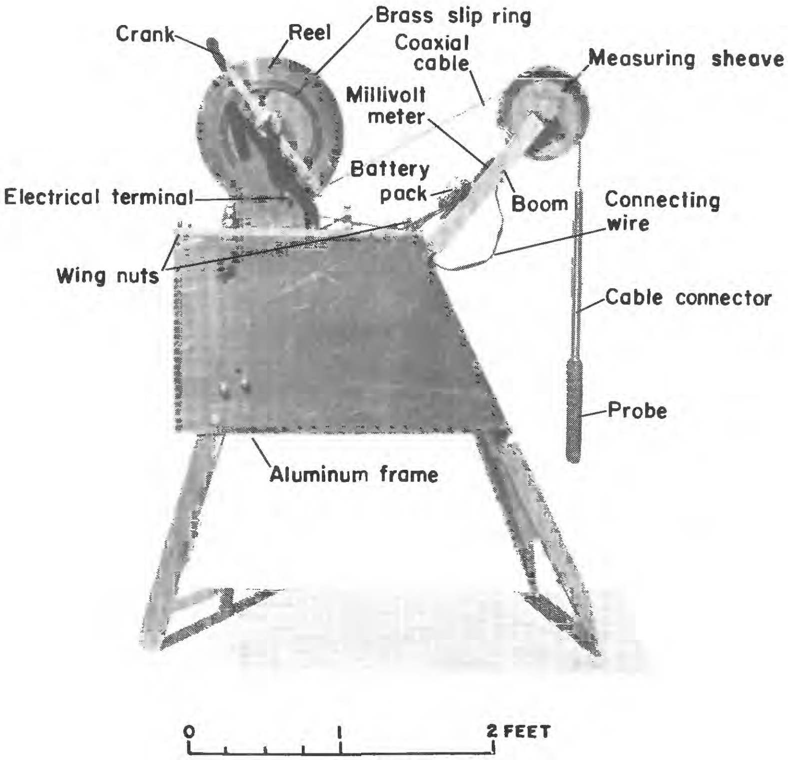

Figure 1.--Iron Horse assembled and ready for use.

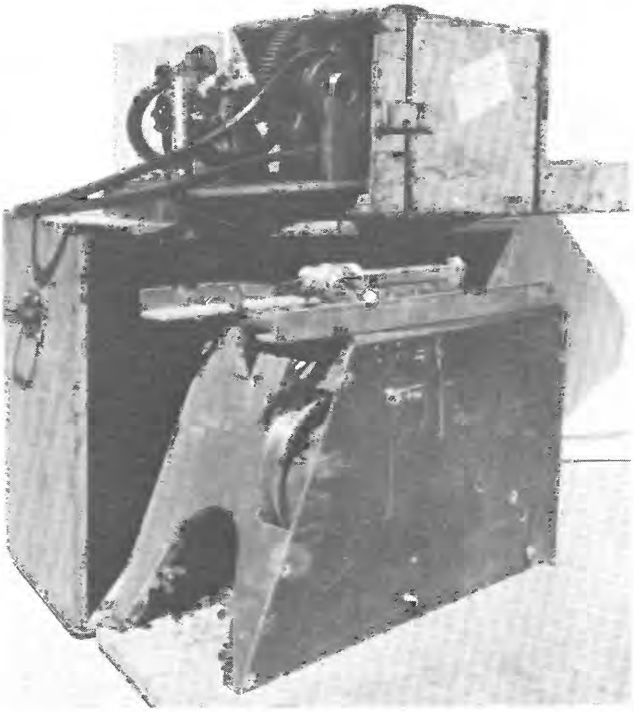

Figure 2.--Iron Horse and motor as they arrive in shipment.

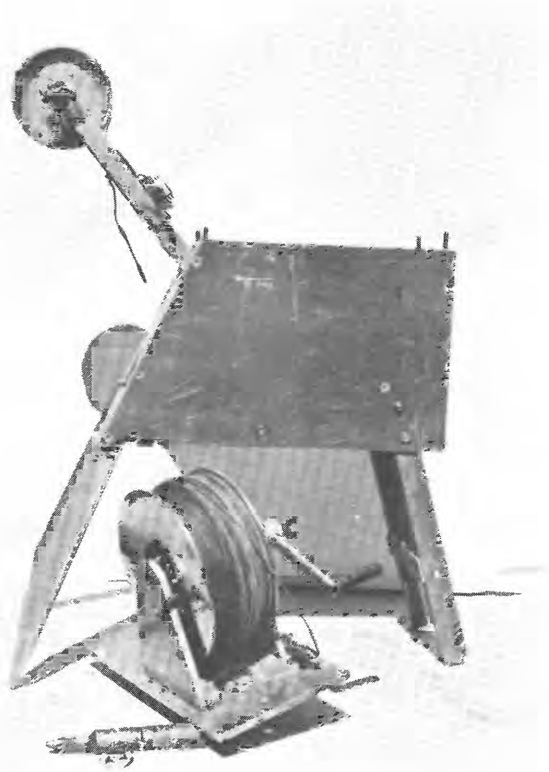

Figure 3.--Iron Horse partly assembled for use.

end of the set screw. Hand tightening of the set screw usually must be supplemented by a very slight tightening with a pair of pliers. The levered length of the crank handle can be varied for different reeling loads by loosening the other set screw in the outer end of the hub and shifting the position of the crank shank. To prepare the Iron Horse for shipment, the assembly procedure is reversed.

The water-level probe is attached to the cable connector by screwing the two units together. Two types of cable connectors are available. When a Well Reconnaissance, Inc.,[1] connector (fig. 4) is used, the contact point of the magnesium screw should protrude very slightly from the water-level connector so that the spring-loaded contact in the connector will touch the magnesium screw contact. When a Survey-type connector (fig. 5) is used, the upper contact point of the magnesium screw should be down in the water-level probe while the probe is being screwed onto the connector; then the magnesium screw is advanced until it just barely makes contact with the head of the brass wood-screw in the connector. Extreme care should be taken not to overtighten the magnesium screw and damage the connector.

Friction drag is applied with a gloved hand to the left side of the reel when releasing the cable. This keeps the reel from spinning too fast and enables the operator to smoothly stop the reel by slowing the spin and ultimately setting the brake. As more cable, thus more weight, is put in the hole, more friction drag will be essential to maintain an even, moderate reeling rate. A smooth, even, moderately slow rate of descent is desirable and is important for several reasons. Slow, steady descent maintains constant wire contact with the measuring sheave thus providing a more accurate measurement. The lowering of the instrument package can be stopped more readily which prevents damage to the brake or slippage of the brake adjustment.

