$CO_2 + H_2O$ = CORROSION

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ABSTRACT

This paper contains a discussion, with examples, on how one type of casing inspection survey is used to identify the depth and circumferential extent of casing corrosion.

Corrosion results from one or more of a family of electrochemical processes. Some of these electrochemical processes will be generally described in the later topics.

The Dresser Atlas casing inspection log and casing evaluation logs (for the detection of corrosion) provide such information as:

1. Whether the corrosion is external or internal.
2. The degree to which the pipe's wall thickness is reduced by the corrosion.
3. The circumferential extent of the corrosion.
4. Whether corrosion is general or isolated.
5. Basis for monitoring corrosion and effectiveness of cathodic protection of chemical treatment.

Corrosion is an electrochemical process that involves chemical reactions and the flow of electricity. Corrosion requires an anode, a cathode and an electrically conductive path between the anode and cathode.

In the west Texas-New Mexico area there are many zones with differing electrical potentials with which the casing forms the electrical coupling. These conditions represent the prime cause of external corrosion.

With the addition of CO_2 inside the casing internal problems as CO_2 + water = corrosion can be expected.

This paper will show a way, though the use of Vertilog, to monitor corrosion activity and assist in evaluating the techniques to combat such problems.

INTRODUCTION

In most areas of the world electrochemical conditions are such that tubular goods suffer external corrosion. The west Texas-New Mexico area in particular has always been very hostile to casing. The association of subsurface voltage potentials in many zones react upon the steel casing, and current flow is induced into the casing. With the installation of cathodic protection, casing corrosion is controlled or at least minimized. However, in many wells cathodic protection was installed too late or in some cases was ineffective.

With the injection of CO_2 corrosion can be expected to increase the problem, especially in wet environments because:

1. electrolysis is still working on the outside of the pipe
2. the chemical reaction of CO_2 and H_2O form acids that erode the inside of the pipe.

For enhanced oil recovery to be economically successful we must work toward prolonging the useful life of casing.

The monitoring of casing corrosion and the treatment of this corrosion is required. Cathodic protection to handle the external problems and chemical retarders to protect the interior of the casing are necessary.

The gas storage industry has instituted a casing monitoring program very similar to this and has been able to greatly extend the life of the gas storage fields.

Their technique has been to periodically run the Vertilog and casing potential profile on selected field wells and from these periodic surveys adjust the remedial actions as necessary to protect the casing.

Three basic pieces of information are gained from periodic surveys:

1. They indicate current wall thickness, location of corrosion defects (external or internal) and the extent of the corrosion (generally distributed or localized corrosion).
2. If surveys are run periodically they will indicate the effectiveness of the corrosion remedial techniques being used.
3. They provide information, when plotted, that helps predict the need for liners or other means of protection.

On many old wells there is additional information that is gained through the use of casing inspection surveys. Among these are:

1. location of existing perforations,
2. location of surface casing,
3. location of centralizers, scratchers, DV tools and other man-made changes in the casing strips.

Casing evaluation surveys identify the location and extents of casing corrosion and abnormal internal wear or damage. These two types of deterioration differ in their causes and in the type of casing inspection survey which can best identify them.

Corrosion results from one or more of a family of electrochemical processes. These electrochemical processes are described later. Casing evaluation logs for the detection of corrosion provide information such as: whether the corrosion is internal or external, the degree to which the pipe's wall thickness is reduced by the corrosion, and the circumferential extent of the corrosion.

Internal wear, on the other hand, is caused by processes which differ distinctly from those which cause corrosion. A typical cause of internal wear is the rubbing of drill pipe on casing in a deviated hole, resulting in a nonuniform reduction of the casing's wall thickness.

The Vertilog is a casing inspection survey designed to record the anomalies caused by corrosion in casing which is already in service.

The tool is best used to evaluate and monitor anomalies due to corrosion. Other type surveys are better for determining the extent of internal wear.

CORROSION

Refining Process

Iron ore is converted to steel in two successive processes which convert the ore from an oxide of iron (hematite) to an alloy of iron and carbon (steel). In the first process the hematite ore is transformed by a blast furnace to molten pig iron, which is a solution of iron, carbon, silicon, phosphorus and sulfur. Then the pig iron is refined by a steelmaking process to reduce the high concentrations of carbon, silicon, phosphorous and sulphur to acceptable levels. Essentially, the steelmaking process converts molten pig iron into steel.

Referring to Figure 1-1, iron ore in the form of hematite (chemical formula, Fe_2O_3) is converted to steel by successive blast furnace and steelmaking processes. The steel, an alloy of iron and carbon with other desired additives, is formed into casing by a pipe mill.

Both blast furnace and steelmaking operations require heat energy to accomplish the conversion of iron ore to steel. Interestingly, the energy supplied during these processes is the same energy that supports corrosion of the steel casing during its use in a well.

Corrosion Process

In Figure 1-2, steel pipe is shown as well as casing in the presence of the earth and an electrolyte, which is typically water. A part of the electrically conducting casing (labelled +) acts as an anode during corrosion, and iron is removed from the anode site by the corrosion, reducing the thickness of the pipe wall. Another part of the pipe (labelled -) acts as a cathode during corrosion. At the cathode site, other chemical reactions essential to corrosion occur. The result of corrosion is the transformation of iron in the steel back to its original state, Fe_2O_3.

Corrosion requires an anode site, a cathode site, an electrically conductive path between the anode and the cathode, an electrolyte such as water and a source of energy. The source of energy for the corrosion process is the same energy that is supplied during the blast furnace and steelmaking.

Electrochemistry of Corrosion

Corrosion is an electrochemical process, that is one which involves chemical reactions and the flow of electricity. This aspect of corrosion is illustrated by Figure 1-3. At the anode site, which is shown as an electrically positive portion of a buried casing, the following oxidation reaction occurs:

$$Fe \rightarrow Fe^{2+} + 2e \quad .$$

During this reaction, iron enters solution as iron ions in the electrolyte (water), leaving electrons in the metal casing. As the iron ions enter solution, there is an erosion of the casing surface, and a resulting reduction of casing thickness at the anode. The electrons remain in the metal of the casing and flow toward the cathode site by electrical conduction.

The cathode is a portion of the metal which does not dissolve, but which is the site of reduction reactions which consume the electrons that flow through the metal from the anode. At the cathode a typical reduction reaction is:

$$2H^{+} + 2e \rightarrow H_2 \quad .$$

In this reaction, hydrogen ions from the water combine with electrons to form hydrogen gas. If oxygen is present, two other reduction reactions are also possible. In the first of these, oxygen and hydrogen ions in the water combine with the electrons in the metal to form more water:

$$O_2 + 4H^{+} + 4e \rightarrow 2H_2O \quad .$$

This reaction is typical of acid solutions which are in contact with the casing wall.

If neutral or alkaline solutions are in contact with the casing wall, the following reduction reaction may occur:

$$O_2 + 2H_2O + 4e \rightarrow 4OH^{-} \quad .$$

In this reaction, oxygen and water combine with electrons from the metal to form (OH^{-}).

To maintain the flow of electrons through the metallic conductor between the anode and cathode sites, a source of voltage, or potential difference, is required. The potential difference is illustrated schematically in Figure 1-3 by showing the anode as electrically positive with respect to the cathode. This potential difference provides electrical energy to the electrons as they move through the metal from the anode to the cathode. Corrosion generally occurs in localized "cells" that minimize the distance over which ions move in the electrolyte.

