Cathodic Protection of Oil Well Casings

By E. J. SIMMONS

Sun Oil Company

In recent years cathodic protection has been used with increasing frequency throughout the oil and gas producing industry for protection of the external surfaces of well casings against corrosion. Costly workovers of oil and gas wells due to leaks in the casing caused by external corrosion have prompted much investigative work and many individual as well as field-wide installations of cathodic protection systems. Workover costs to repair leaks can vary over quite a wide range. Where the leak is simply isolated by packers (usually only a temporary remedy at best) the cost may run only a few hundred dollars. Cement squeezes may run up to several thousand dollars; where casing has to be pulled and replaced the costs may reach many tens of thousands of dollars. Other factors such as loss of production, and safety of personnel and equipment sometimes alter the economics. When one considers that in most cases well casings can be cathodically protected for a few hundred dollars plus a few dollars per month for power, the economics usually appear favorable.

Detection of external casing corrosion and determining its extent is one of the most difficult problems in the entire field of corrosion control. The inaccessibility of the external casing surface from the standpoint of direct observation and measurement hampers the corrosion engineer not only in assessing the problem but also in determining the feasibility of cathodic protection. If the problem is assessed to be of economic significance and cathodic protection is deemed feasible, this inaccessibility still hampers the corrosion engineer in designing the proper size system. Certain tools and techniques have been developed through the years which help in all these phases of the problem, and although on some aspects there is not universal agreement, nevertheless these tools and techniques are useful.

In assessing the problem, oftentimes the occurrence of leaks in the casing is the first indication of possible trouble. Once it has been established that leak occurrence is a general trend rather than an isolated instance, projections of expected leaks based on past experience can give an indication of how serious the problem is expected to be. If cumulative leaks are plotted logarithmically against time, a projection of the best straight line through the points can give an idea of what is to be expected in future years. Economic projections based on leak repair costs versus estimated costs of cathodic protection can indicate the economic feasibility.

Certain tools and techniques are available to help in assessing the economic feasibility as well as the physical feasibility. It is important early in the study to determine for certain if the leaks are due to external or internal corrosion and these tools and techniques are useful here also.

To obtain an idea of the extent of corrosion damage, the casing thickness logging tool (Fig. 1) is useful. This tool consists of a downhole instrument connected to a surface recorder. The downhole instrument consists of a transmitter coil which puts out a signal picked up by the receiver coil. This signal undergoes a phase shift dependent on, among other things, the mass of metal surrounding the coils. This phase shift is recorded continuously on a chart at the surface as the tool is pulled up the hole, giving a continuous indication of metal mass surrounding the coils. A typical recording is shown at the right in Fig. 1, where the collar kicks (to the right) indicate greater metal mass, and the kicks to the left indicate metal loss. Certain configurations of kicks can frequently be interpreted as severe pitting or holes, but due to the averaging effect of the pickup signal (averaged over about a 14-in. length of casing) small holes or pits can often be overlooked. Where there is a known leak, the tool can usually locate it with certainty unless it happens to be a very small hole with very little adjacent metal loss.

Available as an auxiliary tool which can be run simultaneously with the casing thickness tool is the electronic internal caliper log. Figure 2 shows both logs run simultaneously in a section of casing. In the casing log trace on the right the portion labeled "external pitting" is known to be externally damaged due to the absence of