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[1]The use of brand names in this report is for identification purposes only and does not imply endorsement by the U.S. Geological Survey.

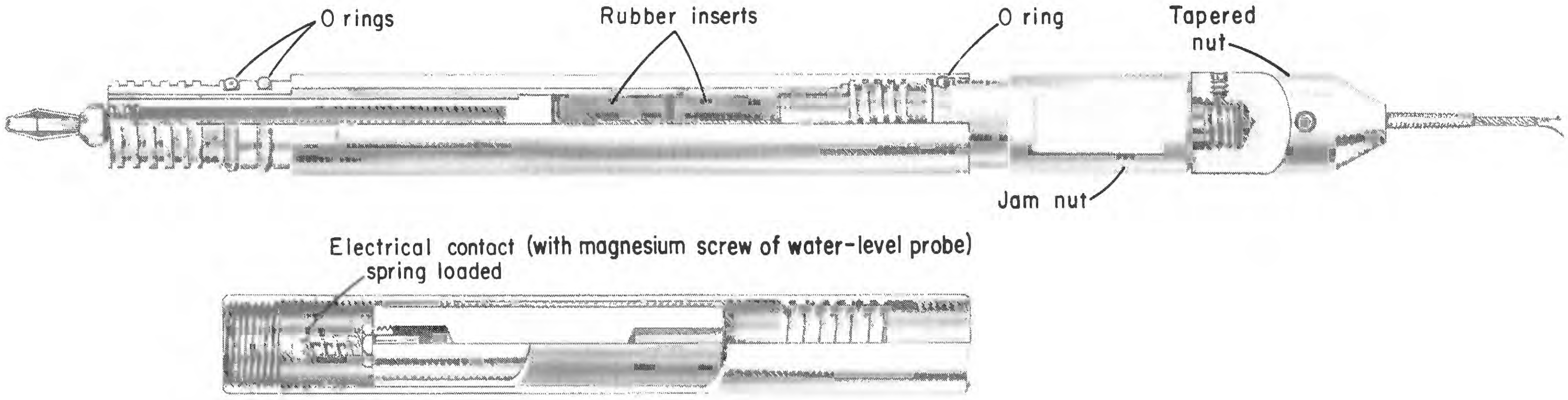

Figure 4.--Cable connector, Well Reconnaissance-type, for Iron Horse.

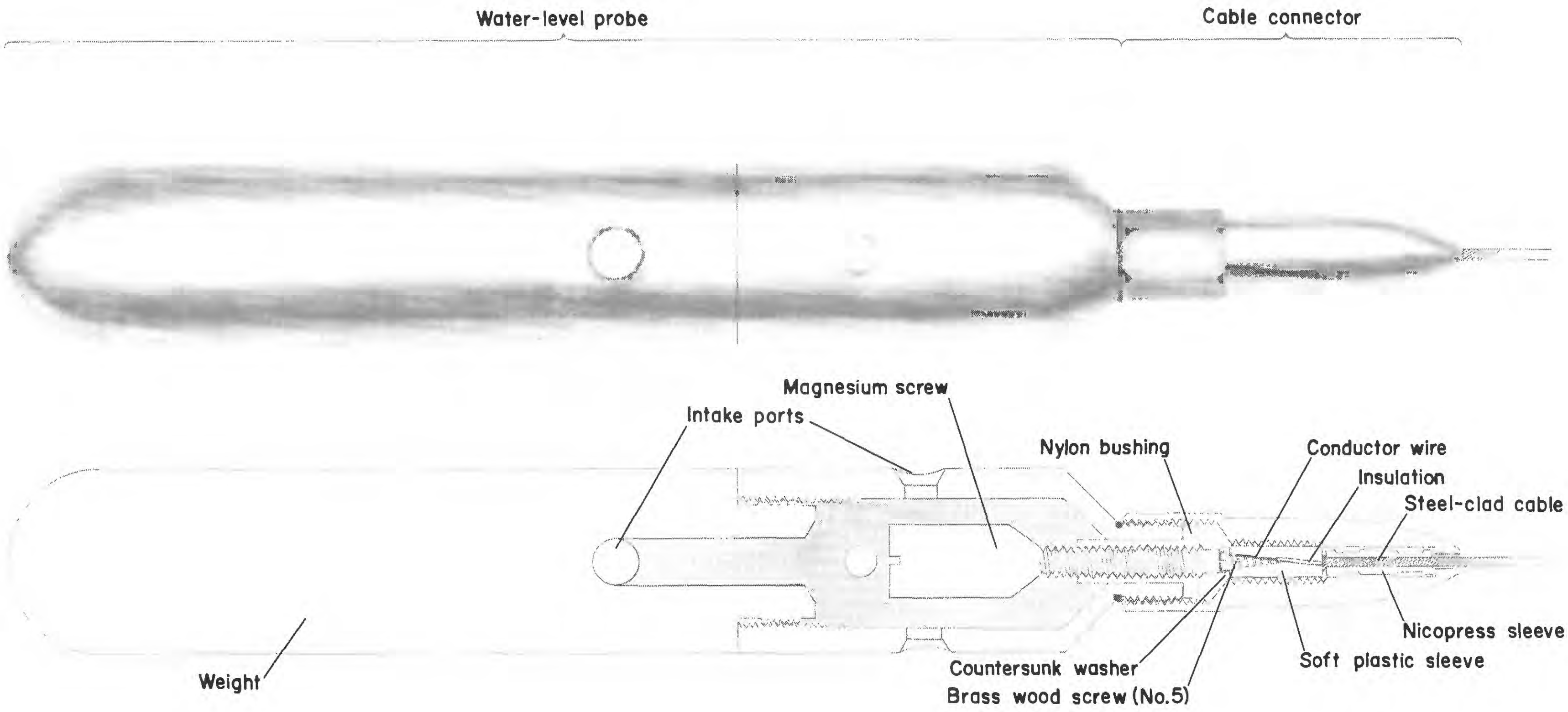

Figure 5.--Survey-type cable connector and water-level probe assemblies for Iron Horse.