Corrosion Sites

A metal is inherently inhomogeneous, and the inhomogeneities result in potential differences on the metal's surface. The potential differences participate in local corrosion cells. Also, the locations of the anode and cathode sites on a metal's surface may change with time. For example, corrosion products may accumulate, shifting the anode sites.

The conductivity of the electrolyte (water) affects the rate of corrosion. Both salt and dissolved gas raise the conductivity of the electrolyte, thereby increasing the rate at which electric current flows in the metal, and correspondingly increasing the rate of removal of metal from the anode site.

Typical gases which may dissolve in the electrolyte include oxygen, carbon dioxide, and hydrogen sulfide. These dissolved gases drastically increase the water's corrosivity, and correspondingly heighten the rate of removal of metal from the anode site. Elevated pressures increase the concentrations of gases which are dissolved in the electrolyte, and thereby raise the corresponding corrosion rate. Increasing temperature generally raises the corrosion rate. While elevated temperatures tend to drive dissolved gases out of solution (in open systems), they do not reduce the concentrations of dissolved gases under typical downhole conditions because the systems are closed.

VERTILOG SYSTEM OVERVIEW

During operation the Vertilog tool generates a steady electromagnetic field of constant field strength. As the tool is pulled through the survey interval at a constant logging speed, the electromagnetic field permeates the casing wall. If there is no defect in the casing, the electromagnetic field simply passes from one of the tool's poles, through the casing, and back to the other pole.

If there is a defect in the casing, part of the electromagnetic field "leaks" outside the casing wall, as will be shown later. To detect such leakage, the Vertilog tool includes two sets of shoes which move along the inside pipe wall. One set is arranged in a second ring which also surrounds the tool and is placed below the first ring. Each shoe includes two coils which detect flux leakage (the flux leakage or "FL" coils). In addition, each shoe includes two eddy current ("EC") coils, one corresponding to each FL coil.

When an FL coil detected flux leakage (which indicates a defect in the casing) the companion EC coil generates a signal which indicates whether the defect is on the inside or the outside wall. At the surface a recording is made of the defect detected by the shoes. This recording is called the "FL-1 track." A second recording, called the "EC track," indicates whether a corresponding defect is internal or external. If the EC track records a response, the defect is internal; if no response, the defect is external. Lastly, all signals from the shoes are processed within the Vertilog tool to yield a signal "FL AVG." This signal is also recorded at the surface and shows the circumferential extent of a defect.

A block diagram of the Vertilog System appears in Figure 1-4.

BASIC THEORY OF OPERATION

The Vertilog tool basically consists of 6 or 12 shoes according to which size of casing is being run, an electromagnet and two electronics packages. Each shoe has two transducers. Each of the transducers is connected to other electronic packages. One of the electronic packages (the FL package) processes the signal relating to the severity of the anomaly. The EC package is dedicated to discriminating between internal and external anomalies.

If a D.C. current is sent through a coil wire, a magnetic field is generated along the axis of the coil. The magnitude of the magnetic field is primarily determined by the product of the current through the coil in amperes and the number of turns in the coil (B = NI).

To explain, consider a magnetic field as consisting of an infinite number of lines of force called magnetic lines of flux. These magnetic lines of flux have two basic properties which the Vertilog uses: (1) the magnetic lines of flux travel through ferro-magnetic materials (casing) more readily than through air (or fluids); and (2) one line of magnetic flux cannot cross another line of magnetic flux.

The Vertilog instrument has a coil of wire in its center. A regulated D.C. current is sent to this coil from the logging truck via the wireline. The magnitude of the magnetic field generated will be great enough to saturate the bodywall of the casing with lines of flux. Figure 1-5 illustrates tool design and flux flow.

If the bodywall of the casing is consistent, most of the lines of flux will travel through the bodywall of the casing. Any anomaly in the bodywall of the casing will cause a leakage of flux from the bodywall of the casing. The amount of flux leakage is proportional to the percentage penetration of the anomaly.

A small voltage can be generated if a coil of wire is passed through the area of flux leakage. The magnitude of this voltage will be determined by the size of the coil, the speed at which the coil passes through the area of flux leakage, and the amount of flux leakage through which the coil passes.

Each of the shoes on the Vertilog instrument contains two coils of wire for flux leakage detection (transducers). Since the size of the flux leakage detection coils is constant and since the rate which the coils will pass through an area of flux leakage is the logging speed (125 fpm) (relatively constant), the magnitude of the voltage generated in the transducer will be proportional to the percentage penetration of the anomaly relative to the nominal bodywall of the casing.

Prior to logging each well, a magnetic signal of a known level is induced into each transducer. Each transducer is connected to its own amplifier located within the Vertilog instrument. With the instrument connected to the wireline, each amplifier is adjusted so that the magnetic signal induced in its respective transducer produces the same number of chart divisions on the galvo-readout system. This calibration procedure is necessary to insure that each of the transducers will react as identically as possible to the same anomaly.

Because of the differences in shapes, it has been found that a circumferential anomaly will produce a higher signal than an isolated anomaly of the same bodywall penetration. To help differentiate between anomalies, all of the transducers are connected to a circuit which produces an average channel readout record.

The averaging circuit takes a portion of the signal produced by each transducer in the shoes and adds these together. The output of the averaging circuit is proportional to the number of transducers that produced a signal at the same time. A casing collar appears as a 360° anomaly to the Vertilog instrument. If the height of the indication produced on the average channel is divided by the number of transducers located in the shoes, the contribution of each transducer to the total height of the indication can be determined. Experimentation has shown that an anomaly which produces a signal on the average channel equal to the contribution of 5 transducers should be considered circumferential in nature. Therefore, any anomaly which causes a signal on the average channel equal to or greater than that produced by 5 transducers should be interpreted as indicating a general change in wall thickness. Consequently, the average channel can be considered as the "signature" of the well's casing condition.

The Vertilog will enable the engineer to evaluate the condition of the casing in the well at the time of the survey. The Vertilog, by itself, cannot help evaluate the cause of an anomaly or the rate of progression, but if a base log is established on a given well, subsequent inspections can help evaluate the rate of progression and if the anomalies are caused by corrosion.

LOGGING PROGRAM

Other well logs are available to help evaluate the condition of a given well. Since each logging service/technique relates to different parameters of the well, a combination of different logs can help develop an understanding of the overall condition of a well.

A bond log (CBL) can show the areas where the cement is no longer protecting an external surface of the casing.

A cathodic potential profile (CPP) can help determine the effectiveness of a cathodic protection program. With the well surveyed in its native state, the CPP can help determine the areas where electro-chemical corrosion may exist.

A sonic analysis survey (Sonar) in conjunction with a differential temperature survey can help locate casing leaks, and help determine the magnitude and direction of fluid movement outside the casing.

VERTILOG PRESENTATION AND INTERPRETATION

The Vertilog log records curves described below:

The flux leakage average curve is presented in the "P" track. Its response is scaled from 0 to 100% which is really 0 to 360 degrees. (0^{o} is at P5, increasing in both directions.) Note that a casing collar has a circumferential extent of 100% or 360 degrees.

The average curve indicates circumferential extent of a defect.

The eddy current (EC) is presented in the "R" track from R0 to R5, with EC 0 at R5 and increasing toward R0. The EC curve indicates the presence of internal defects. Casing collar response shows up as an internal change.