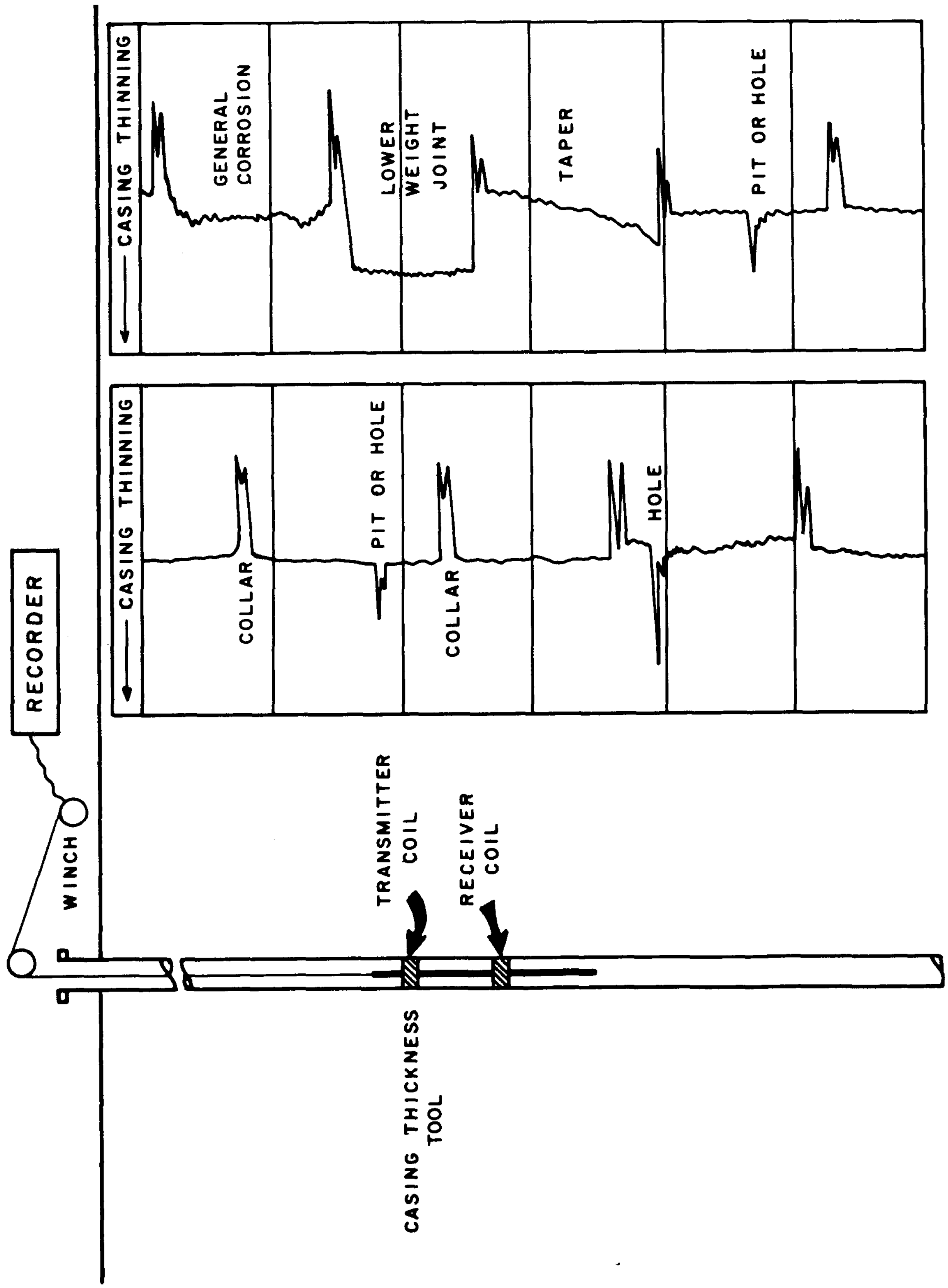
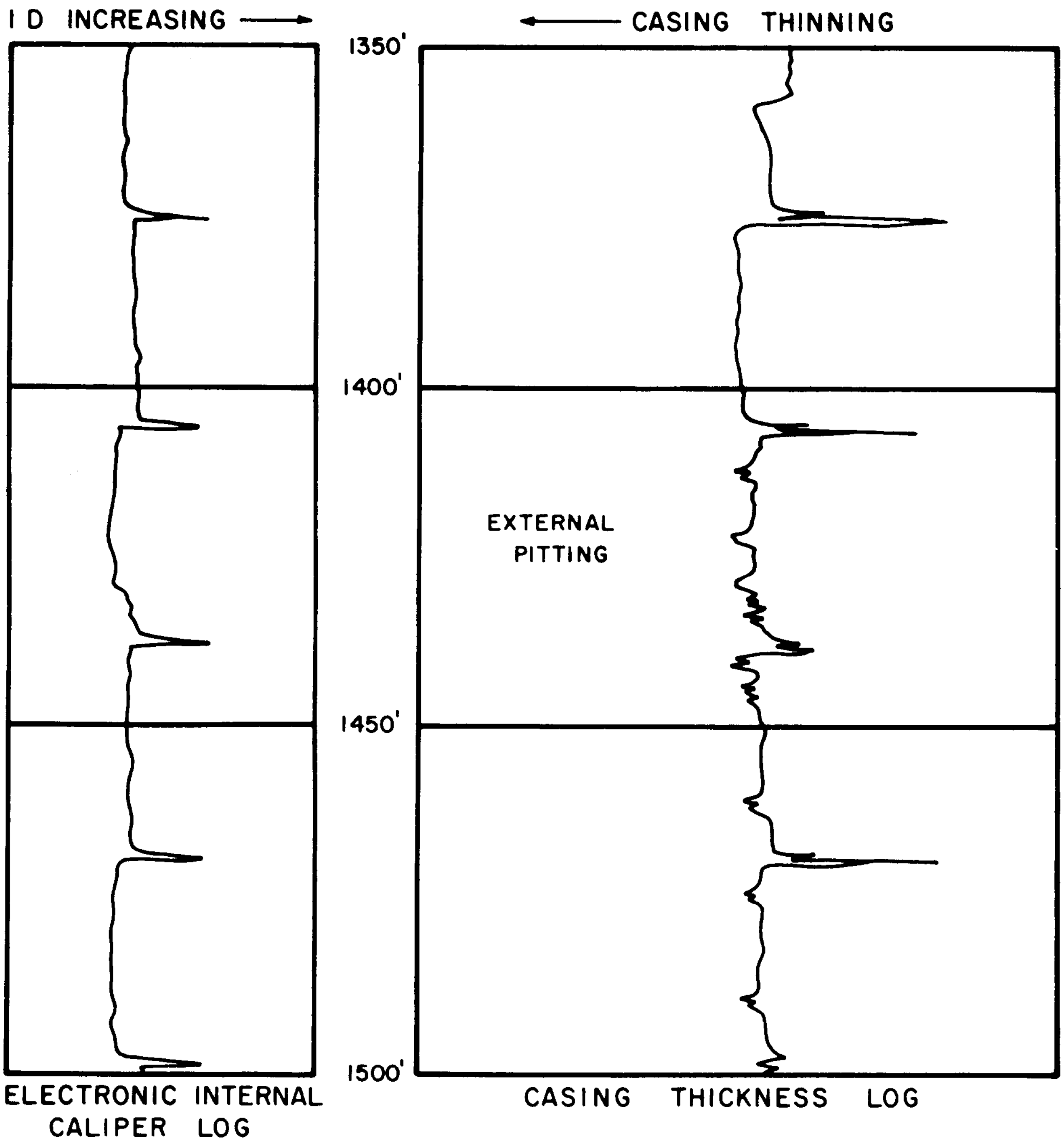

