SIMULTANEOUS MECHANICAL CALIPER - ELECTROMAGNETIC CALIPER LOG

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INTRODUCTION

The Pipe Inspection - Pipe Evaluation Logging System or P.I.P.E. Log is a valuable aid in determining casing deterioration due to wear and/or corrosion.

The P.I.P.E. system combines a multifinger mechanical caliper and an electromagnetic casing evaluation/caliper tool that are run simultaneously in the casing. Run in combination, the two systems complement each other in detecting single string casing corrosion.

TOOL SPECIFICATIONS

The downhole tools were designed to be run in casing sizes from 4-1/2 through 9-5/8 inches. Two sizes of mechanical calipers and three sizes of electromagnetic calipers are available in order to log this wide range of casing sizes. The downhole tool string is rated for 15,000 PSI and 350 degrees Fahrenheit. Table 1 shows the various tool sizes. Figure 1 shows the various tool configurations.

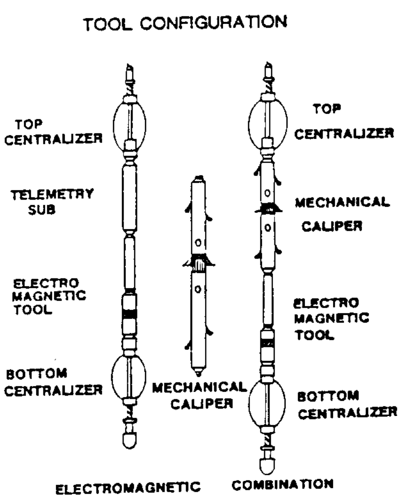


Figure 1

TABLE 1

MECHANICAL CALIPER	
3 1/8" OD	(40 FEELER ARMS)
5 1/4" OD	(70 FEELER ARMS)

ELECTROMAGNETIC MANDRELS	
3 1/2" OD	4 1/2"—5 1/2" CASING
4 1/2" OD	5 1/2"—7" CASING
6 1/4" OD	7"—9 5/8" CASING

PRINCIPLES OF OPERATION

Information from the downhole tools is digitally processed and a digital telemetry system is used to arrange the signals for transmission to the surface. This digital telemetry system allows the use of a single conductor wireline for transmission of multiple downhole signals. This eliminates the problems associated with effects of wireline sizes, types, and lengths on analog signals. The surface panel processes information received from the downhole tools.

The mechanical caliper tool generates two signals that represent minimum Internal Diameter and maximum Internal Diameter of the pipe. There is a single row of independently actuated spring-loaded feeler arms equally spaced around the tool. Angular movement of the feeler arms conforming to the Internal Diameter of the casing produces axial displacement of the minimum diameter plate and maximum diameter plate (Figure 2). The position of these plates determines tool output which corresponds to the pipe Internal Diameter.

The minimum Internal Diameter is computed in inches, from tool center to the nearest casing point. This diameter is determined by the minimum plate's response to feeler arm movement.

The maximum Internal Diameter is computed in inches,from the tool center to the farthest accessible casing point. This diameter is determined by the maximum plate's response to the feeler arm movement.

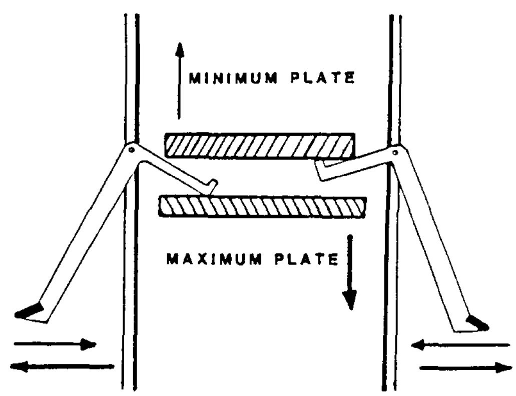


Figure 2

The system can accurately resolve .05 inches of feeler arm movement. The tool is calibrated for diameter rather than radius so no conversion is necessary.

As the feeler arms move away from the tool, i.e. larger size casing, the measuring points of the feeler arms move further apart. The distance between measure points determines the minimum hole size that can be detected with absolute certainty. Table 2 gives the distance between feeler arm measuring points for various casing sizes. It should be noted that this table lists the lightest weight pipe for each API size casing. This represents the widest distance between feeler arms in each size casing. As the casing weight increases, the Inside Diameter decreases, creating a narrower space between feeler arms.

Tool centralization is critical to the correct operation of the mechanical caliper. The tool features two rows of roller type centralizers located above and below the feeler arms (Figure 3). Each row contains three centralizers spaced 120 degrees apart. The two rows of centralizers above the feeler arms are slaved to each other, as are those located below the feeler arms. This provides minimum decentralization without having the centralizers hang in the gap between the casing joints inside a collar. As one row of centralizers moves through a collar, the adjacent row will keep the centralizers out of the joint gap and prevent tool decentralization.