The flux leakage is presented in the "R" track with 0 at R5 and increasing to R20. The magnitude of the FL in response units is the measure of depth of penetration of an anomaly.

From these three curves we can determine:

1. general or isolated defects (from Avg.),
2. internal or external defects (from EC),
3. depth of penetration of defect (from FL).

With the information from these three curves we can go to the appropriate chart for determining actual wall thickness or percentage of penetration.

The log response-wall penetration chart (see Figure 1-6) correlates this data to casing size, casing weight and the grade of the casing. Charts are available for most sizes, weights and grades of casing.

LOG EXAMPLES

Example 2-1

The log shows three sets of perforations in the area 6600 ft to 6650 ft. The anomaly at 6700 ft was most likely caused by a packer being set at this depth.

Example 2-2

This log example shows selective perforating intervals.

Example 2-3

This is a typical example of scale deposit build-up on the inside of casing. Note that there is EC activity with no FL response. There is no metal missing. The response indicates scale on the inside of pipe.

Example 2-4

This is an example showing scratchers on the outside of the casing. The average curve shows a 360° response with no EC response and regularity of the casing wall is indicated.

Example 2-5

This example shows selective perforations and a centralizer on the casing collar.

Example 2-6

This example shows general external corrosion. Note how some joints corroded whereas others did not corrode (illustrates a sacrificial (anode) joint).

Example 2-7

This example shows general external corrosion with some areas approaching 100% penetration of casing wall.

Example 2-8

This log shows moderate general corrosion with some spots approaching 100% penetration.

Example 2-9

This log shows moderate general corrosion with some spots approaching 100% penetration.

Example 2-10

This examples shows severe general corrosion and some holes through the casing. Note: Holes show both EC and FL kicks.

Example 2-11

This example shows severe general corrosion with some total penetration.

Example 2-12

This log detects the location of a DV tool or Float collar at 4720 accompanied by some minor internal scale.

Example 2-13

This is an example of a typical west Texas casing string suffering general external corrosion which stops at 1028 feet (bottom of surface casing).