RECORDER
WINCH
CASING THINNING
GENERAL CORROSION
LOWER WEIGHT JOINT
TAPER
PIT OR HOLE
CASING THINNING
COLLAR
PIT OR HOLE
COLLAR
HOLE
TRANSMITTER COIL
RECEIVER COIL
CASING THICKNESS TOOL

FIGURE 1

any indication at that depth on the internal caliper log. Without both logs it would be impossible to tell whether this pitting is external or internal. Mechanical internal calipers can also be run to assess internal damage and, by difference, external damage.

From a study of the thickness and caliper logs, leak frequency curve predictions, leak repair costs, expected well life and other considerations, a decision can usually be made to justify, from the standpoint of economics, the feasibility of installing cathodic protection. If the leaks



FUGURE 2

are fairly shallow, normally it can be assumed that protection can be obtained with a modest outlay for equipment and labor. The deeper the leak zone, the more necessary it is to determine feasibility, for it cannot be assumed that current in the necessary amount can be made to reach the zone where protection is required without prohibitively costly techniques.

Certain tools and techniques are available to determine whether applied current can be made to reach the depth required, and these same tools and techniques are very useful in obtaining design parameters, particularly the amount of current which will be required. It is the amount of required current which primarily governs the design of the installation.

The casing voltage profile tool (Fig. 3) plays an important part in casing corrosion control work, since it is the only service presently available which enables the corrosion engineer to determine a number of things about what is happening on the external surface of the casing. This tool consists of two sets of three spring-loaded contractor knives each, the sets usually being spaced 25 ft apart (See Fig. 1). These sets of knives are insulated from each other, and from the body of the tool. Leads from the knives are connected to a microvoltmeter at the surface. The tool can be placed at any depth required, the knives are set to make good electrical contact with the wall of the casing, and a reading is taken of the voltage between the knives. This voltage is the IR drop in a 25-ft length of the casing due to currents traveling either up or down, and the amount of IR drop (since the resistance, R, of the casing wall is assumed to be constant in a string of casing all the same grade and size) is proportional to the amount of current flowing. The polarity of the voltage measured at the surface indicates whether current is flowing up or down.

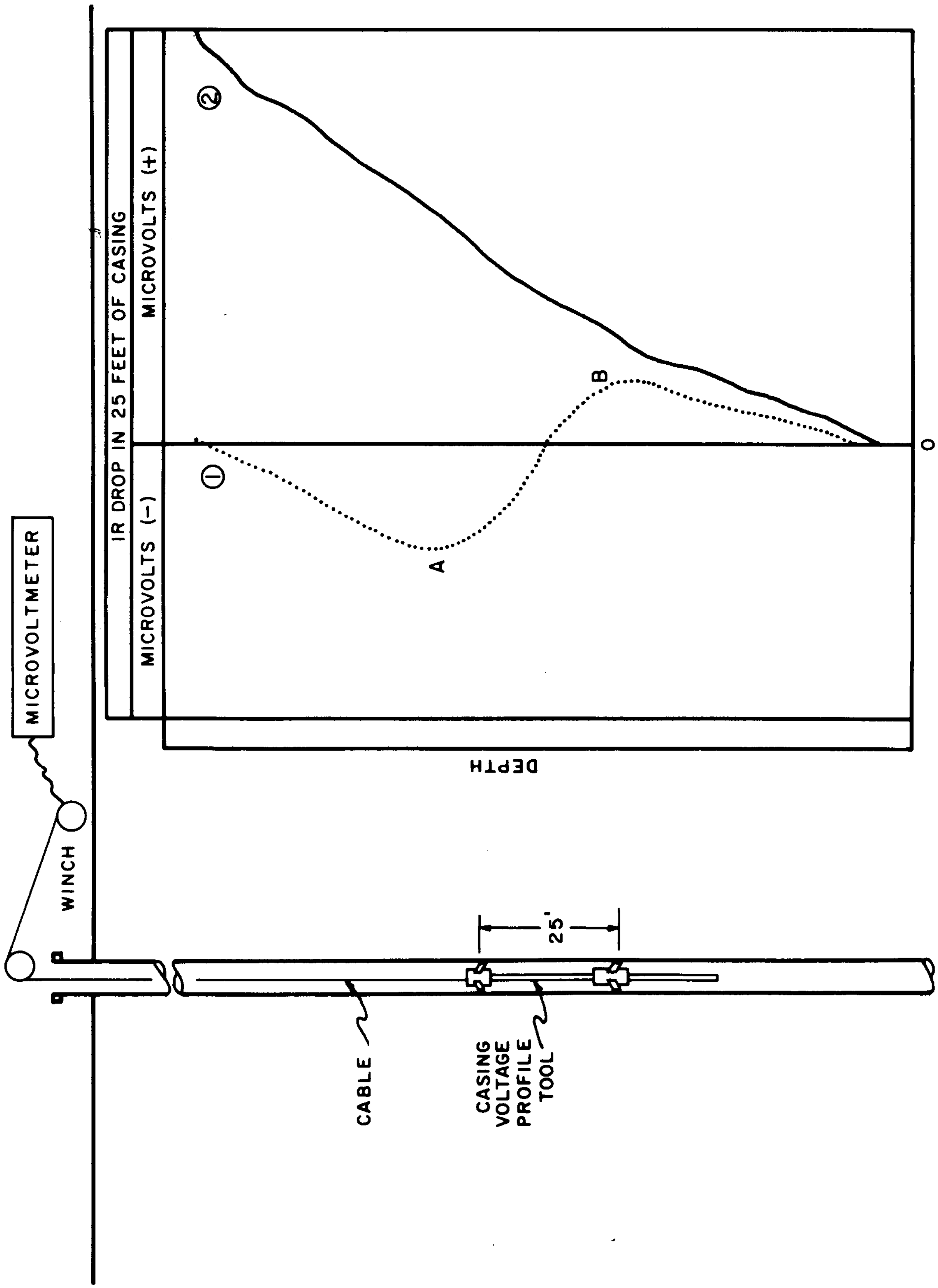
By taking a series of readings at intervals of, say, 50 ft, and connecting the points, a curve or log is obtained which can be interpreted to provide a variety of information. Curve No. 1 in Fig. 3 is an example of a log which might be obtained in a casing under so-called "native state" conditions, i. e., with no external current applied.