A motor to withdraw the probe from wells is of great value in using the Iron Horse because a) the withdrawal operation is smoother and gives better outreadings; b) level winding is more easily attained; and c) the reeling operation can be done by one person. Primarily two kinds of motors have been used on the Iron Horses at the Nevada Test Site: a two-cycle 3/4-horsepower gasoline engine and an engine driven by compressed air. The gasoline engine is somewhat more versatile because it can be used at remote well sites where no compressor is available. The air-driven motor has been very useful when the Iron Horse is used in wells and holes that have a drilling rig on them. Some rigs have air compressors that will develop at least 100 psi which is necessary to drive the motor. The principal disadvantage of the gasoline-driven engine is that the small engine sometimes requires very sensitive carburetor adjustments to operate properly--a tuning operation that is done best while the motor is pulling a load. The gasoline engine is extremely noisy and issues objectionable fumes. These motors are mounted on an angle-iron frame (fig. 6) inserted through a rectangular slot at the back of the Iron Horse. The reel is driven by a v-belt stretching between two sheaves, one of which is on the engine and is about 4 inches (102 millimetres) in diameter and the other replaces the crank on the reel shaft and is 16 inches (406 millimetres) in diameter.

A third type of motor, one powered by a wet-cell, 12-volt battery, is built at the Property Control Section, U.S. Geological Survey, National Center, Reston, VA 22092. This electrical motor is quiet, unlike the gasoline motor, and is convenient for remote-area operation where it can be connected with jumper cables to a vehicle battery.

Tools and Spare Parts

A list of the tools and the spare parts needed for effective field repair of the Iron Horse follows:

Parts

Water-level probe
- Screw, magnesium
- Body of probe, brass
- Bushing, nylon
- Sealer, ribbon-thread, teflon
- Cloth (or paper), emery, fine

Cable connector (Survey-type)
- Sleeves, Nicopress, 7/8-inch long
- Sleeves, plastic
- Screw, brass, no. 5
- Washers, countersunk (for above screw)

Cable connector (Well Reconnaissance-type)
- Inserts, rubber
- O-rings, 1/16-inch x 3/8-inch diameter
- Connector, spring-loaded (Grayhill no. 29-101R)

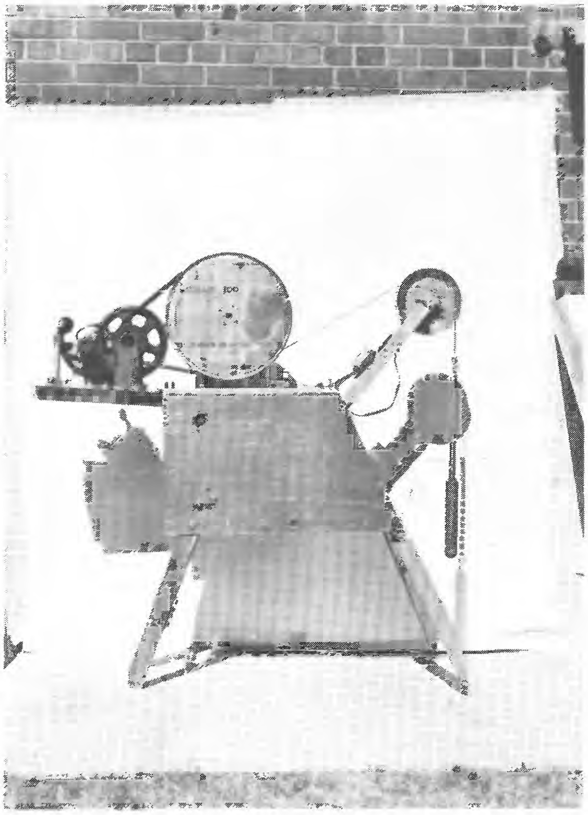

Figure 6.--Iron Horse assembled for withdrawal with gasoline motor.

Reel assembly (body)

Brushes, spring-loaded (bronze)

Screws, nylon, flat-head, 8-32, 3/8-inch long (for holding brass slip ring to cable reel)

Screws, brass, round-head, 6-32, 3/8-inch long (cable to slip ring connection)

Connections, end, crimp-on, small eye (for reelend of cable)

Tubing, insulation, "spaghetti", 1/8-inch inside diameter

Reel assembly (head)

Meter, millivolt D. C. (such as Triplett Model 221-T)

Indicator, depth, with gears (WRD Supply Warehouse)

Leads, wire, insulated, 0.5-foot and 3-foot long

Batteries, D-cell and holder

Tools

Meter, multimeter, Simpson-type

Cutter, cable, front-cut

Diagonals, side-cut

File, flat, bastard--fine

Tool, crimper (for Nicropress sleeve)

Tool, crimper, small (for "eye" end connections)

Brush, wire

Wrenches, spanner, open end (2) (for adjusting brake)

Wrenches, crescent, 10-inch (2)

Wrench, nut-runner, 1/4-inch (for spring-loaded connection)

Wrenches, allen, one standard set

Tape, electrical, plastic

Tape, masking

Gloves, leather, heavy-duty

Electric Motor

Cables, jumper, heavy-duty

Battery, wet-cell, 12-volt (high amperage)

Checking the Cable

Cable for the Iron Horse should be comparable to U.S. Steel Amerograph 1-H-100 cable. This cable is 0.100 inch (2.5 millimetre) in diameter and weighs 17 pounds per thousand feet. The cable has a breaking strength of about 1,000 pounds. It has two oppositely wound layers (reverse-lay) of plow-steel armor, has either plasticized nylon or ampyrol insulation, and has a stranded copper inner conductor. The electrical resistance of the copper inner conductor is 24 ohms per thousand feet. That of the steel outer sheath is 22 ohms per thousand feet. The inner conductor can withstand high voltage but not high amperage. Amperage greater than 250 milliamperes will cause electrical deterioration.

To check for continuity of the electrical system, a Simpson-type volt-ohm meter should be used as follows:

1. Plug the prod for the black test lead in the jack marked Common. Plug the prod for the red test lead in the jack marked +.
2. Short the crocodile clips or test points to each other. Rotate the Zero OHMS Knob until the meter indicates zero ohms at right end of the dial.
3. Connect one lead to the brass collector base of slip ring located on the side of cable reel.
4. Connect the other lead to the center of the cable connector.
5. A reading of approximately 24 ohms for each 1,000 feet (305 metres) of cable should be obtained, that is, 1,000 feet (305 metres), 24 ohms; 2,000 feet (610 metres), 48 ohms; and so forth.
6. No reading at all indicates that the cable circuit is open. The circuit is most likely to be open at the cable connector.