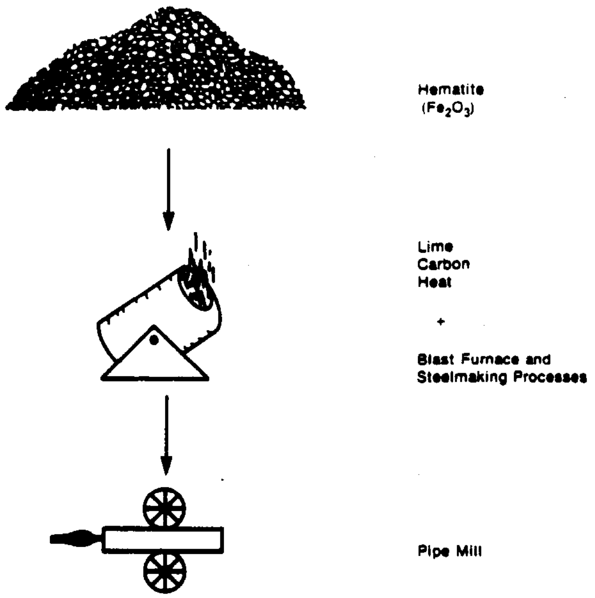


Figure 1-1 - Production of pipe, beginning with hematite ore

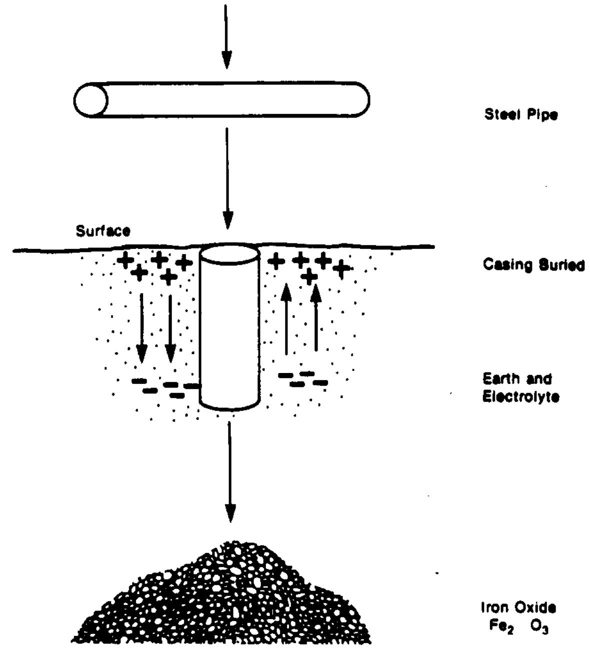


Figure 1-2 - Reversion of steel pipe to iron oxide during use in a well

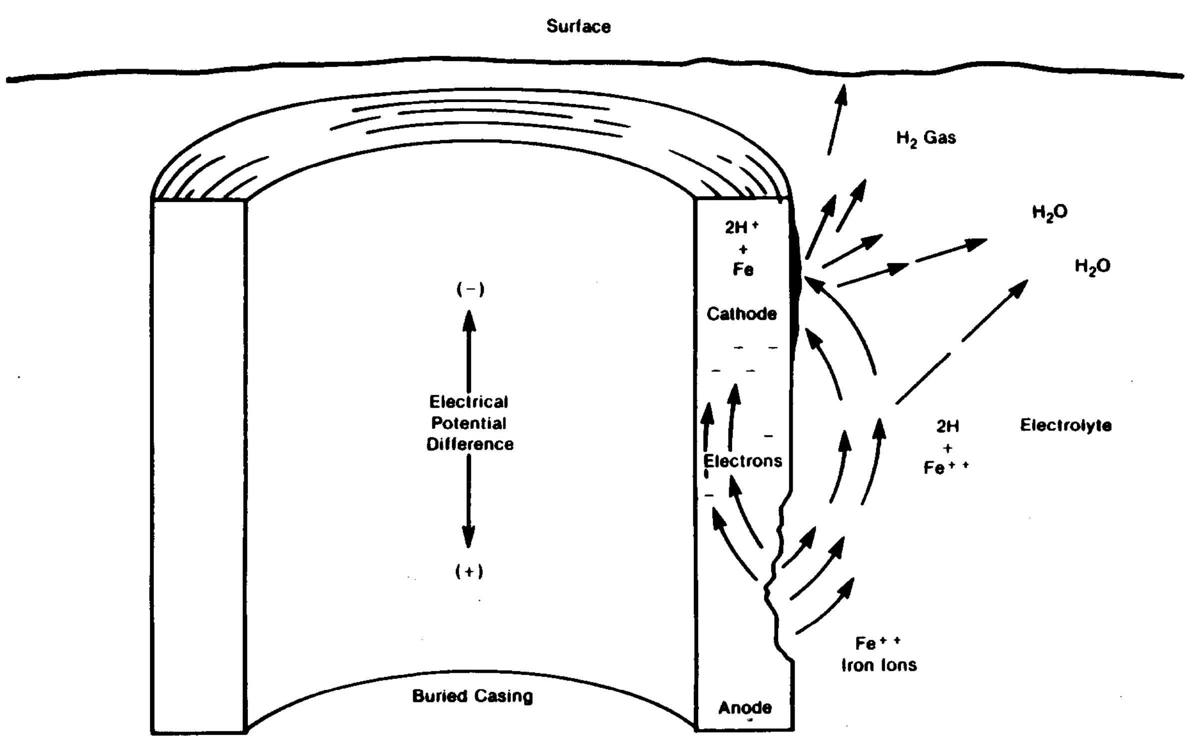