TABLE 2

TOOL SIZE	CASING O.D.	CASING I.D.	CASING WEIGHT	SPACING Between Feeler Arms
3 1/8"	4 1/2"	4.090	9.50	.32
3 1/8"	5"	4.560	11.50	.35
3 1/8"	5 1/2"	5.044	13.00	.39
3 1/8"	6"	5.524	15.00	.43
5 1/4"	6"	5.524	15.00	.24
5 1/4"	6 5/8"	6.135	17.00	.27
5 1/4"	7"	6.538	17.00	.29
5 1/4"	8 5/8"	8.097	24.00	.36
5 1/4"	9 5/8"	9.063	29.30	.40

To calculate the distance for a specific weight casing use the following equation.

$$\text{Distance between Feeler Arms} = \frac{3.14 \times \text{I.D. of Casing}}{\text{Number of Feeler Arms}}$$

MECHANICAL CALIPER

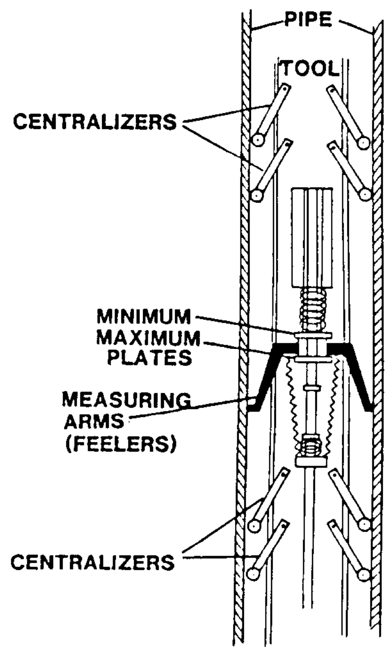


Figure 3

The feeler arms and centralizers can be opened and closed as required while in the well. As a result, a repeat section is always run for log quality purposes. This also allows for multiple runs across intervals of particular interest.

The electromagnetic tool generates two measurements critical to proper interpretation of casing conditions. One measurement looks at the inside surface area of the pipe and is scaled in average Inside Diameter on the P.I.P.E. log. The other measurement is Wall Thickness Index. This is average casing metal volume between the transmitter-receiver spacing (17 inches) of the tool.

The Internal Diameter of the pipe is measured using a high frequency eddy current technique. A 30 KHz alternating current is applied to a transmitter coil in the downhole tool, producing a magnetic field around the coil. Magnetic flux lines produced by this transmitter coil penetrate the casing only a negligible amount due to the high frequency. This "skin effect" causes eddy currents to be generated on the inside surface of the pipe. These eddy currents produce a magnetic flux field of their own which changes the amplitude and phase of the transmitter coil flux field (Figure 4).

Signal attenuation and phase shift are both possible methods of measuring this effect. Since phase shift may not be readily measured downhole at high frequencies, this tool measures attenuation.

A "sensor" or receiver coil is positioned in close proximity to the transmitter coil. As a result, the magnetic field, which is the vector sum of transmitter coil magnetic flux and eddy current magnetic flux, induces a voltage in the sensor coil that is representative of the inside surface area of the casing.

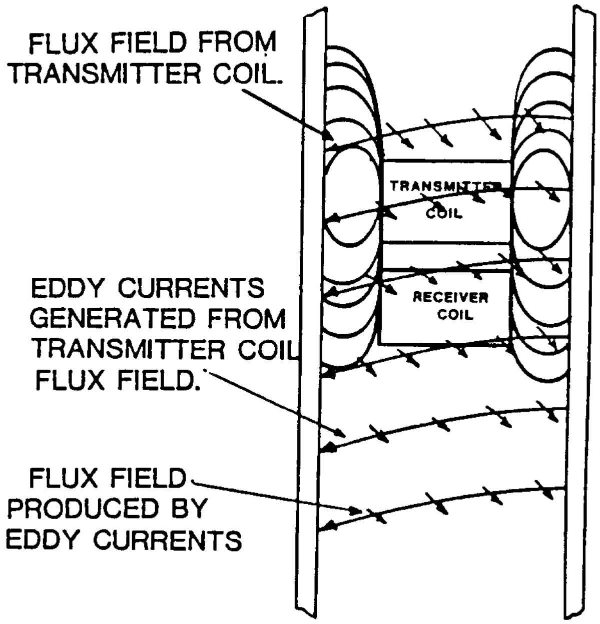


Figure 4

As the Inside Diameter of the pipe changes due to weight change, pipe size change, drift, corrosion, tubing wear, etc., the amplitude of the eddy current will change. The resultant magnetic field produced by eddy currents will change. It is this change, representative of pipe Inside Diameter that causes change in the amplitude of induced voltage in the sensor coil. This induced voltage is then digitized and transmitted to the surface for processing and recording.

The magnetic permeability and electric conductivity of pipe do have an effect on produced eddy current amplitude. Because of these variables, quantitative values cannot be assigned to this measurement. These variables are assumed constant within each joint of pipe.