Starting from the top of the log to point A on curve 1, these readings, since their polarity is negative, indicate that current is flowing down the casing. Since the curve slopes toward a more negative direction (proceeding toward point A) this means that each successive reading indicates that more current is flowing. This indicates that current is entering the casing from the formation, and thus this portion of the casing is designated to be a cathodic area, or an area where current is entering. From point A to the zero axis of the log, the slope changes to the opposite direction, indicating that current is leaving the casing, and that, therefore, this portion of the casing is an anodic area, or an area where current is leaving the casing. Where the curve intersects the zero axis of the log, no current is flowing. From this point to point B, the readings, since they are on the positive side, indicate that current is flowing up the casing, and since each successive reading indicates more current flow, the indication is that this, too, is an anodic area. From point B to the bottom, the slope reverses, and this indicates again that this area of the casing is a cathodic area, where current is entering.

Summarizing, the native state log of this well indicates that generally the zone from point A to point B is the zone where current is leaving the casing, or an anodic zone, and this is where corrosion is taking place. Where current leaves a metal surface to enter an electrolyte there is a definite relationship between the amount of current leaving and the amount of metal lost. In the case of steel casing where current leaves to enter the electrolyte (the earth) each ampere of current leaving results in the loss of twenty pounds of steel in one year's time.

The example cited is greatly oversimplified, and there may be numerous anodic areas indicated in a particular casing. Furthermore, the 25 ft spacing of the knives in the tool eliminates the possibility of finding small local corrosion cells, indicating only those anodic areas extending over a much longer interval of pipe. However, the casing voltage profile log does give the corrosion engineer a very important general picture of what is happening on the outside of the casing.

Since the aim of cathodic protection is, by applying current to the structure from an external source, to eliminate anodic areas, thereby stopping the corrosion which is taking place, the casing voltage profile tool helps the corrosion engineer to determine how much current is necessary to accomplish this.



MICROVOLTMETER
WINCH
IR DROP IN 25 FEET OF CASING
MICROVOLTS (–)
MICROVOLTS (+)
DEPTH
A
B
1
2
0
25'
CABLE
CASING VOLTAGE PROFILE TOOL

FIGURE 3

Curve 2 of Fig. 3 represents a log which might be obtained while current is being applied to the casing from a temporary source. In this log the entire curve has been shifted to the right, and the formerly anodic portion (A to B) is now cathodic, indicating that the test current is entering the casing at all points from top to bottom. As stated earlier, these examples are somewhat idealized, and in many cases, several different values of test current may have to be applied before the correct amount is chosen.. To conserve logging time (as well as down time for the oil or gas well being logged) estimates of predicted current are oftentimes made, and there are a variety of techniques used to make these estimates. Some operators use a rule-of-thumb of a certain amount of current per unit (1 ma. per sq. ft. is a typical amount) to arrive at an estimate for confirmation by the voltage profile log. Others use a patented method* commonly referred to as the "Current-Potential" method, or "E log I" technique to make their estimates. In this method, which requires no interruption of production and no well work, and is a relatively simple technique, current in increasing increments is applied to the well structure from a temporary source. After each incremental application for a short period of time, usually about three minutes, the potential of the structure with respect to an outside reference (usually a copper-saturated copper sulfate half-cell) is taken. This potential is plotted against the logarithm of the current, and the curves thus obtained are interpreted in various ways. Frequently there is a break in the curve somewhere in the vicinity of the current density which eventually turns out to be the correct amount. In the final analysis, however, the voltage profile is considered by most corrosion engineers to be desirable, not only to confirm or establish the proper current density, but also to make certain that current is getting to the corrosive zone. This is particularly true with deeper and deeper corrosive zones, since there is no guarantee that the current is reaching these deeper areas without the direct confirmation which the voltage profile log provides.