Figure 1-3 - Electrochemical aspects of corrosion

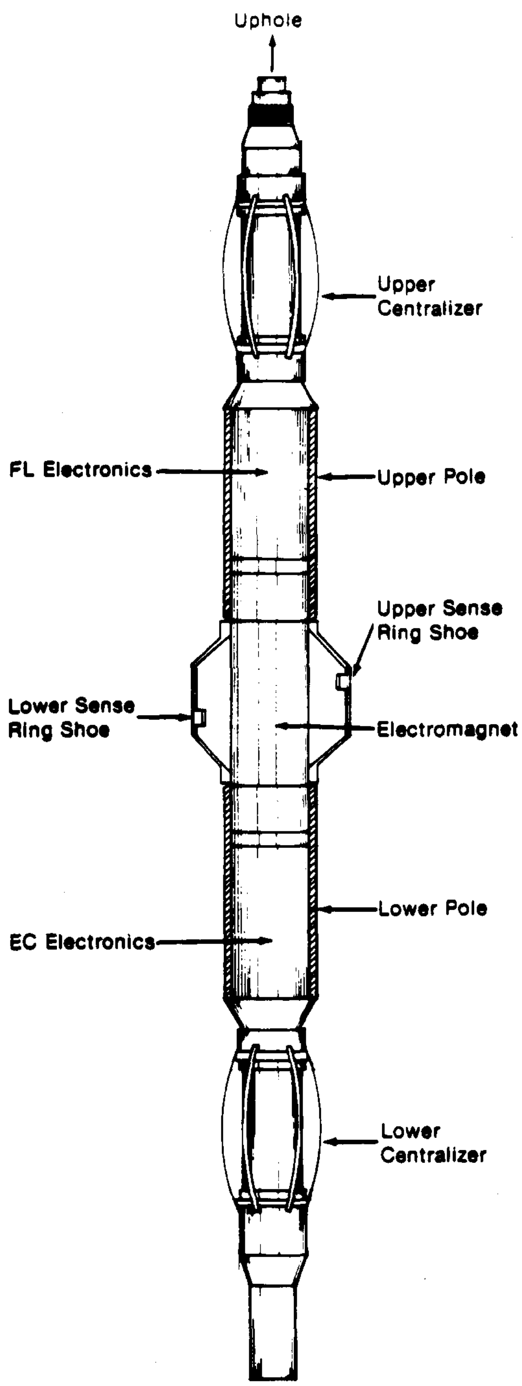


Figure 1-4 - Vertilog instrument perspective

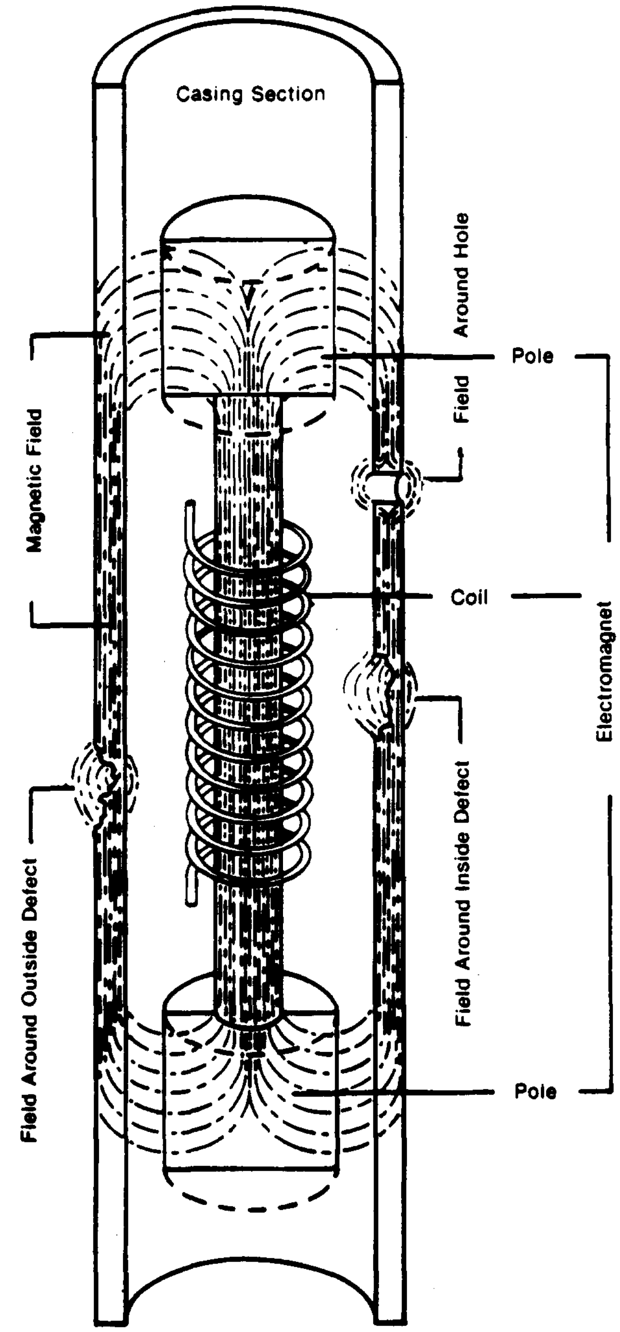
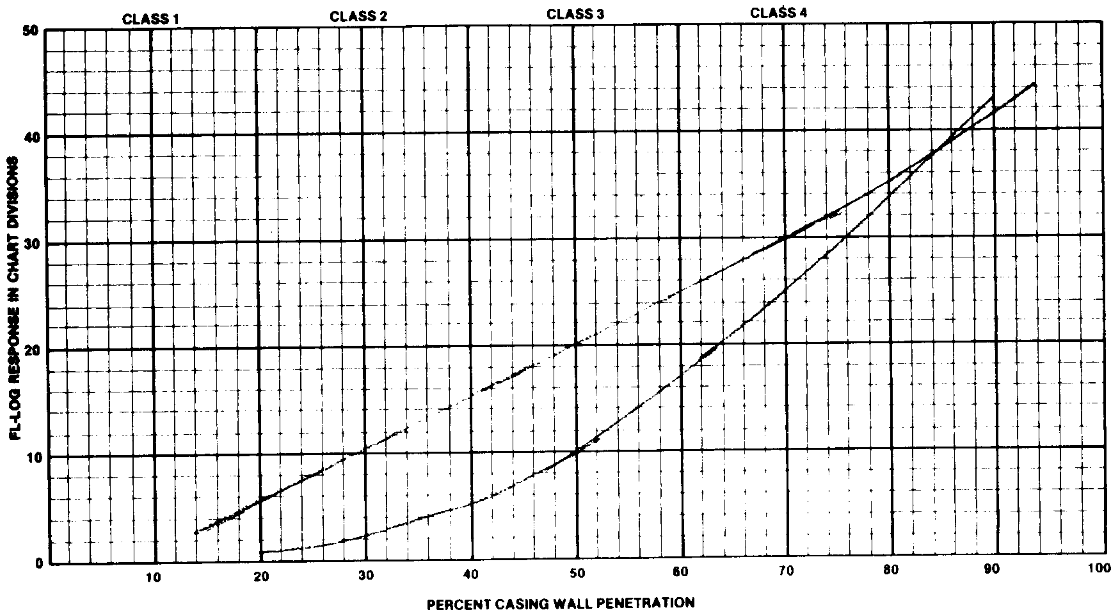
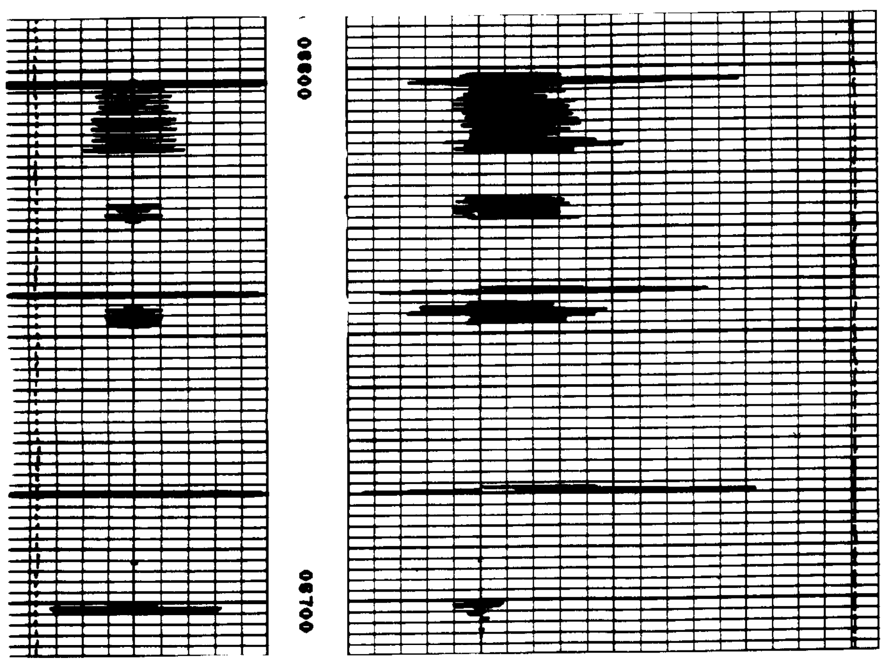