To check for voltage leaks between the inner conductor and the outer sheath, use the following procedure:

1. Set range switch on highest resistance scale. When checking cable for leakage, and so forth, be sure to disconnect cable from milliammeter/millivolt meter.
2. Repeat steps 1, 2, and 3 of previous test.
3. Clip the other lead to the sheath of the cable, near the cable connector end. If the cable is in perfect condition, the pointer should read infinity (∞), which is the symbol at the left end of the ohm scale. Any other reading is an indication of leakage within the cable or at the connector.
4. If the meter reads less than maximum ohms, the cable connector should be cut off and the cable rechecked. If cable checks out, reconnect the cable connector and recheck the system.

Attaching Cable Connector

When the Well Reconnaissance, Inc., cable connector is used, the procedures listed below should be followed:

1. Cut the cable off square and insert it through the long coiled spring and tapered nut (fig. 4).
2. Insert the cable through the stainless steel jam nut.
3. Install the two rubber inserts on the cable. Use new inserts when making up, or remaking, cable connector.
4. Push the inserts up on the cable several inches.
5. Unwind the outer steel strands from the cable for approximately 1 inch (25 millimetres). Cut off the strands squarely.
6. Unwind the inner steel strands from the cable and cut off flush with the outer strands.

7. Take care to insure that the insulation is not cut and that the steel strands are cut as evenly as possible.
8. Strip the insulation off of the bottom 3/4 inch (19 millimetres) of the conductor wire, leaving about 1/4 inch (6.4 millimetres) of insulation exposed between the conductor wire and the cut off steel strands.
9. Push the rubber inserts down until approximately one half of the bottom insert is beyond the steel cable, and the end of the insert is at the top of the bare conductor wire.
10. Bend the bare conductor wire back over the bottom rubber insert.
11. Insert the entire assembly into the 1/2-inch (13-millimetre) diameter hole in the cable connector body. Make sure that the cable is not pulled out of the bottom rubber insert.
12. Push the jam nut down until its threads engage with those of the cable connector body. Then, using two crescent wrenches on the flat parts of the stainless steel jam nut and the cable connector body, tighten the nut down as far as possible. Be sure to hold the cable connector body stationary while turning the jam nut.
13. Screw the tapered nut onto the jam nut.
14. Check the cable connection for electrical continuity.

If the Well Reconnaissance, Inc., cable connector has been properly installed, it will have to be removed only if the cable itself is damaged. This connector has been submerged in water more than 1,000 feet (305 metres) without electrical shorting.

When the Survey-type cable connector is used, the following procedures apply:

1. Wrap two layers of masking tape on the cable and neatly cut the cable at the center of tape with the front-cut tool from the repair kit.
2. Carefully remove the tape and thread the cable through the upper tapered end of the brass cable connector (fig. 5) and through a Nicropress sleeve until about 1 1/4 inches (32 millimetres) of the cable protrudes from the sleeve. Crimp the sleeve in three places with the larger hole (labeled "D") in the crimper tool; then crimp the sleeve in one place with the smaller hole "C" in the crimper tool. File smooth the crimping ridges in the sleeve so that the sleeve will slide into the deepest recess of the cable connector body.
3. Unstrand the steel cladding in bunches of three or four strands back to the sleeve, bend each bunch back, and clip it closely with the side-cut diagonals; the clipped ends of wires should not protrude to a larger diametric dimension than the Nicropress sleeve.
4. With a match or cigarette lighter, melt the nylon insulation on the protruding conductor to within about 3/8 inch (10 millimetre) of the Nicopress sleeve. Be careful not to damage insulation on the remaining 3/8 inch (10 millimetre) of the conductor. Use emery cloth to remove the melted portion of the insulation remaining on the conductor.

5. Slide a soft plastic seelve over the protruding conductor until it seats against the clipped wires of the outer cladding and cut off any of the conductor that protrudes more than 1/8 inch (3 millimetres) beyond plastic sleeve. Put the slightly protruding part of the conductor through the washer (countersunk face away from plastic sleeve) and bend it over onto the countersunk face of the washer. Start the Number 5 brass wood screw through the washer and into the soft plastic sleeve. Screw it down only about 1/4 inch (6 millimetre). Carefully push this end assembly into the cable connector body until it is properly seated. In this position, the outer end of the plastic sleeve will be very slightly below the rim of the central recess (fig. 5).
6. Advance the brass screw into the plastic sleeve until the washer is just barely, but firmly, against the plastic sleeve. Too much tightening of the screw could shear off the center wire inside the plastic sleeve.
7. Check the cable connection for electrical continuity.

The Survey-type cable connector has been used successfully for measuring water levels. However, during work below water, this connector may develop electrical shorts.

Cable Winding and Brake Adjustment

Always level wind the cable onto the reel when pulling the probe out of the hole so that the cable does not pile up near the center of the reel and make shifting, loose loops on the reel. Loose loops can cause difficulties in reeling off the cable, and the cable can be badly damaged if these loops kink. Level winding can be done with a large screwdriver inserted into a hole in the aluminum plate in front of the reel. Of course, the screwdriver must be shifted from one side of the cable to the other as necessary to guide the cable evenly onto the reel. A forked-guide attachment that fits on the crank handle shank has been used to level wind when a motor is used to withdraw the probe from the hole. The forks on this attachment are two cylindrical rollers that turn with the cable. The end of the crank handle shank used with this attachment has a machined tip small enough to fit into the hole in front of the reel.

Adjustment of the clutch-type brake on the Iron Horse may be necessary occasionally. This brake is an internal part of the reel and is controlled by the crank. Moving the crank about one-third turn counterclockwise with the dog set releases the brake and frees the reel for running the probe downhole. Conversely, turning the crank clockwise sets the brake. The two brass nuts on the right-side reel shaft are used to adjust this brake:

1. Two 1 1/4-inch (32 millimetre) opening, 1/4-inch (6-millimetre) thick, open-end wrenches or spanners are used to loosen the brass nuts to start adjustment.