The Wall Thickness Index Curve is produced with a much lower transmitter coil frequency. A 30 Hz alternating current is applied to the Wall Thickness Index transmitter coil downhole. Low frequency magnetic flux lines produced by the transmitter coil react differently with the casing than do high frequency flux lines. As the field expands around the transmitter coil, the magnetic field penetrates the casing completely. Flux lines that penetrate the casing are affected by the volume of metal, casing magnetic permeability and electric conductivity. These variables cause changes of both the phase and amplitude of the voltage induced into the receiver coil. (Figure 5)

The receiver coil is positioned to insure that only flux lines which completely penetrate the casing are sensed by the receiver. The signal phase induced by the magnetic flux lines is compared to the transmitter signal phase. A phase shift representing condition of the casing averaged over the transmitter-receiver spacing is digitized and transmitted to the surface for processing and recording.

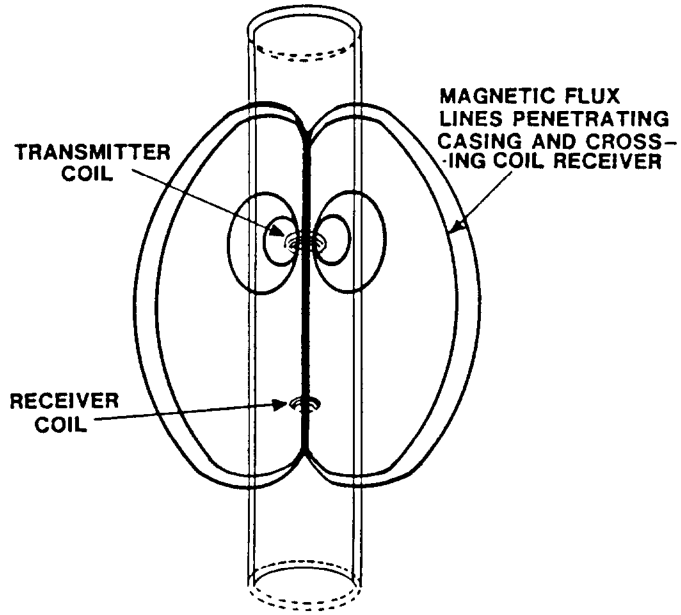


Figure 5

As previously stated, phase shift is an indication of the volume of casing metal (Wall Thickness Index), magnetic permeability, and electric conductivity. The last two variables are undesirable for this measurement and cannot be controlled. They are assumed to be constant for each joint of casing; therefore, each joint must be interpreted on an individual basis.

LOG PRESENTATION

Mechanical caliper curves are presented in Track 1 (Figure 6). The mechanical caliper maximum Internal Diameter curve is labeled MCMX and mechanical caliper minimum Internal Diameter Curve is labeled MCMN. These curves are calibrated and scaled for 0.1 inch of diameter change per chart division with a total deflection of 1.0 inch or ten (10) chart divisions on the log. As Internal Diameter of the pipe increases, the curves will respond from right to left with the Outside Diameter of the pipe represented at the left side of Track 1.

The Electronic Caliper Average Internal Diameter Curve is presented in Track 2 of the log and is labeled ECAV. Prior to logging, this curve is normalized to the specific casing size in the well. Each chart division of deflection represents 0.1 inch of average Internal Diameter change. As the average Internal Diameter of the casing increases, the curve deflects from right to left.

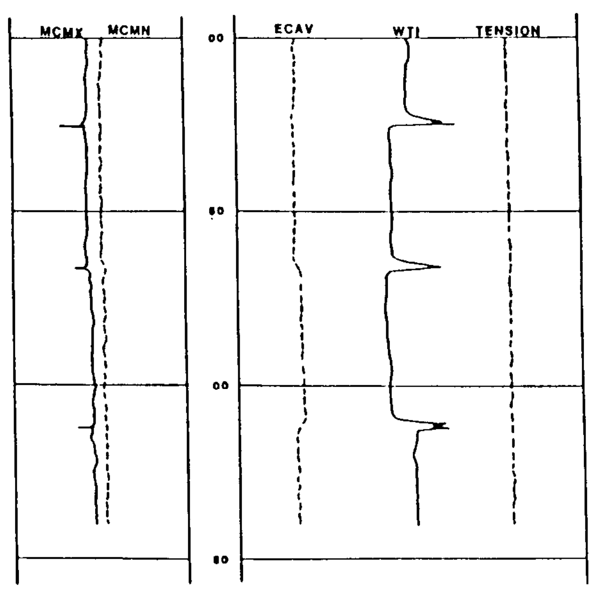


Figure 6

The Wall Thickness Index Curve is presented in Tracks 2 and 3. The curve is labeled WTI and deflects from right to left as average volume of casing metal decreases. Wall Thickness changes, whether inside or outside the pipe, affect the response of the WTI curve.