Figure 1-5 - Flux lines in defective casing

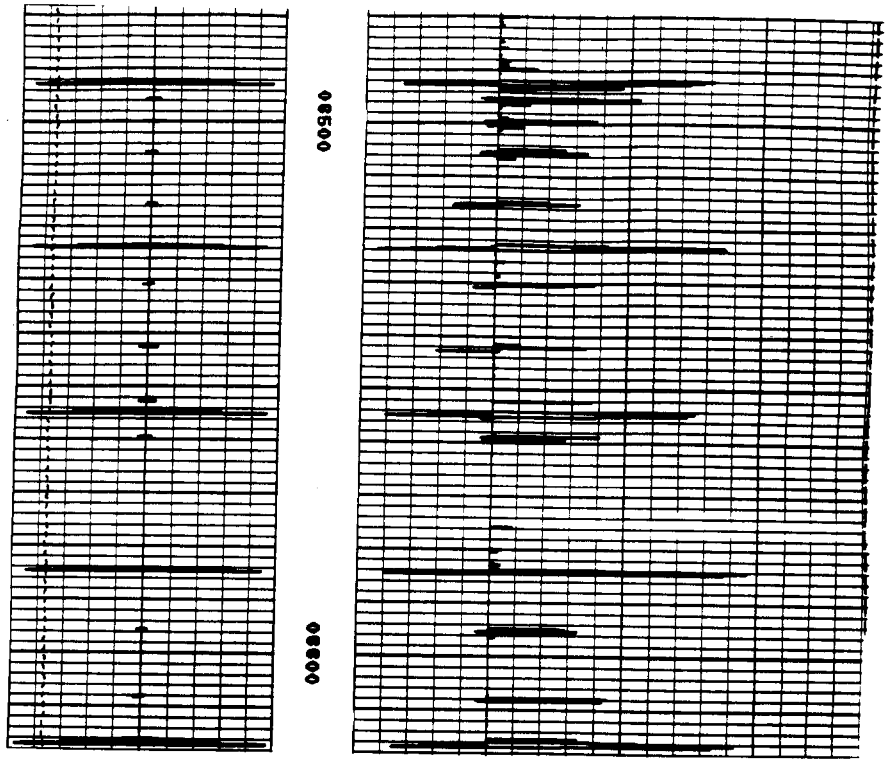


DATE	11-11-82	CASING O.D.	5.5 " 139.7 mm	RECORDING VOLTS/DIV.	.2
INST. SERIES	2905	GRADE	K-55 K-55	LOGGING SPEED	125 fpm 38 mp
ELEC. SERIES	2912 / 2913	WEIGHT	15.5 lb/ft 23.07 kg/m	SURFACE/INTERMEDIATE CASING	None
REFERENCE	340795	M3 CALIBRATION	370 mA 10 div@ .1 V	CHART #	55K6