2. The reel shaft is then turned to where the hollow pin on the left side of the shaft has about one-fourth to one-third turn of clockwise movement before it comes in contact with the stop, a short, hollow pin protruding from the brass ratchet gear.
3. Tighten the inner nut and hold it with one wrench. Steady the crank and reel, then tighten the outer nut firmly against inner nut. This tightening operation may require two people.
4. Try the braking action of the reel several times. Repeat the adjustment of the hollow pin if braking action is not correct. When the brake works satisfactorily, tighten the outer nut very firmly against the inner nut. If the spanner wrenches are not immediately available, some open-end wrenches are thin enough for use.

SURFACE TEST AND CALIBRATION

Before the assembled probe is lowered into a well, it should be tested in a container of water. The probe should be immersed to the point that the magnesium screw is touching water and the electrical circuit is closed. Generally, the millivolt meter will register between 0.4 and 1 volt (using the Survey 1.5-inch or 38-millimetre diameter, brass water-level probe) when the magnesium screw touches the water in the container, and will drop back to zero when the screw is removed from the water. Sometimes a few seconds of submersion is necessary for the charge to build up and the battery action to take effect; however, meter action is instantaneous when the battery pack is used. Water with a very low dissolved-solids content (about 300 milligrams per litre or less) is a poor electrolyte and may cause a charge of less than 0.4 volt, in which event the battery pack can be used more effectively. When response is instantaneous, the weight or sinker bar is screwed onto the bottom of the probe and the device is ready for use.

Sometimes, the standard-size, brass probe is too large to fit certain accesses. A 3/4-inch (19-millimetre) diameter, partly plastic probe is available and has been used successfully with the battery pack. When this smaller-diameter probe is used without the battery pack, response on the millivolt meter is usually no greater than 0.1 volt. In addition to the readily available standard-size brass and smaller-diameter plastic probes, a custom-built, 3/4-inch (19-millimetre) diameter, brass probe has been used with operation and response comparable to the larger-diameter, standard brass probe. A sinker bar can be attached to the bottom of the probe to facilitate cable release.

A cable connector built by Well Reconnaissance, Inc. (fig. 4), and modified by the junior author has been used with the Iron Horse for several years with some added degree of reliability. The modified connector was shorter by several inches. The spring-loaded contact at the bottom of the cable connector makes a positive electrical contact, and the connector is more securely fastened to the electrical line. This shorter, modified connector is easier to insert into tubing that may be inconveniently located. However, the modified connector cannot be used with the sampling device.

A water level should be measured at least twice with the Iron Horse. This requires a minimum of two trips down the well with the probe, and the two readings on the depth indicator should be within 0.1 foot (0.03 metre for a metric measure device) of each other for adequate repetition. The smallest calibration on an English-unit depth indicator is 0.2 foot and interpolation to half a unit (0.1 foot) is easily possible. The smallest calibration on a metric-unit depth indicator is 0.02 metre. Before lowering the probe in the hole, the depth indicator should be set at zero when the bottom of the magnesium screw is set at the measuring point--usually the top of casing or access tubing. The screw can be seen through an access hole in the side of the probe. Before the probe is removed from the well after the depth to water has been measured, the outreading must be recorded. The outreading is the difference between zero and the reading (either plus or minus) on the depth indicator with the probe returned to the original position at the measuring point. Outreadings vary somewhat for different devices depending apparently on sheave, depth-indicator, cable, and gear characteristics. These outreadings should agree about as closely as the water-level measurements for an individual device. If a motor and v-belt sheave (attached to the reel shaft in place of the crank) are used to withdraw the probe from the hole, outreadings usually are more uniform. To correct measurements to absolute values, the outreading difference should be added to or subtracted from the measured value.

Garber and Koopman (1968, p. 9) concluded that the difference between the outreading and zero resulted from cable elasticity and from increased drag along the casing as the cable is withdrawn. They further indicated that thermal expansion or any other change in the cable length after it had passed over the sheave and had been tallied on the depth indicator would be impossible to determine.

Outreadings probably are significant if absolute values for depths to water are required. However, during most hydraulic tests in wells, the probe remains in the hole and many measurements of changing conditions are made. During these tests, the relative differences between successive measurements are more important than absolute measurements of depths to water, and the outreading is, therefore, less significant.

Further experience with the device at the Nevada Test Site, where water levels are often measured from a distant datum, such as land surface, has shown that the corrections for hole tortuosity or multiple deviations are far more apt to significantly change the measurement than are corrections for elasticity, thermal expansion, or variations in tension due to drag. The authors feel that the measurement out of the hole represents the best absolute depth to water because withdrawal is far less subject to sheave and cable slippage arising mainly from momentum; moreover, corrections for usual tension and thermal expansion are accounted for during calibration of the Iron Horse.

The Iron Horse should be calibrated when it is first assembled and at about 6-month intervals if it is used frequently. The Iron Horse is calibrated by comparing water-level measurements between the Iron Horse and a steel tape under identical conditions and by mathematically compensating for the differences.

Tape measurements of the water level are made with a 2,000-foot (610-metre) steel tape. A compound such as "Gage-O", which changes color when wetted, should be applied evenly on the lower 10 to 15 feet (3 to 5 metres) of the tape. The tape should be lowered far enough to submerge the bottom few feet. Two measurements should be made; agreement to within 0.1 foot is adequate to indicate that the measurement is true liquid level and not the effect of wetted casing walls. Closer agreement of the tape measurements is possible if hole conditions are favorable.

The difference between the Iron Horse measurement and the tape measurement is calculated, and a factor of correction per unit length is computed by dividing tape measurement (actual water level) into the difference. If the tape measurement is less than the Iron Horse measurement, the correction factor will be negative; conversely, if the tape measurement is greater than the Iron Horse measurement, the correction factor will be positive.

For example, if the Iron Horse measurement was 526.86 metres and the steel tape measurement 526.30 metres, the calculations for correction factor would be

$$526.86 - 526.30 = 0.56;$$

$$\frac{-0.56}{526.30} = -0.001064 \text{ metre/metre}$$

which represents a negative correction. A positive correction would be

$$526.24 \text{ (tape)} - 525.83 \text{ (Iron Horse)} = 0.41;$$

$$\frac{+0.41}{526.24} = +0.0007791 \text{ metre/metre.}$$

TRANSPORT

During large-area reconnaissance programs, the Iron Horse has been successfully transported by and used from pickup trucks. A topless plywood box with an open end is bolted to a 3/4-inch (19-millimetre) thick plywood board that fits the pickup bed. The front legs are removed, and the back legs are folded under so that the device slides into the end of the box that is open toward the rear of the truck (fig. 7). A steel strap is hinged to the top of the box and bolted to the other side to safely hold the device during transport over rough roads.