In a group of wells in a field, all traversing the same formations, all completed in the same manner and all having the same cement program, it may be necessary to run only a few current requirement tests, especially if the results of those tests do not vary more than, say, 10 to 20 per cent. Where large variations in current requirements occur, or where there are many wide variations in well completion techniques, it may be necessary to run a larger number. Since the test work on a single well may cost as much as or more than the cathodic protection installation itself, the design engineer must decide whether to spend more money in testing, or to risk under- or over- designing his system. Under-design will result in incomplete protection, and over-design is costly not only from the standpoint of equipment investment, but also from the standpoint of wasted power throughout the remaining life of the well or field. In areas of high power costs this is particularly important.

Once current requirements have been established, the design of ground beds can be made. Ground beds consist of one or more anodes of inert conductive materials, usually graphite or high silicon-content cast iron, buried at some suitable depth in the ground at some distance from the well head, typically 100 to 200 ft. It is from these anodes that the current leaves to travel to the well casing and provide the protection required. In order to provide as low a resistance path as possible, zones of low soil resistivity are sought in the vicinity of each well casing to be protected. Soil resistivity surveys can be made with a variety of instruments, one of the most common being a self-contained instrument capable of injecting alternating current of 97 Hz into the ground between two pins or electrodes. By using this frequency of 97 Hz, interference from 60 Hz or 120 Hz stray ripple voltages flowing through the soil may be avoided. Two inner electrodes spaced equally between the current electrodes are connected to a resistance bridge in the instrument. By adjusting a calibrated resistor in the bridge circuit the resistance between the inner electrodes is determined, and this resistance can be used, with appropriate factors, to calculate the soil resistivity of a hemisphere or soil whose depth is equal to the spacing between the two inner electrodes. By varying the distance between electrodes, resistivities up to 100 ft.depth or more may be determined. From these data one can establish the depth and proper placement of anodes, and from appropriate tables

*U. S. Patent No. 2,862,177

available in numerous reference works the expected ground bed resistance using the number of anodes as required by our current demand can be estimated. Sometimes, particularly in areas of high power costs, if the estimated ground bed resistance is still too high, additional anodes can be planned for the ground bed.

In areas where shallow low resistance soil is available within, say, three to eight ft of the surface, a ditch type anode bed (shown at bottom in Fig. 4) may be used. The anodes, whether they are graphite or high-silicon iron, are surrounded by a highly conductive granular material called "coke breeze" which effectively increases the area available for current to leave to enter the soil, and thus effectively decreases the bed resistance. From a foot or so above anode level, the remainder of the ditch may be filled with loose gravel which allows gases evolved at the anode to diffuse upward and minimize "gas