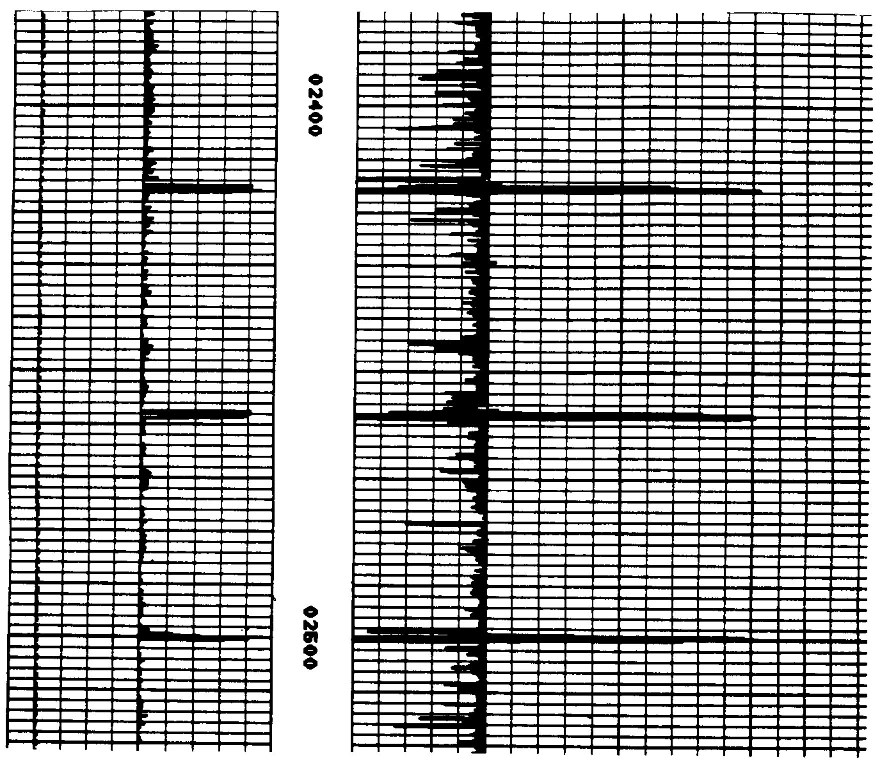
Figure 1-6



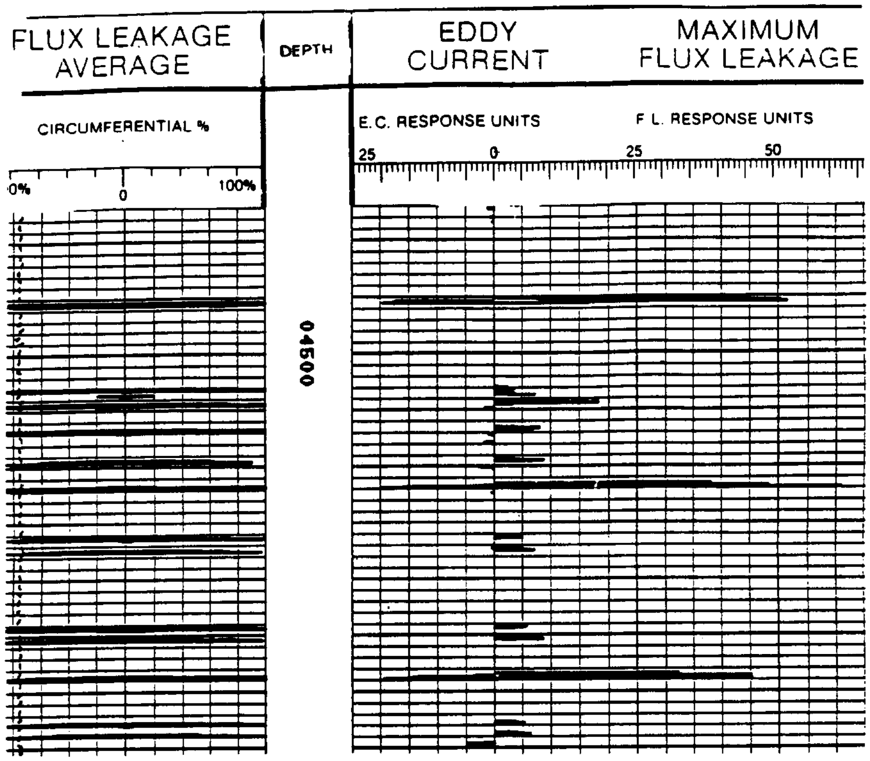
Example 2-1



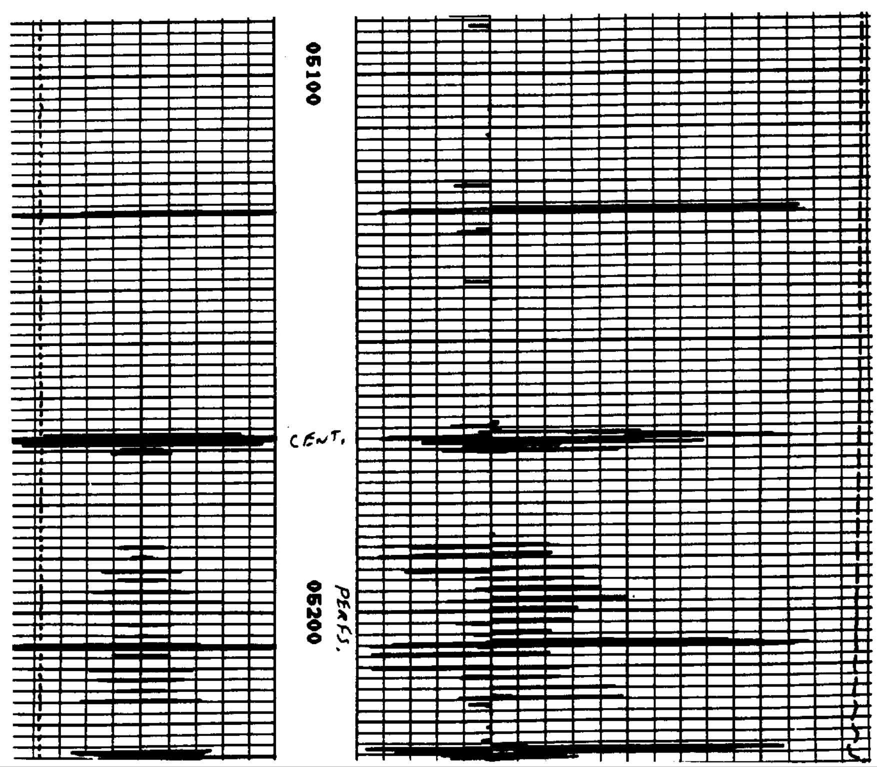
Example 2-2

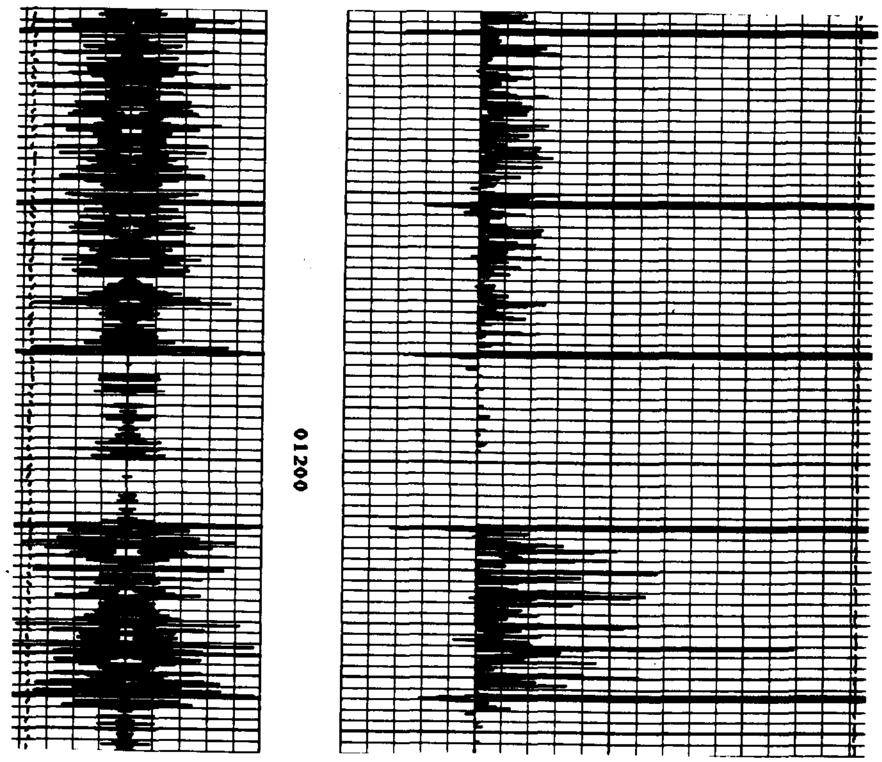


Example 2-3

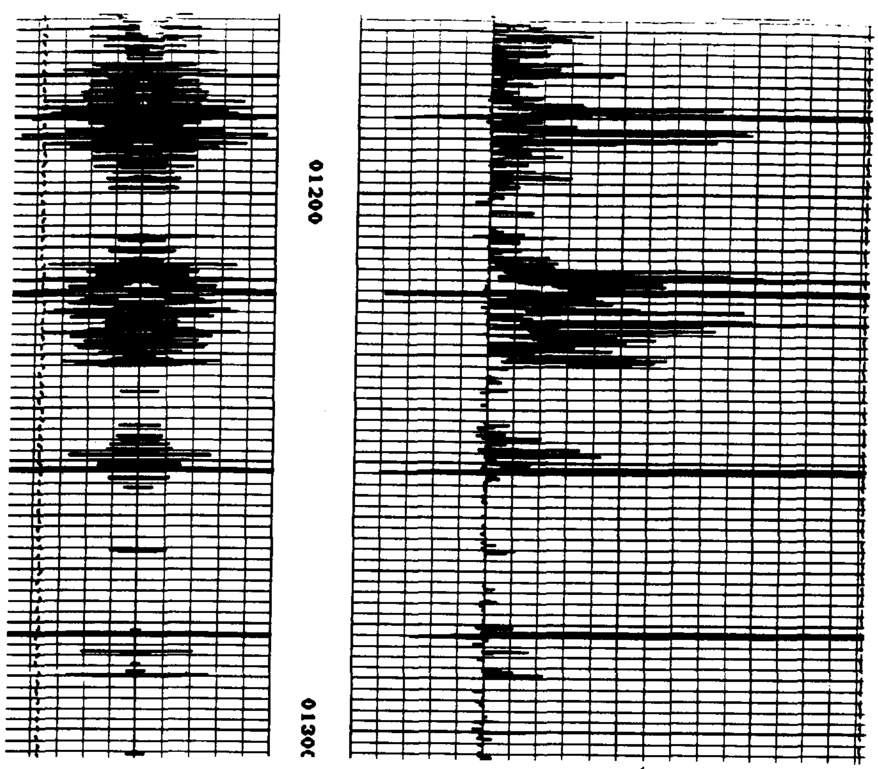

FLUX LEAKAGE AVERAGE
DEPTH
EDDY CURRENT
MAXIMUM FLUX LEAKAGE
CIRCUMFERENTIAL %
E.C. RESPONSE UNITS
F L. RESPONSE UNITS
25
0
25
50
0%
0
100%
04500