A tension curve is run at the right side of Track 3. It is a recording of line tension at the sheave wheel, determined by an hydraulic pressure transducer. System precision is adequate to detect and identify a fifty (50) pound weight change.

CALIBRATION

The mechanical caliper curves are calibrated at the job site prior to being run in the borehole. A graduated Step Calibrator (Figure 7) is used to calibrate the mechanical caliper maximum Internal Diameter Curve and the mechanical caliper minimum Internal Diameter Curve.

A slotted collar is positioned around the feeler arms, allowing movement of only one arm. The step calibrator is attached to the tool over the feeler arm. The feeler arm is positioned in the appropriate "step" corresponding to the size of the casing in the borehole. This positions the tip of the arm at a precise distance from the center of the tool. The calibrator is then moved to the appropriate step allowing a 1 inch diameter change of feeler arm tip movement. The feeler arm controls the position of the maximum plate since all other arms are held in the closed position. The surface equipment is adjusted to span ten (10) chart divisions in Track 1 as a response to the one inch change in diameter. For example, in 5-1/2 inch casing, the 5-1/2 inch and 4-1/2 inch position of the step calibrator is used.

The curve is positioned at the left side of Track 1 in the 5-1/2 inch position and at the right side of Track 1 in the 4-1/2 inch position. This calibrates the curve to a sensitivity of 0.1 inch diameter change per chart division. This curve generated by the mechanical position of the step calibrator, feeler arm, and maximum plate is labeled MCMX (Mechanical Caliper Maximum Internal Diameter).

MECHANICAL CALIPER STEP CALIBRATOR

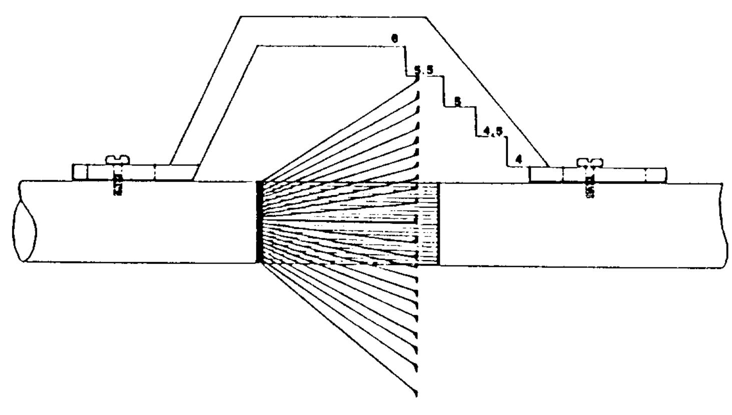


Figure 7

The collar is then removed, allowing all arms to extend to the fully opened position. The procedure discussed above is repeated. However, the minimum plate is positioned with the feeler arm and step calibrator since the feeler arm used is at a less than fully opened position. This curve is scaled to 0.1 inch per chart division across Track 1. The curve is presented with the measurement representing the Outside Diameter of the pipe at the left of Track 1 and the pipe OD minus 1 inch at the right side of Track 1. This curve generated by the step calibrator, feeler arm, and minimum plate is labeled MCMN (Mechanical Caliper Minimum Internal Diameter).

The electronic caliper average Internal Diameter Curve (ECAV) is normalized to the specific size of casing in the borehole. This is accomplished by placing sleeves of specific Inside Diameter (Figure 8) around the electromagnetic caliper transducers. The sleeves selected correspond to the Outside Diameter of the pipe and the pipe OD minus 1 inch. The changes in the tool response representing one inch change in sleeve Inside Diameter, are used to calibrate the recorder. The curve is positioned with the larger measurement at the left side of Track 2 and the smaller measurement at the right side of Track 2.

The response of these curves is checked on the job site at the end of the logging operation to insure there has been no change in the system that would affect log quality.