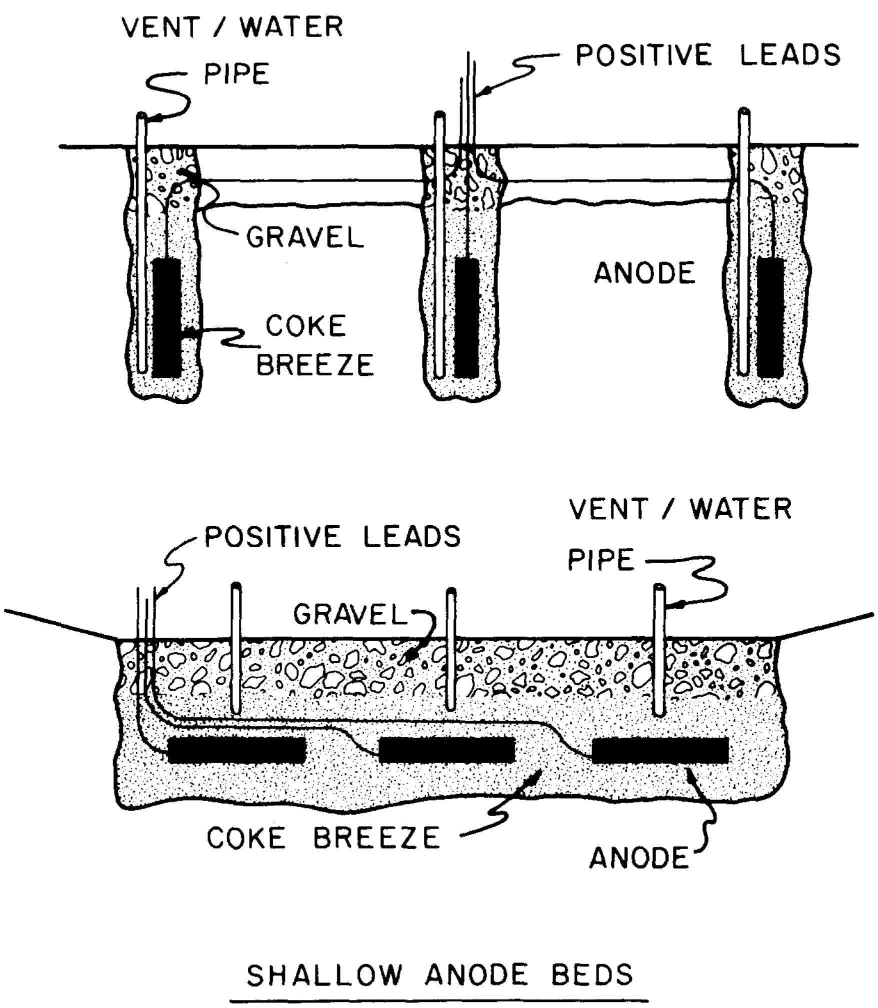


FIGURE 4

blocking" which is a condition where evolved gases displace moisture from around the anode, greatly increasing its resistance. There is also a tendency, especially in soils containing certain clays, for moisture to migrate from around the anodes due to the passage of electrical current, a phenomenon known as cataphoresis. Moisture retention can be aided by sloping the ground inward (as shown in the drawing) to facilitate the drainage of rainfall into the ground bed. It may be desirable, particularly in dry areas, to install a plastic pipe above each anode, as shown in the drawing. This "vent/water" pipe aids in venting evolved gases, and also serves as a built-in pipe for adding water at intervals if the ground bed should have a tendency to dry out and consequently increase in resistance. The positive leads are brought out individually as shown, or an underground splice can be made, with only one lead being brought out. Although there are many excellent splicing kits available, some operators prefer to avoid this possible trouble source by running the leads individually to the rectifier, or by making an above-the-ground splice.

Another type of shallow anode bed is shown at the top in Fig. 4. Here the anodes are placed in individual holes drilled to a depth of perhaps 10 to 20 ft with auger rig. Again, the anodes are surrounded with coke breeze, and the upper part of the hole is filled with gravel. A vent/water pipe may be spotted in each hole close to the anode, and several holes are drilled in the pipe throughout the length of the anode to facilitate venting of evolved gases. A shallow ditch is dug between the holes and the anode leads are laid in the ditch and brought out individually to the surface.

In many areas low resistivity formations are not found near the surface. This often necessitates the drilling of deeper anode beds as shown in Fig. 5. These anode beds, which may be up to 100 ft or more in depth, can be drilled with a water well rig using native or bentonite mud. Placement of the anodes opposite zones of lowest resistivity can be accomplished by logging the hole using an anode and an external battery or other current source. Usually a fixed voltage is applied between the logging anode and the well casing, and current readings are measured at 5-ft intervals down the hole. The drawing shows such an anode bed with four anodes placed in low resistance zones.

After anode setting depths are determined the required number of anodes are placed in the hole at the proper depths, and the mud is displaced by the coke breeze which is pumped in as a slurry. An alternate method, if the hole will stand without caving, is to displace the mud with water, place the bottom anode, tie it off temporarily, and pour in coke breeze until the anode is completely surrounded and covered. The next anode is spotted and tied off, more coke breeze is added, and the process is repeated until the anodes are all in place and the coke breeze column is complete.

It is desirable, although sometimes difficult to accomplish, to have a vent/water pipe installed all the way to the bottom anode with

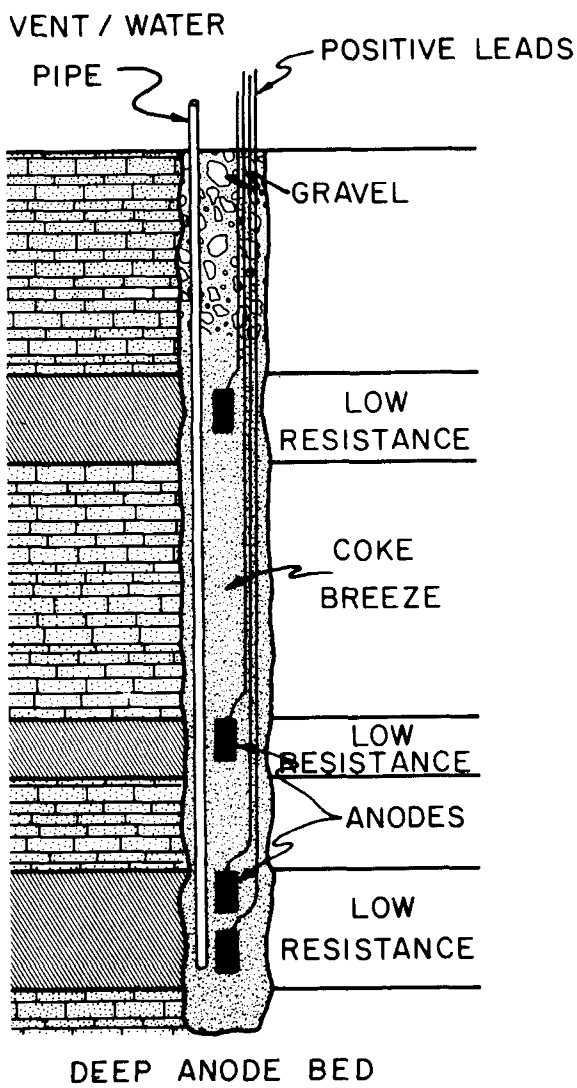


FIGURE 5

small holes drilled opposite each anode to allow for venting of gases and watering of the anode bed if necessary.

Gases (chlorine and oxygen) evolved from the anodes due to the discharge of current, attack many types of insulation materials. High density polyethylene has proven satisfactory in this regard. Not only has this material been found to be quite resistant to the action of chlorine and oxygen, but also its smooth, hard surface makes for easy handling and minimizes damage due to abrasion. Obviously, care must be exercised in handling the anode leads since any abrasion or cut may lead to premature failure.

