IMPROVED ANALYSIS OF ACOUSTIC LIQUID LEVEL DEPTH MEASUREMENTS USING A DUAL CHANNEL ANALOG/DIGITAL STRIP CHART RECORDER

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ABSTRACT

A new acoustic instrument has been developed for measuring the distance to the liquid level in the casing annulus of a well. The instrument features modem analog/digital technology to acquire and record acoustic reflections on a strip chart. The dual channel instrument accents the liquid level on a low frequency channel. Collars are accented and recorded on a second channel using automatic gain control to ease the counting of the number of tubing collars from the surface to the liquid level. The collar amplifier/filter response can be selected to accent sharp upper collar reflections or to accent lower collars in a deep, low-pressure well.

Another feature of this instrument is the use of an automatic mode for selection of gain on both channels. The instrument automatically acquires and processes acoustic noise data before generation of the acoustic pulse and preselects the proper gain. In the automatic mode, the operator must turn on the amplifier power and the chart drive. These are the only instrument functions required for most tests. The sensitivity controls are not adjusted by the operator unless special recording is desired.

Analysis forms are printed on the strip for entry of liquid level depth, casing pressure and casing pressure buildup rate. Software is supplied for use with a separate computer to determine bottomhole pressures even in wells which have gaseous liquid columns. The operator inputs the proper well parameters into the software and the program calculates the producing bottomhole pressure, the formation producing rate efficiency and the maximum production capability of the well. The results of the software analysis are manually entered in an additional form printed on the strip chart which serves as a permanent record and analysis of the acoustic test.

A microprocessor, clock and timing circuit records a time and date stamp on each record to ease bookkeeping. The time between tests can be determined from these time stamps. If the casing pressure is manually measured during each test, the casing pressure buildup rate can be determined which aids in the calculation of casing annulus gas flow rate and producing bottomhole pressures. Additionally, one second time marks are placed on the strip chart which aid in chart analysis and the calculation of the gas specific gravity.

This new system improves the ability of the operator to determine an accurate liquid level depth and analyze the liquid level depth with casing pressure data to obtain the bottomhole pressure and perform a better well performance analysis.

INTRODUCTION

The most commonly performed diagnostic test on a well produced by artificial lift is an acoustic liquid level depth measurement. The operator desires to know where liquid is present in the wellbore. In most cases, the acoustic liquid level depth measurement can be obtained with a minimum of effort and time. The acoustic liquid level depth measurement can be analyzed in conjunction with the casing pressure and casing pressure buildup rate to determine the producing bottomhole pressure (PBHP) when the well is at producing conditions and the static bottomhole pressure (SBHP) when the well is shut-in.[1,2] With these measurements, the inflow performance relationship can be determined. The PBHP and SBHP can be used in conjunction with the well test to determine the maximum production capability of the well.[3]

Acoustic liquid level instruments are also used for many special applications. The shut-in liquid level in abandoned wells is often required for government regulations and environmental concerns. The depth of the operating valve in gas lift wells should be known. The productivity and reservoir pressure is desired in high-volume water wells. Bottomhole pressures can be computed using acoustic techniques in onshore and offshore wells where extremely high surface pressures and downhole pressures are encountered.[4] These bottomhole pressures can be obtained inexpensively and safely with acoustic techniques, but if downhole pressure gauges are utilized, the tests are expensive and can result in downhole problems if the gauges are lost in the well.

Fully computerized acoustic liquid level instruments are available, some of which can be used to perform a complete well analysis including dynamometer measurements, motor power/current measurements and acoustic pressure transient data acquisition and analysis.[5] However, if the main objective is the determination of the liquid level, the need continues to exist for a compact acoustic strip chart instrument which is rugged, simple to operate and can be used to determine a well's performance and productivity with a minimum of time and effort.