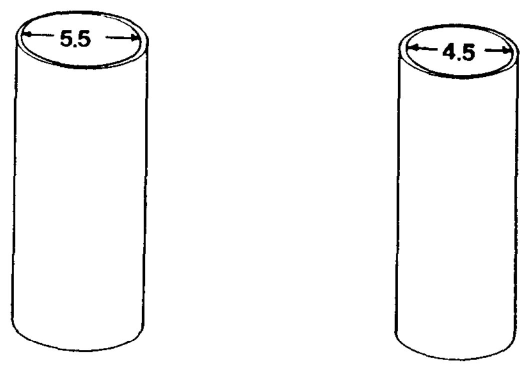
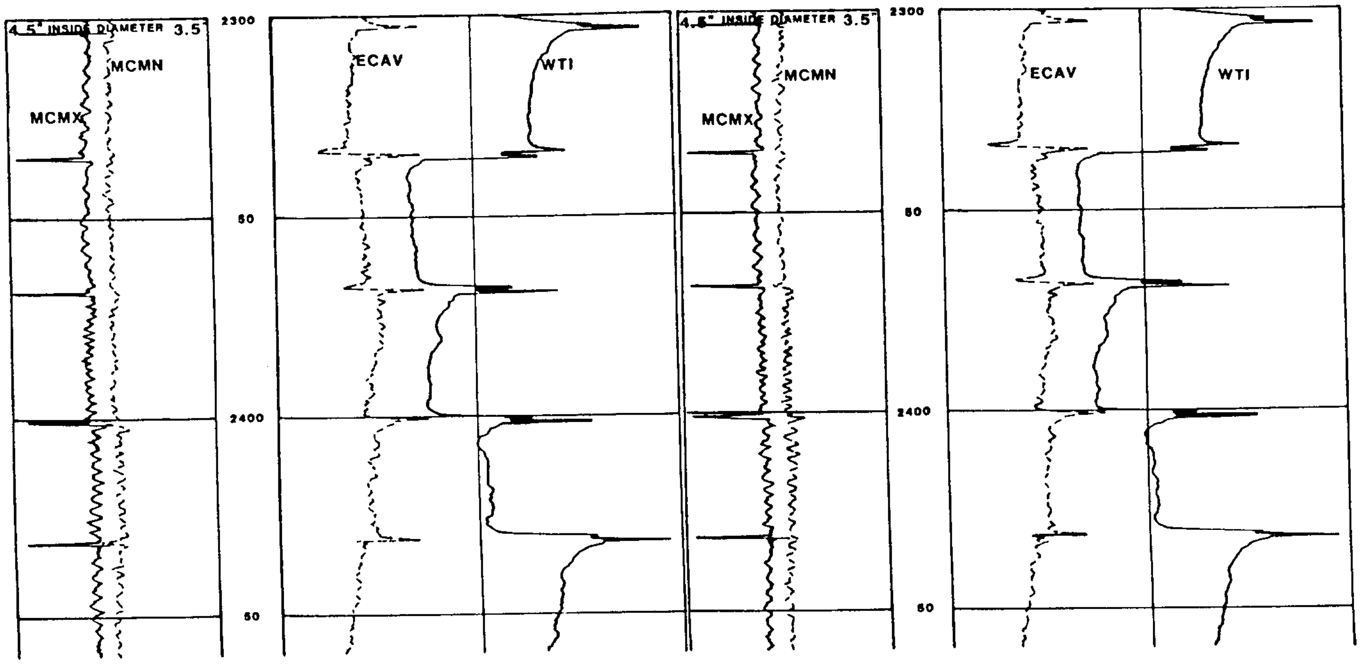


Figure 8

LOG EXAMPLES

Figure 9. Reeves County, Texas producer. Well completed in 1959. 4-1/2" 9.5# casing. Log run to check the condition of the casing.
Conclusion: Log indicates no significant corrosion. The inside of the pipe is rugose as shown by the character of the mechanical caliper and ECAV curves.



ORIGINAL RUN

REPEAT RUN

Figure 9

Figure 10. Stephens county, Oklahoma producer. Well completed November, 1955. 5-1/2" 14# casing. Well produced trace of H_2S. Recompletion work planned which included a frac job through tubing. Log was run to check the condition of the casing prior to setting packer. Conclusion: A short dog leg or partially collapsed casing was located at 2852'. The packer was successfully run past this area. Packer and casing below the packer was tested at 500psi. (Note the roundness of casing as indicated by mechanical caliper curves.)