The weight and probe should be removed from the cable connector while the device is being transported. Many Iron Horses are equipped with a threaded brass nut behind the reel where the cable connector can be attached to prevent the cable being jiggled off the reel during transport. If this nut has been removed, the cable connector can be tied to the reel with string or taped to it. The Well Reconnaissance-type connector is carried for ready transport in a pipe-like sheath or spring clamps mounted to the right side of the reel base.

When the Iron Horse is in the box, it is not necessary to remove the sheave boom or the crank handle. The open-end box facilitates sliding the device out onto the end of the pickup tailgate to make a water-level measurement (fig. 7). Caution should be used when making a measurement in this manner, as the rear of the Iron Horse tends to rise whenever downhole progress is slowed or stopped. If the operator places a foot on the rear-legs pivot bar, this rising action is minimized.

CORRECTION OF FAILURES

If the millivolt meter fails to show any response when the probe is immersed in water, at least one of several components or electrical connections may be at fault. Suggestions for detecting faulty components and means of correcting or replacing the parts follow:

Failures Due to Faulty Electrical Connections

1. Check the contact between the magnesium screw in the probe and the brass screw in the cable connector. This is done by retracting the magnesium screw a few turns and then gently advancing the screw until it barely touches the brass screw or spring-loaded contact in whichever connector is on the cable. Infrequently, the nylon bushing in the water-level probe, through which the magnesium screw advances, becomes loose in the probe body so that both bushing and screw turn together. This friction-fit bushing can be replaced with one from the repair kit, or another probe equipped with a bushing can be substituted.

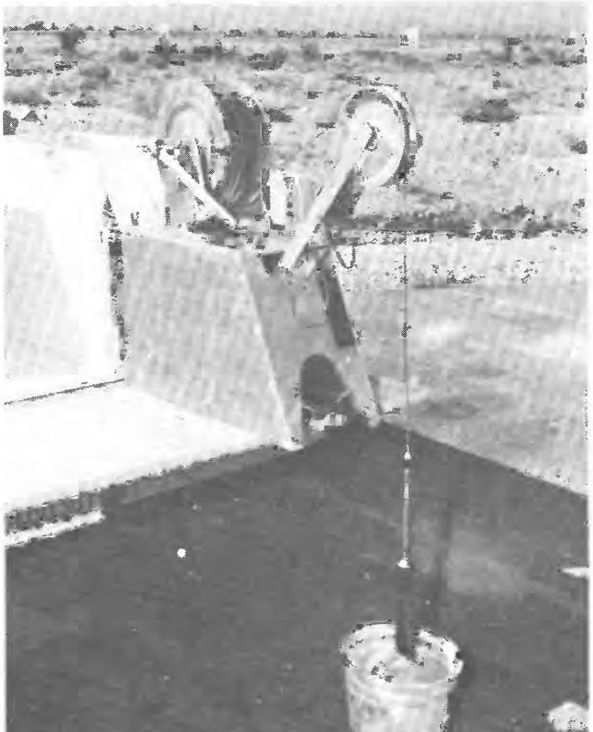

Figure 7.--Truck mounted Iron Horse.

2. Check the connection of the conductor to the brass slip ring on the right side of the reel to insure that the small screw has not fallen out. A replacement screw should be in the repair kit. Also, wiggle the cable end slightly at the brass slip ring while the electrode is immersed. Intermittent millivolt-meter response indicates parting of the insulated conductor from the crimp-on end connection. Sufficient wire usually remains with which to replace the crimp-on end connection with one from the repair kit.
3. Crank the reel slightly while the water-level probe is immersed. If millivolt-meter response is intermittent, clean the brass slip ring and the end of the spring-loaded brush that drags on the slip ring with fine emery cloth or emery paper. The slip ring is easily accessible for cleaning. The end of the brush can be cleaned by inserting a knife blade between the slip ring and the brush and then sliding the emery cloth, abrasive side toward the brush, into the space made by the knife blade. Remove the knife and work the emery cloth back and forth several times. The slip ring and brush should be cleaned periodically to remove deposits that built up during use. When the brush becomes badly worn, replace it by removing the terminal from its hard rubber insulator, extracting the spring-loaded brush unit from the inner part of the terminal assembly, and inserting a new spring-loaded brush unit from the repair kit.
4. Check the terminal connections and continuity of the insulated wire leading from the brush terminal to the millivolt meter and of the ground connection leading from the millivolt meter to the boom. The terminal connections may be jarred loose or apart during transport and handling. A multimeter on the resistance scale can be used to check electrical continuity of the insulated wire. However, the insulated wire should be disconnected from the millivolt meter before checking because the battery power supply in the multimeter exceeds the 1-volt maximum scale of the millivolt meter.
5. To check for continuity within the cable connector use the resistance scale on the multimeter. Detach the wire from the brush terminal on the reel mount so that no electrical current from the multimeter will be transmitted through the millivolt meter. Hook one multimeter lead to the upper-end fitting on the cable where it joins the brass slip ring. Disconnect the probe and, without touching the body of the cable connector, touch the other multimeter lead to the head of the small screw or spring-loaded electrical contact in the connector. If continuity is not indicated--that is, if the multimeter needle does not move toward the right side of the dial--the disconnect probably is in the cable connector. If the circuit is continuous, check also for a ground short by touching the multimeter lead to the body of the cable connector. If there is no ground short, the multimeter will indicate no continuity. A cable connector of either kind can be removed and refitted on the cable by the methods described in earlier sections of this report.

6. After removal of the cable connector--when the insulated conductor in the cable is exposed--the cable can be checked for continuity or shorts to the ground. These tests are done with the multimeter used in the same way as described in 5 except that the exposed insulated conductor, instead of the small screw or spring-loaded connector in the cable connector, is touched to one multimeter lead to determine electrical continuity through that insulated conductor. The cable cladding near the connector end, instead of the connector body, is touched to the multimeter lead to check for ground shorts in the cable. If the cable fault is a short between the insulated center conductor and the armor shield, a resistance reading can be used to determine where the cable is shorted. If the cable fault is an "open" in the insulated center conductor it might be worthwhile to connect the multimeter, as described, and "flex" the cable while monitoring the meter. If the cable is faulty, check the lower 100 to 200 feet (30 to 60 metres) of the cable for visible damage, cut off the damaged part, and test again. Cable can be faulty and have no visible damage; therefore, it is worthwhile to attempt to eliminate cable problems by cutting off several lengths from the lower end before deciding to replace the entire cable.
7. Infrequently, the millivolt meter becomes faulty. To determine whether the millivolt meter is functioning properly, check operation of the Iron Horse with a new millivolt meter (positive terminal to ground) from the repair kit. Do not test the millivolt meter with the multimeter because its 7.5-volt power supply exceeds the 1-volt capacity of the millivolt meter and will cause damage.