Example 2-4

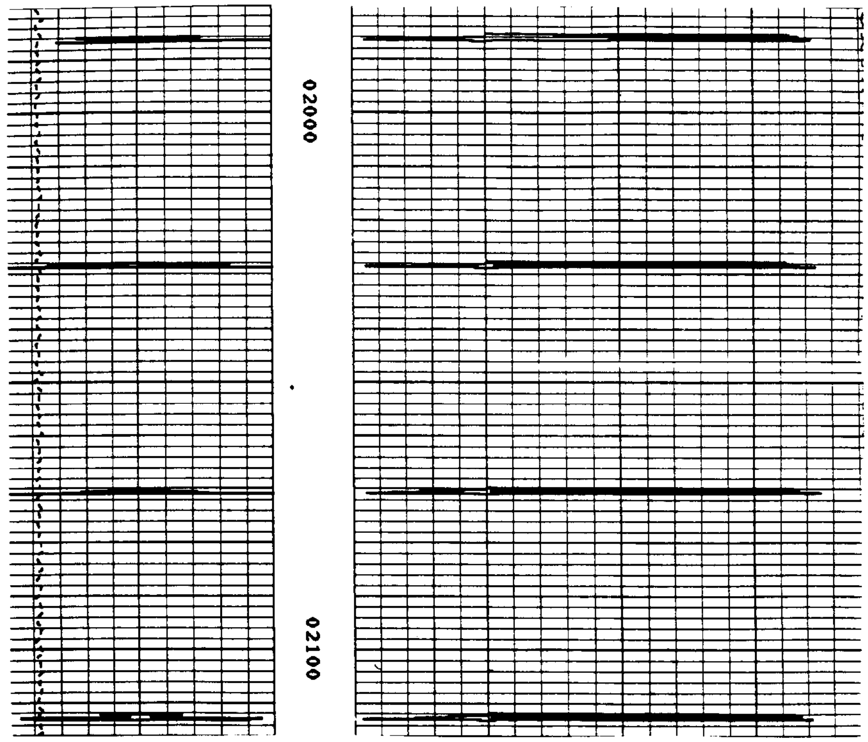

05100
CENT.
05200
PERFS.



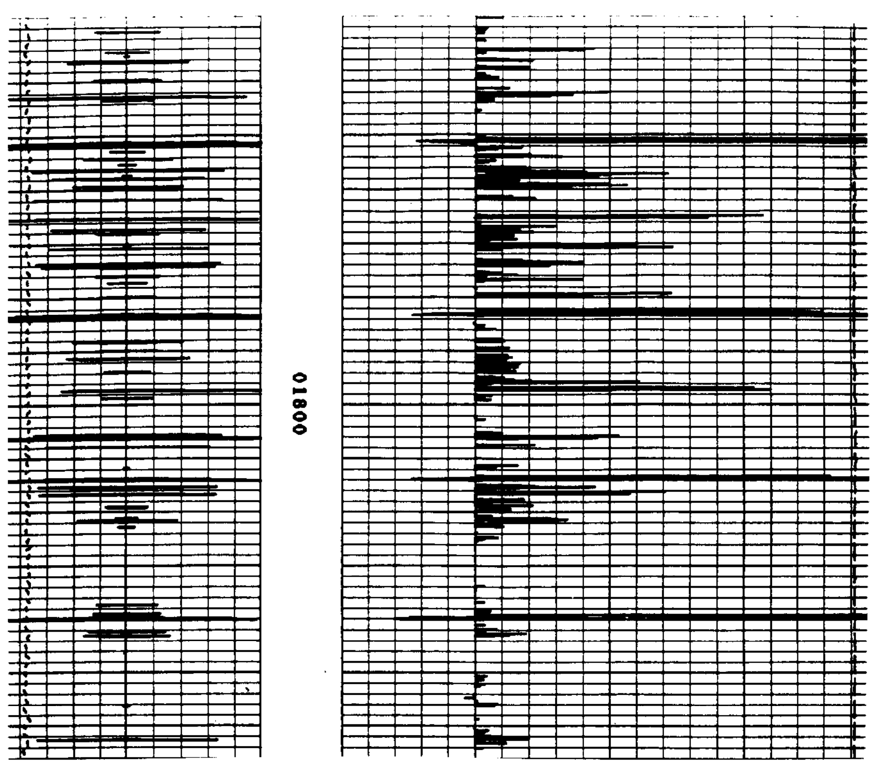
Example 2-6



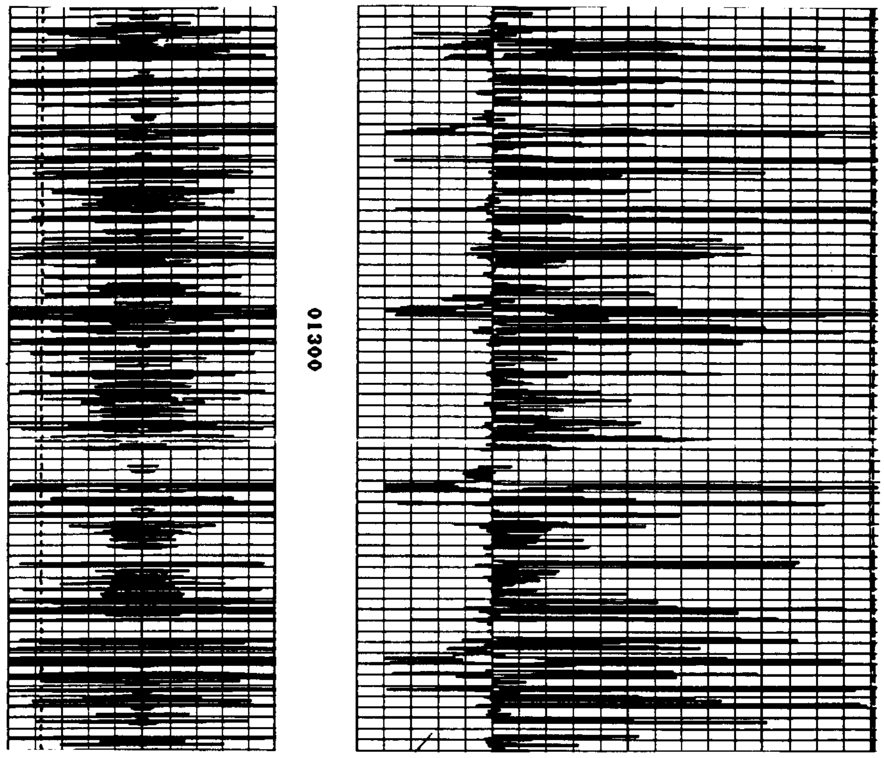
Example 2-7



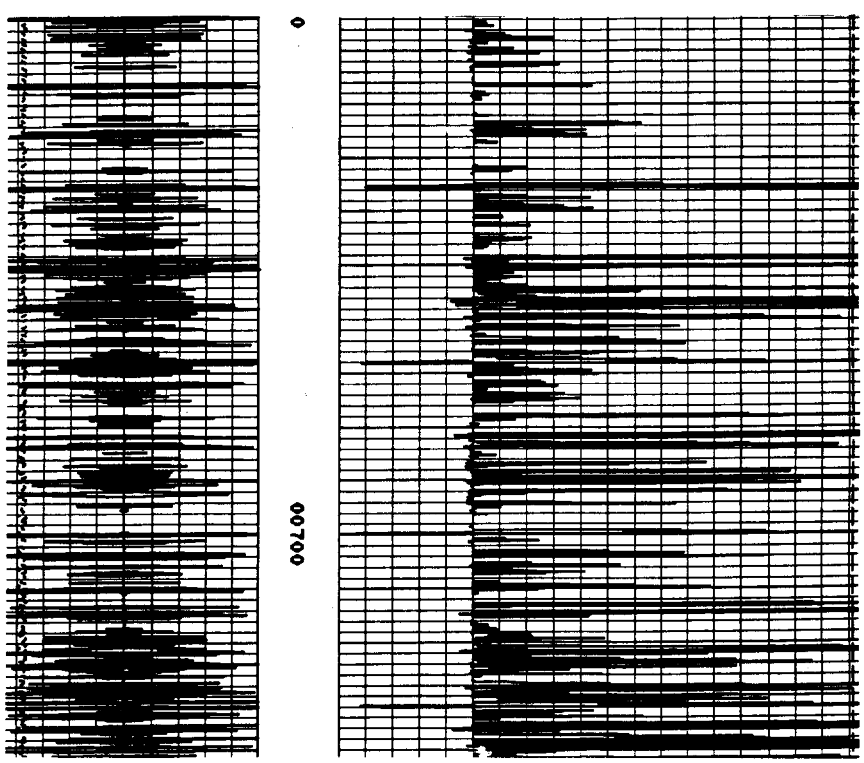
Example 2-8



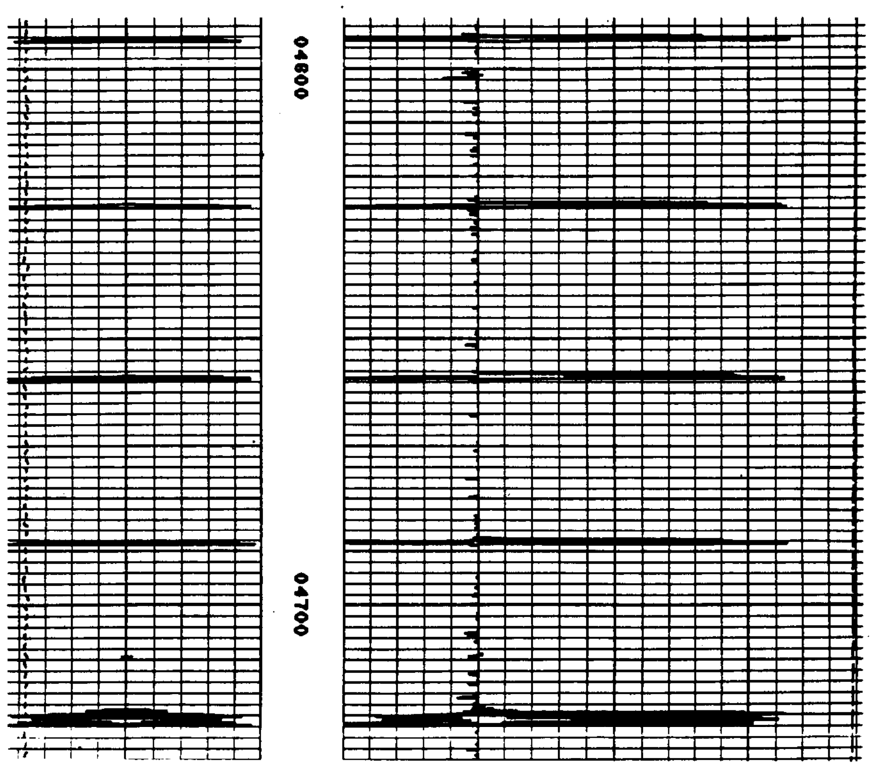
Example 2-9



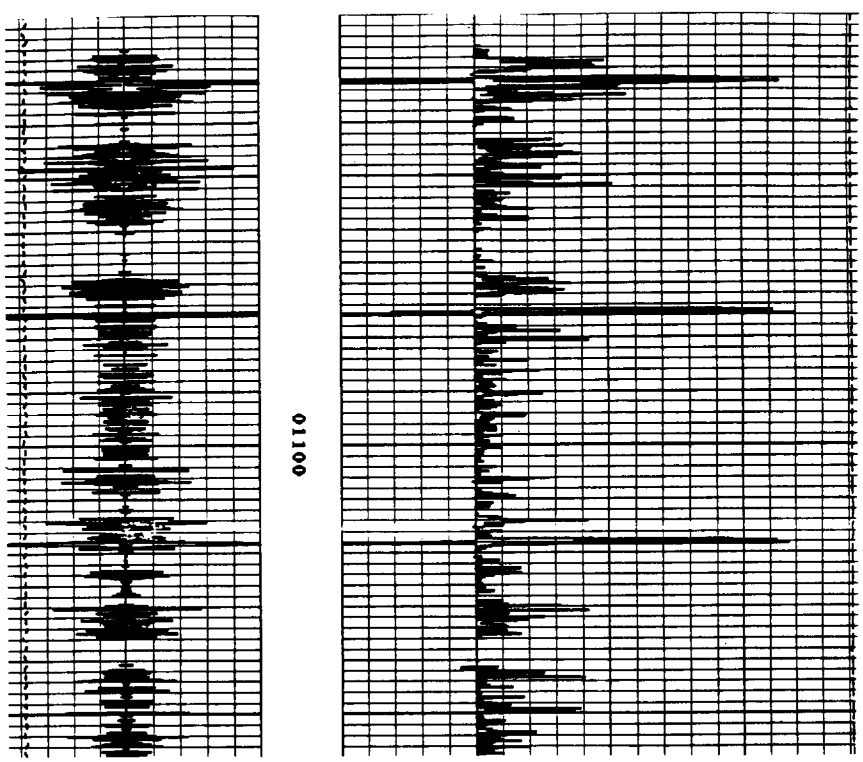
Example 2-10



Example 2-11



Example 12



Example 13