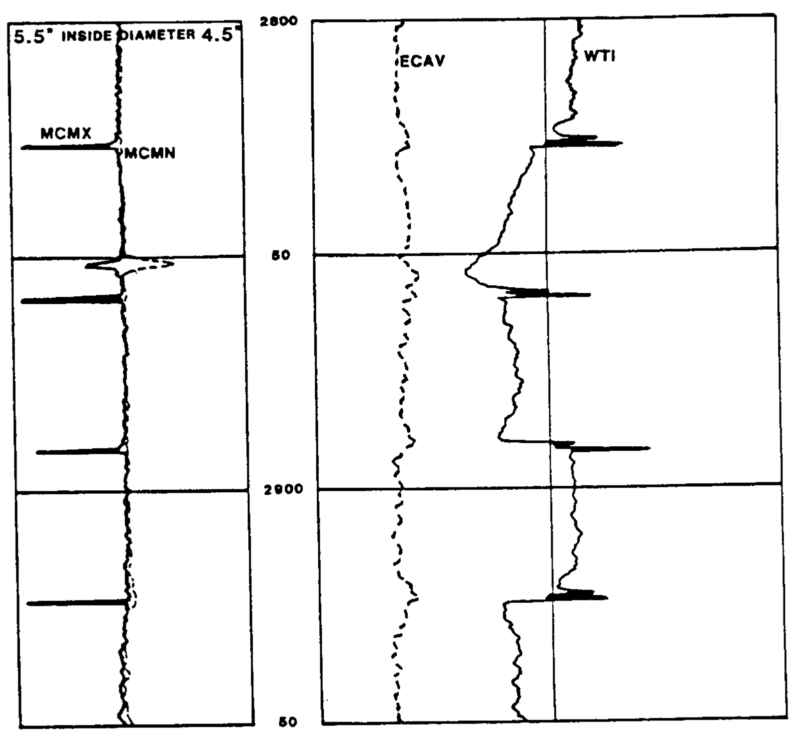
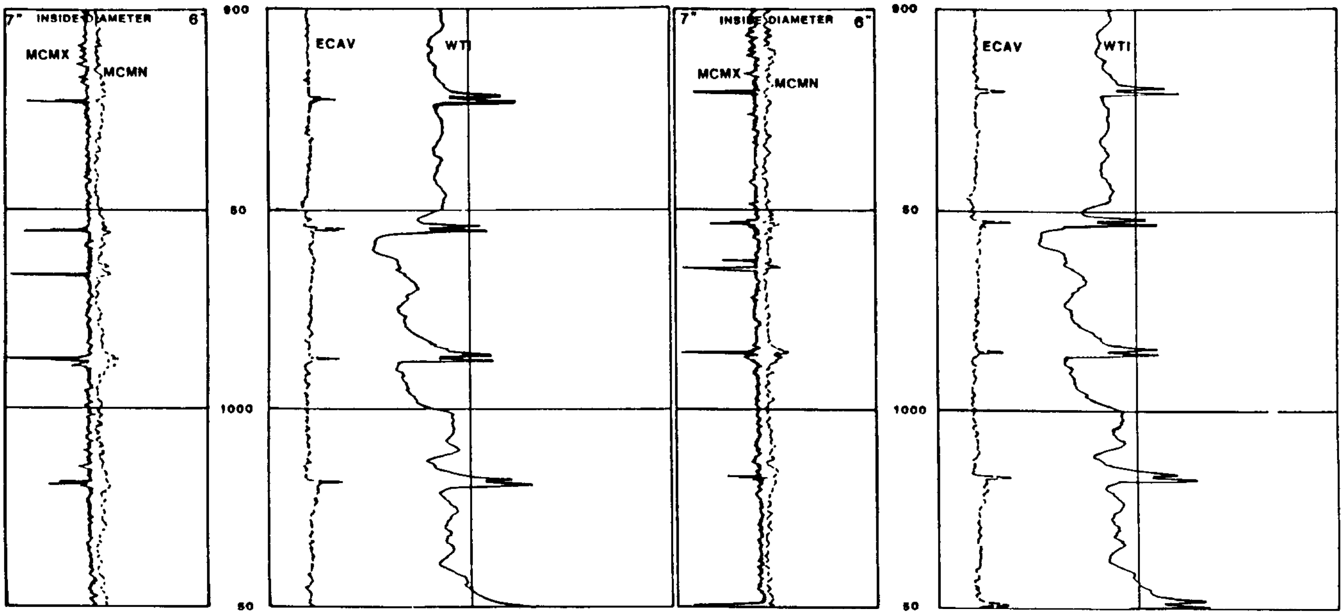


Figure 10



ORIGINAL RUN **Figure 11** REPEAT RUN

Figure 11. Ector County, Texas producer. 7" 23# casing. Log run to check condition of casing prior to possible re-entry. Conclusion: A hole in the casing was located at 964'. The repeat section shows the hole on the original run and an additional hole or severely pitted area at 962'. This additional information was due to the different position of the feeler arms on the casing.

Figure 12. Union County, New Mexico producer. 5-1/2" 14# casing. Well cemented with a total of 900 sacks of class H cement. 240 sacks excess. Log was run to check the condition of the casing. Conclusion: A hole was located at 1224'. The anomaly in the WTI curve indicates substantial metal loss across a small area of casing.