Anodes may be made of graphite or a special high silicon content cast iron. Graphite anodes are limited to about one ampere discharge per square foot of surface and it is essential to have a good coke breeze back-fill to avoid local pitting action of the graphite with possible premature failure. The high silicon cast iron anodes permit up to 3 or 4 amperes discharge per square foot of surface area, and the coke breeze back-fill may be eliminated since the alloy is not as subject to pitting as the graphite. In the case of the alloy, coke breeze serves to lower the ground bed resistance, but it can be eliminated where its use would complicate the construction of the ground bed, as in formations where heaving and sloughing occurs.

The connection of the lead wire to the anode is a critical area where premature failure can occur. A good epoxy seal or cap should be employed over the lead connection, and an additional safety factor can be provided by a heat shrinkable plastic cap which fits over the critical area where the lead joins the anode.

Once the ground bed is complete and its resistance is determined, the final component of the system, the rectifier, can be chosen. Rectifiers can be ordered in practically any shape and size, with a variety of output voltages and current capacities. Large rectifiers, having up to several hundred amperes output can be used in multiple installations, but the more common practice in casing protection is to use one small rectifier for each well. In areas where large seasonal variations in anode bed resistance may be expected, rectifiers are available which put out a constant current regardless of wide variations in circuit resistance.

Figure 6 shows a typical rectifier installation on a well casing. While many variations in design are possible, some of the desirable features of a good rectifier installation are summarized below, with reference to Fig. 6.

(1) A good lightning arrestor at the top of the pole on the AC supply helps protect the system against lightning surges coming in from the supply lines.

(2) A fused disconnect switch is desirable so that power can be completely shut off when it is necessary to service the rectifier. This is necessary even though the rectifier may have its own magnetic circuit breaker.

(3) The rectifier should be securely mounted on the pole with bolts going all the way through the pole. It should be mounted high enough so as not to become a back scratcher for cattle. The case should be of heavy gauge steel to prevent damage from small arms fire (in some areas rectifiers are favorite targets). Good quality components of adequate capacity should be used. Separate or combination meters for monitoring current and voltage output are desirable, although some operators prefer to use shunts and terminals with a portable meter. A DC surge protector (lightning arrestor) should be mounted across the output terminals to minimize damage from lightning and other power surges coming in from the system side of the rectifier. While air-cooled rectifiers are usually sufficient, oil-immersed rectifiers afford protection for the electrical components in highly corrosive atmospheres such as offshore, or in sour crude areas.

(4) A seemingly minor, though important part of the installation is the ground lug which should be brazed or welded on to the case—not screw or bolt connected.

(5) The ground wire should be size 6 or 8 although codes may vary in different parts of the country. This is primarily a safety factor to prevent electrical shock to personnel in case of some internal short in the rectifier. Mechanical strength is as much a consideration as current-carrying capacity.

TYPICAL RECTIFIER INSTALLATION

1. LIGHTNING ARRESTOR
2. FUSED DISCONNECT SWITCH
3. RECTIFIER
4. GROUND LUG ON RECTIFIER CASE
5. GROUND WIRE
6. CONDUIT (S)
7. GROUND ROD
8. NEGATIVE LEAD TO CASING (+ LEAD NOT SHOWN)
9. CONNECTION TO CASING
10. INSULATING UNION OR FLANGE