Failures Due to Conditions in Wells

Poor conditions in wells can create problems during water-level measurements with the Iron Horse. Some of the unfavorable conditions, problems, and remedies are as follows:

1. Tool-joint compound applied in great abundance on tubing threads will be squeezed into the inside of the tubing when the joints are made up. The compound is very sticky and greasy, accumulates on the probe parts, and prevents proper battery action. Electrical properties are impaired when the compound forms an insulating layer on the brass or magnesium parts. Ask the driller, in charge of installing pipe tubing through which the probe must be lowered, to apply the tool-joint compound sparingly and only on the pin to assure that none gets inside the tubing; or ask that the compound not be used at all.
2. Dirt and grease on the inside of tubing may coat the probe as it is lowered. Ask the driller to run a "rabbit" through the tubing and also to hit each piece of tubing with a hammer while it is hanging in the rig elevators. If the tubing is exceptionally dirty, steam cleaning or a swab drawn several times through the tubing column usually will clean out most of the dirty deposit.

3. An access tube composed of two kinds of pipe, such as galvanized pipe and uncoated steel pipe, might cause problems in determining water level or logging with the Iron Horse. Under these conditions an electrical charge may sometimes be induced by the dissimilar metals. This charge can be great enough to cause an apparent ground short in the probe and cable inside the tubing.
4. Water having a very low (less than about 300 milligrams per litre) dissolved-solids concentration is a poor electrolyte, and battery action of the probe in such water is slight. A small quantity of salt put into the water in the access tube will greatly increase the battery action and cause a much greater response on the millivolt meter. Rock-salt crystals can be lowered into the water by putting them into the recess of the weight (sinker bar) below the probe, or a bucket of salt solution can be poured down the tubing. If the depth to water is great, a long time may be required for the salt solution to reach the water surface. If the depth to water is not great, salt can be dropped into the water. The battery pack is recommended for use if the dissolved-solids concentration is low.
5. Air and detergent are sometimes used in drilling, and residual detergent in the well will cause foaming at the water surface. This foam will activate the battery action of the probe and measuring water levels may be extremely difficult or impossible. Moreover, the foam sticks in the probe after it is pulled up out of the liquid. Salt added to the water in the same manner as described in 4 above helps to minimize foam problems. An anti-foam chemical is available and has been used effectively. However, the chemical also produced visible deterioration of the steel cladding on the cable and its use is not recommended.
6. While lowering the probe down an access tubing or well with wet walls, the millivolt meter may show a gradually increasing voltage as the probe attains greater depth in the interval known to be above the water level. Under these conditions, the probe can be stopped and the gradual increase in indicated voltage will continue. Such a response usually indicates that the nylon insulation on the inner conductor of the cable has developed many very small cracks and that short circuits exist through the water filled cracks between the outer cladding and inner conductor of the cable. The reason for the development of these cracks is not known, but they appear in cable used only a very short time as well as in cable used extensively. This condition apparently may develop very suddenly and without any warning. A spare Iron Horse is advised at wells during extended testing.

7. If the probe becomes inoperative during a water-level measurement, first check electrical connections on the surface and thoroughly clean the brush and slip-ring connection at the reel. If millivolt-meter responses become successively less, the magnesium screw in the probe may have accumulated a film or layer of oxide. Sometimes this accumulation can be removed by leaving the probe submerged between measurements. Additional salt solution in the measurement access pipe may improve the readings if previously injected salt solution has become dispersed and diluted. This is generally not a problem when using the battery pack. As a last resort before pulling the probe out of the hole to check it for problems, a multimeter may be successfully used to obtain water-level measurements. This method utilizes the battery power source in the multimeter instead of the battery action of the probe, and a resistance scale on the multimeter is read instead of the millivolt meter. To convert the probe assembly to a multimeter, detach the wire lead from the brush terminal and attach the positive multimeter lead to the brush terminal. Hook the negative multimeter lead to a ground on the Iron Horse--any convenient non-moving part. A high-resistance reading will be indicated with the probe out of the water, and the resistance reading will decrease noticeably (needle on multimeter will deflect to the right) when the magnesium screw is in water. One of the resistance scales on the multimeter usually gives the greatest needle-deflection differential, and the best scale can be found experimentally.

REHABILITATION AND MAINTENANCE

A major part of rehabilitation of the Iron Horse is replacement of the cable. This should be done in an instrument shop or office if at all possible. To remove and replace the cable the following steps should be followed:

1. Removal of the Survey-type cable connector from the faulty cable.

   Remove and save the brass screw and special washer from the inside of the cable connector; then push the connector body up the cable with a counterclockwise twisting motion. The soft plastic sleeve that the brass screw was in will drop from the insulated conductor as the end of the cable begins to protrude below the cable connector. The sleeve sometimes can be salvaged but it is usually stretched out of shape by the screw and should be replaced. Cut the cable with the front cutters a short distance above the Nicopress sleeve and remove and save the brass connector body. If the connector cannot be removed from the cable by twisting, cut the cable near the top of the cable connector.

2. Removal of the faulty cable.

Remove the faulty cable by pulling it off the reel over the sheave, or with one wrap of cable around the sheave, so that the reading on the depth indicator when the reel is empty will be approximately the length of new cable that is to be put on the reel. Before detaching the end of the faulty cable from the reel, carefully examine the manner in which it is attached to the reel. This will help the reader understand the following discussion on how to attach the new cable.