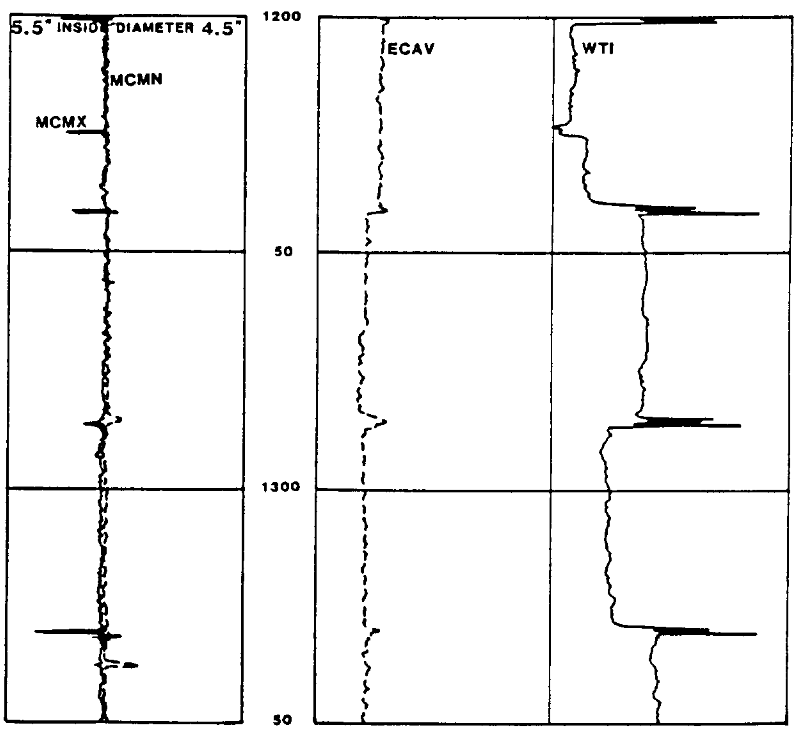


Figure 12

Figure 13. Martin County, Texas producer. New well completion. 4-1/2" 10.5# casing. Casing would not hold pressure,well started taking fluid at 1200 psi surface pressure. Log was run to locate casing leak.
Conclusion: Split collar was located at 7398'.

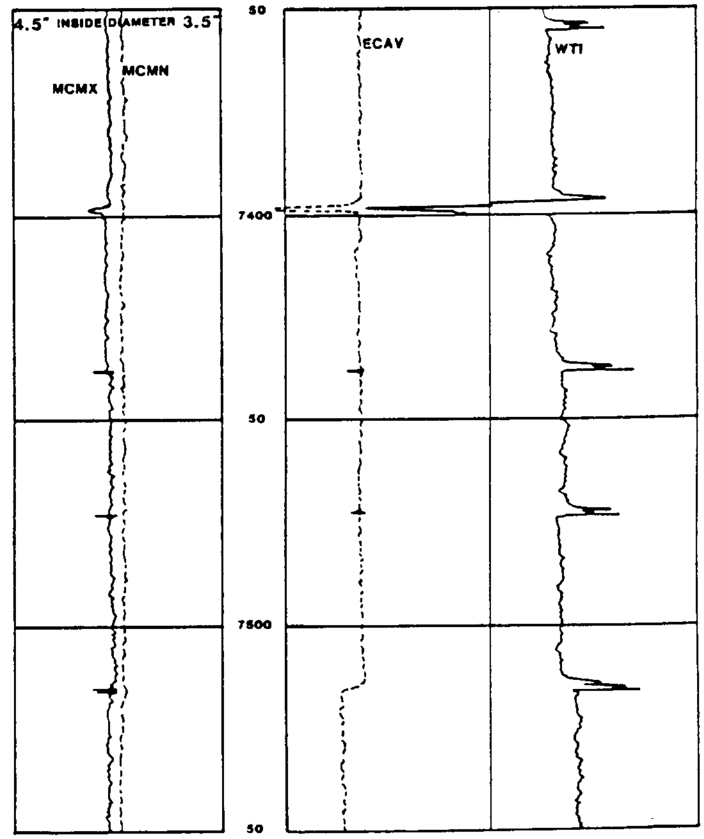


Figure 13

Figure 14. Schleicher County, Texas producer. Well completed April,1962 4-1/2" 9.5# casing. Well shut in due to high water/oil ratio. Tubing pulled and found to be severely corroded from approximately 1745' to 1900'. Log was run to identify bad casing.
Conclusion: Casing severely corroded from 1705' to 1770'. Water entering borehole through the casing killing production zone. (Well produced with tubing anchor.) Customer ran bit and scraper in well,set packer above the perforations, isolating corroded interval from production zone.