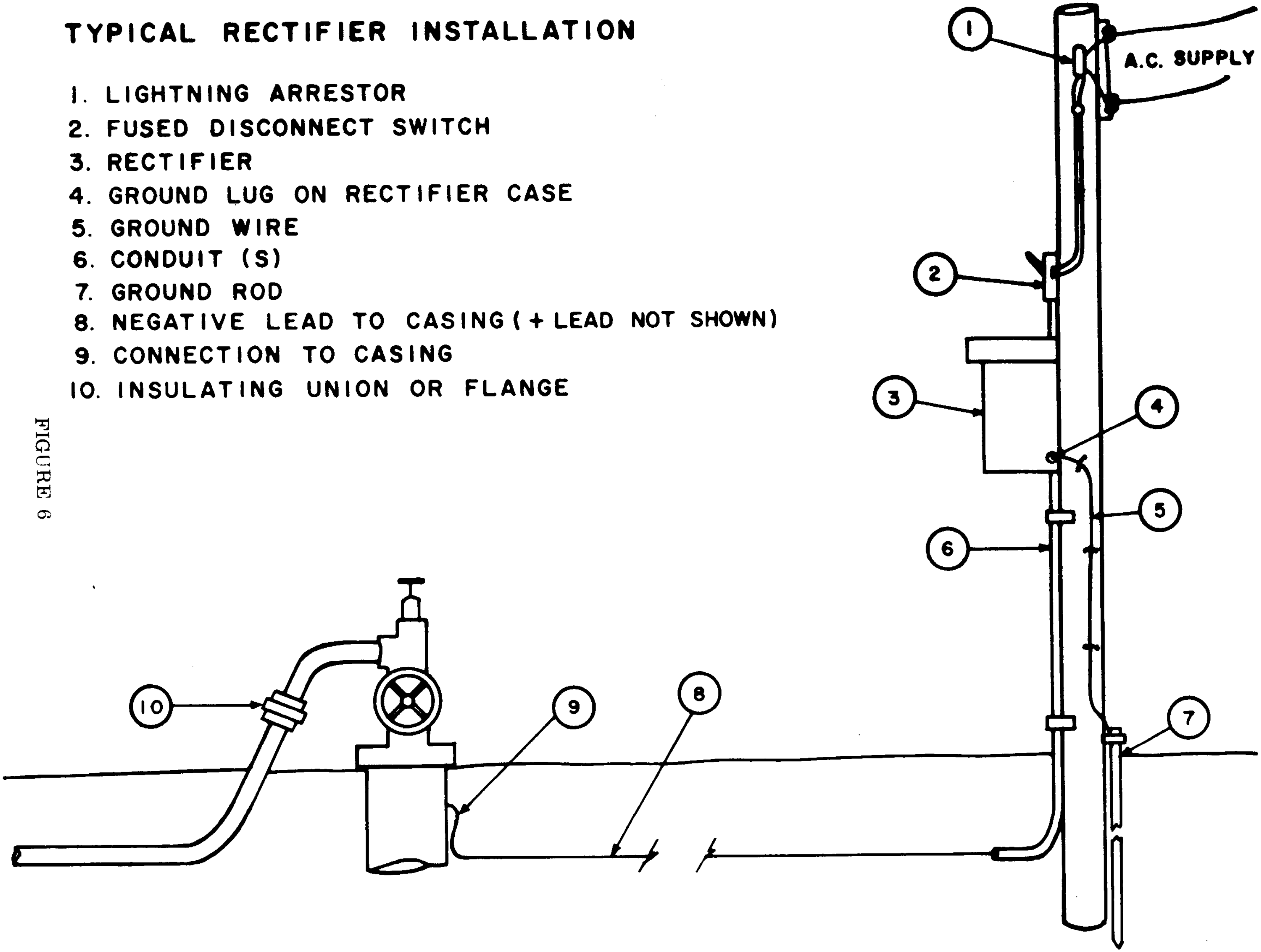


FIGURE 6

(6) The output leads, negative to the well casing and one or more positive leads to the anode bed (not shown in Fig. 6) are brought out of the bottom of the rectifier in one or more conduits. The conduit or conduits should be bent at a right angle underground to minimize mechanical damage to leads.

(7) A good copper or copper-clad ground rod of at least 8 ft length should be provided for connection to the ground wire. An alternate method is a copper plate at the bottom of the pole.

(8) The negative lead to the casing as well as the positive lead or leads to the anode bed (not shown) should be buried deeply enough to avoid being cut by well pad operations, plowing, etc.

(9) The connection of the negative lead to the casing head may be made in several ways. Some prefer to weld or braze the lead to the casing underground (as shown here). If this technique is used the weld and bare portion of the wire should be covered with a good mastic type insulation, and this covered with a polyethylene cap before backfilling. Others prefer to have the connection made above ground, either by welding to the casing, or by the use of a large copper or brass lug to a flange bolt.

(10) The insulating union or flange, which electrically isolates the well casing from the attached equipment, should be of good quality, should be above ground, not in a horizontal position, and painted some distinctive color for identification. It should preferably not be used as a working union, and some operators prefer to mount it downstream from a working union to minimize damage to it during well work operation.

Obviously, many variations of some of these features are possible, but these are some of the elements of good design which go into a successful rectifier installation.

Successful operation of cathodic protection systems is dependent upon frequent surveillance and prompt maintenance by knowledgeable people who have an interest in their work. This may appear to be belaboring the obvious, but far too frequently, well-designed systems fail due to insufficient maintenance. Too often untrained people are haphazardly assigned the job of obtaining and tabulating system data which are then filed and forgotten.

Regular checking of all points of the system is necessary to assure uninterrupted and proper operation in order to obtain the results for which it was originally designed.

The output of the rectifier is logically the first clue to any malfunction in any part of the system. If the circuit resistance (as determined from rectifier voltage and current readings) keeps going up over a period of several weeks or months, it is usually a sign that the anode beds are drying out or undergoing gas blocking. In certain areas deficient in rainfall, anode beds may have to be watered occasionally, preferably with salt water, in order to maintain the original low resistance.

Where a check of the rectifier output reveals a normal or near normal voltage but a greatly reduced current or no current, a break in the circuit is usually indicated. A particularly vulnerable spot is the negative lead connection at the well head. Breaks in either the positive or negative leads due to plowing or ditching can usually be found by inspection. Faulty splices in the anode header cable, or faulty connections of the lead to the anode will cause reduced current output, the amount depending on the location of the fault and how many anodes are affected. It is important to check the rectifier output at frequent intervals, possibly once a month, not only to keep it operating as nearly continuously as possible but also to be in a better position to diagnose a problem, if one exists. At less frequent intervals, possibly once or twice a year, a corrosion engineer should check each system thoroughly and make any needed repairs. Faults found on the regular monthly checks should of course be repaired as soon as possible.

Cathodic protection is an effective preventive technique against external casing damage due to corrosion. It has withstood the test of time and has proven that with proper planning, design, installation and maintenance, in all but the most unusual circumstances it can be successful.