3. Attaching new cable to the reel.

Turn the reel so that the three holes on the right side are near the top. Bring the end of the new cable under the reel core from the front and thread about 1 foot (3.05 metres) of cable out through the hole nearest the back of the device, in through the middle hole, and out through the forward hole (see fig. 8). Run the end of the cable under the exterior loop of cable (fig. 8) and pull the cable tight. Wrap the cable twice with masking tape at a position approximately 6 inches (152 millimetres) from the overlapping loop and make a neat cut near the middle of the tape with the front cutter from the repair kit. Hold the cable close to the tape, so the steel cladding strands will not unravel, and carefully remove the tape. Slide a Nicopress sleeve onto the cable as far as the overlapping loop and crimp the sleeve in four places using the largest hole of the large crimper tool. Unwind the steel, outer, cladding strands in bunches of 3 or 4 wires back to the Nicopress sleeve, bend the bunches back, and clip them off as closely as possible with side-cut diagonals leaving the nylon insulation exposed. Cut the insulated conductor so that the remainder extends 1/2 inch (13 millimetres) beyond the screw connection. Strip about 1 inch (25 millimetres) of the insulation from the end of the inner conductor. Cut a piece of "spaghetti" insulation tubing that will reach from the Nicopress sleeve to within about 3/4 inch (19 millimetres) of the end and slide it on the conductor. Double the end of the wire where insulation has been removed, crimp on a small "eye" end connection with the small crimper tool, and join it to the screw connection on the brass slip ring (fig. 8). Level wind the desired amount of cable, maximum capacity is about 3,200 feet (975 metres), onto the Iron Horse reel over the sheave or with one cable wrap around the sheave. Thus, the depth-indicator reading built up in removing the faulty cable would be returned to near zero.

4. Affix a cable connector as previously described.

The reverse-lay, steel-stranded, cladding cable on the Iron Horse is tough and durable. Nevertheless, it can be damaged by misuse. Kinking or bending the cable sharply can damage it irreparably. Running the cable over the edge of the casing or access pipe at a sharp angle may break strands of outer cladding or may crack the nylon insulation on the conductor. To minimize cable damage, always locate the measuring sheave directly above the pipe into which the cable is to be run. Level wind the cable carefully onto the reel during retrieval to avoid sharp bends.

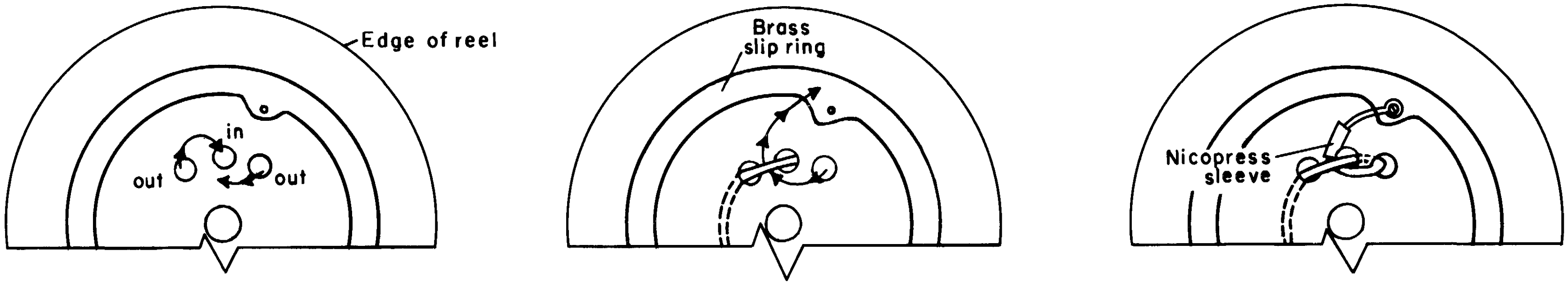

Figure 8.--Part of right side of Iron Horse reel showing steps for attaching cable.

The bearings, clutch brake, gears, sheave, and depth indicator wear during use. Therefore, the Iron Horse should be completely rehabilitated, preferably by the machine shop of the Property Control Section, every 2 to 4 years, depending on the intensity of use.

A few other simple suggestions on care and maintenance of the Iron Horse are as follows:

1. Keep the cable wiped as clean as possible and avoid getting drilling mud and filth from wells in the sheave notch. This grime abrades the sheave notch and quickly causes the device to become inaccurate.
2. Very little oil or grease is used on the bearings and gears of the Iron Horse because dust accumulates readily in the lubricants and causes excess wear of the moving parts. In a less dusty, more humid environment than a desert area, moving parts should be lubricated often with light-weight machine-type oil. DO NOT USE MOTOR OIL, as the detergents and additives will cause damage.
3. An adequate inventory of spare parts should be kept in stock. Cable connector and probe parts are the most frequently needed, but extra millivolt meters and depth indicators are needed occasionally.
4. The Iron Horse should be stored indoors to minimize weather deterioration. If the Iron Horse must be left at a well site for prolonged periods, a tarpaulin cover will help to keep the device in an operable condition.

USES OF THE IRON HORSE FOR OTHER THAN WATER-LEVEL MEASUREMENTS

A sampler, available from Well Reconnaissance, Inc., that will obtain as much as 0.8 gallon (3 litres) of water from a specified depth can be attached to the cable connector. The intake ports are opened and closed electronically by special surface controls. The sampler is 2 inches (51 millimetres) in diameter and about 12 feet (3.7 metres) long.

Flow meters that measure vertical velocity of water in a borehole can be adapted for use with the Iron Horse. Usually a change-over thread adapter is essential to attaching a flow meter onto the cable connector. The battery pack is used with the flow meter, and revolutions per unit time are compared with a flow-meter rating table to determine flow velocity. Caliper data are necessary for calculating flow quantity from velocity if casing diameters are not known.

The bottom of a borehole can be sounded with the Iron Horse. A somewhat larger weight than that used for measuring water levels should be used. Bottom sounding is principally a sensitive manual operation. When the weight touches bottom the cable will tend to go slack. Extreme caution should be exercised to prevent the cable from going downhole in the slack condition. The slack cable will pile up at the bottom of the hole and may kink when lifted, thus ruining the cable. A definite jerk on the crank when the cable slack is taken up and the weight starts to lift will indicate that the bottom has been reached.

REFERENCES

Garber, M. S., and Koopman, F. C., 1968, Methods of measuring water levels in deep wells: U.S. Geol. Survey Techniques of Water-Resources Inv. book 8, chap. A-1.

Young, R. A., 1963, Drilling and well-testing problems in investigation of deep aquifers at Nevada Test Site, Mercury, Nevada: Colorado School Mines Quart., v. 58, no. 4, p. 83-91.

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