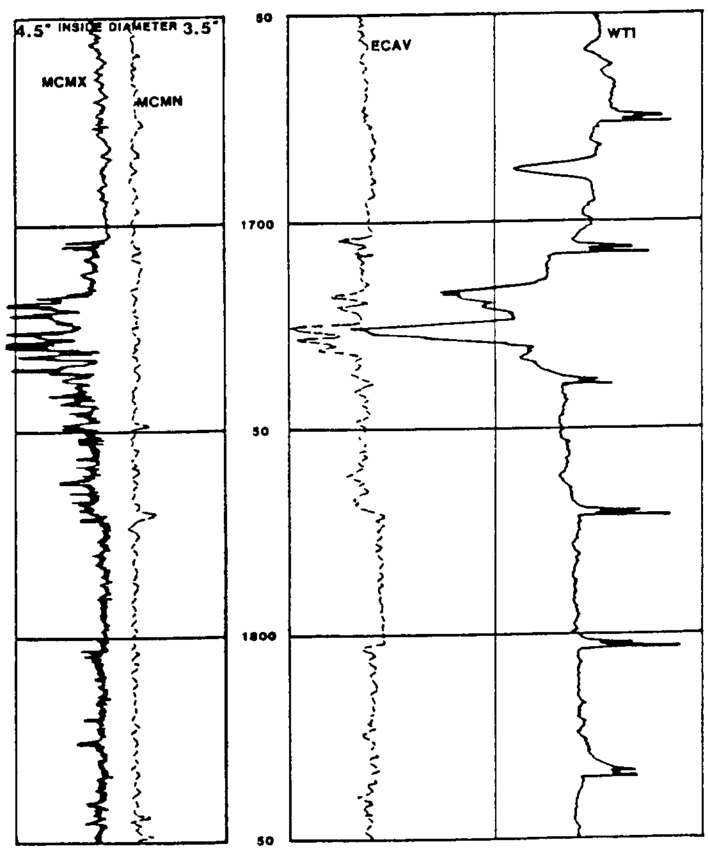


Figure 14

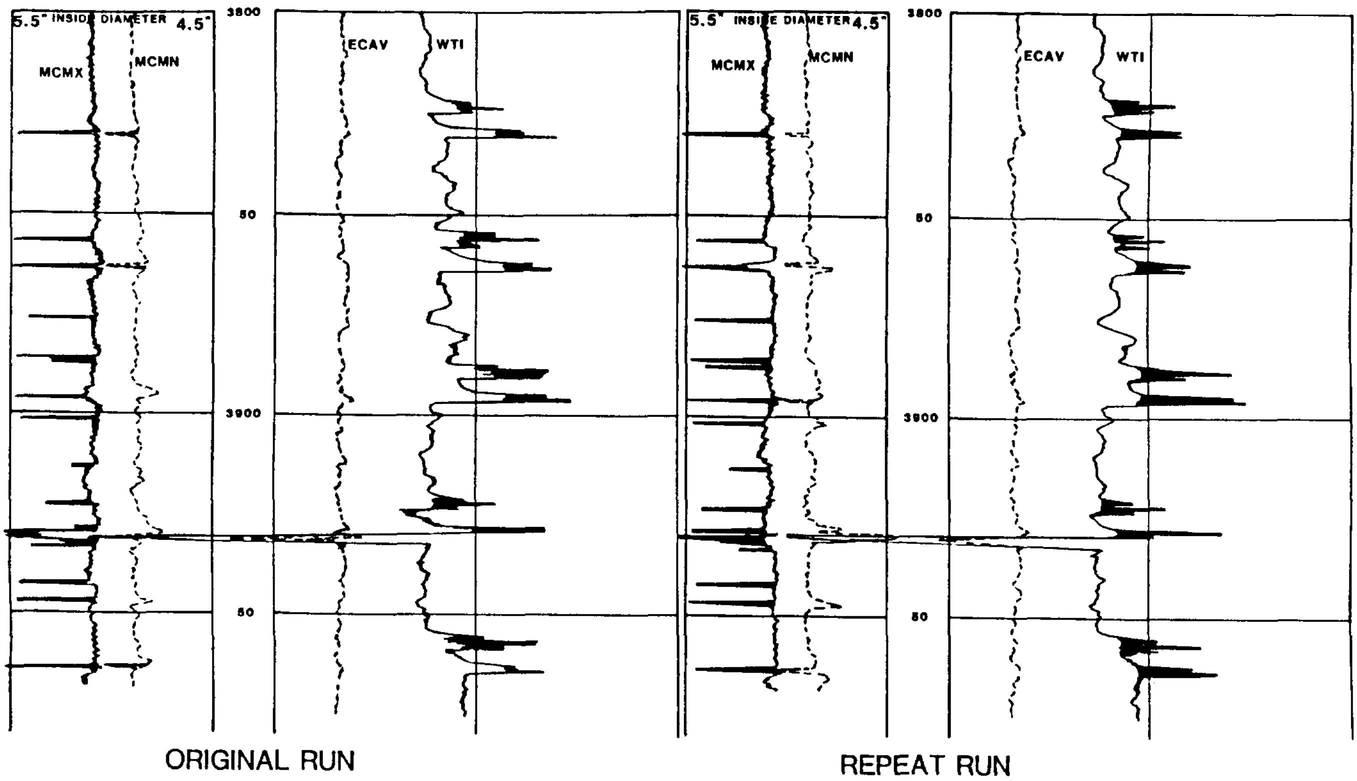


Figure 15

Figure 15. Crane County, Texas producer. Well completed February, 1986. 5-1/2" 15.5# casing. Ten (10) intervals perforated with 4" select fire guns. Log was run to check the condition of casing due to H_2S environment.
Conclusion: No casing damage due to H_2S corrosion. Note the perforations located by MCMX curve. The anomalies seen on the WTI curve above the casing collars are caused by the presence of welded-on centralizers.

ACKNOWLEDGMENTS

The author expresses his appreciation to the management of CRC Wireline, Inc. for their permission to present this paper and to the oil companies for permission to publish the log examples. In addition, the author is indebted to Bob McCourt for preparation of the examples and to Hank Killion, James Wheatley, and Rosemary Norris who assisted with preparation of the text.