PRINCIPLE OF OPERATION OF EXISTING SYSTEMS

Acoustic liquid level instruments were developed in the 1930's.[6] An acoustic wellhead attachment is connected to an opening into the casing annulus at the surface of a well. See figure 1. The acoustic wellhead attachment consists of an acoustic pulse generator and a microphone. Throughout the years, acoustic pulse generators have included a dynamite cap, 45 caliber blank, 10gauge black powder blank, a compression gas pulse and a rarefaction gas pulse. The explosive dynamite caps and blanks are a safety hazard and have resulted in damage to wells and the environment. While the explosive devices should not create a problem if the casing annulus contains only hydrocarbon gas or $C0_2$, major explosions have occurred which resulted in damage to the well and environment when oxygen was allowed to enter the casing annulus during work-over or during special conditions when a vacuum exists in the casing annulus.

The versatility, economy and convenience of gas guns has resulted in widespread use of this type of acoustic pulse generator. The expansion of gas from a volume chamber into the well generates the acoustic pulse. In most cases, compressed $C0_2$ or N_2 gas is loaded into the wellhead attachment volume chamber. The volume chamber is charged to a pressure greater than the well pressure. A gas valve is rapidly opened either manually or electrically resulting in a pressure pulse being generated in the casing annulus gas. This acoustic pulse travels through the gas in the casing annulus and is reflected by changes in cross-sectional area such as tubing collars, tubing anchors, perforations and the liquid level. The initial gas pulse can also be generated by releasing gas from the well into a volume chamber if the well pressure and volume chamber size are sufficient to cause satisfactory acoustic signals to be reflected from downhole anomalies. Most guns are designed for a particular pressure range, and a gun will perform best when utilized for its intended purpose.[7]

A microphone within the wellhead attachment converts the reflected acoustic signal into an electrical signal. The microphone must operate over a wide pressure range from vacuum to the maximum pressure that exists in the wells to be tested. Generally, the microphone sensitivity decreases as the microphone pressure range increases. The microphone should be vibration canceling as often-times the wellhead is vibrating during acoustic liquid level depth measurements on both off-shore and on-shore wells.

RECORDING AND INTERPRETATION OF SIGNALS

The amplifier/recorder filters and amplifies the electrical signal from the microphone and records the enhanced signals on a strip chart. The frequency content of the reflected acoustic signals varies depending on the initial pulse, the distance traveled, the type of cross-sectional area change and the pressure. The acoustic collar responses near the top of the well are high frequency energy. The acoustic collar responses from deep collars in a low-pressure well are medium frequency. The liquid level response in a deep low-pressure well is low frequency. Analog acoustic instruments are available with either two channel recording or single channel recording. The dual channel instrument accents the collars on one channel and the liquid level on the second channel. The single channel instruments are switchable from accenting the collars to accenting the liquid level. The single channel instruments are initially operated in the collar position so that collars are recorded. When the collar signal fades, the instruments may be manually or automatically switched to accent the liquid level reflection.

DEPTH CALCULATION

In most cases, once a strip chart record has been obtained, the operator must count the number of tubing collar reflections from the surface to the liquid level. The number of joints is multiplied by the average joint length to obtain the liquid level depth. Other techniques are available for determining the liquid level depth. When other downhole anomalies are identified on the chart such as gas lift mandrels, liners, upper perforations or a tubing anchor, the depth to these anomalies can be used to determine the depth to the deeper liquid level by using chart distance (or elapsed time) ratio calculations. If the lengths of tubing joints vary considerably in a well, some operators have placed an over-sized tubing collar downhole to serve as a depth reference. If a gas gravity or gas analysis is known, the gas velocity can be calculated very accurately.[8,9] The acoustic roundtrip travel time from the initial pulse to the liquid level reflection is obtained directly from the strip chart which has elapsed time markings. The roundtrip travel time is divided by two in order to determine the one-way travel time. The one-way travel time is multiplied by the acoustic velocity to determine the liquid level depth.

Still another technique for determining the-acoustic velocity is to vent gas from the surface of the well into a sampling tube and measure the velocity of the gas in the tube. This technique is better suited to wells which are normally venting gas at the surface into the flowline so that a representative sample of gas from the flowing stream may be obtained. The velocity thus determined will approximate the velocity throughout the casing annulus. However, in a shut-in well, light gases will migrate upward and the measured acoustic velocity of the surface sample will be greater than the velocity of a heavier downhole gas. This technique is also suited to applications where the average joint length is not known or the tubing joint lengths vary considerably.[10]

The most common application of an acoustic liquid level instrument is to measure the distance to the liquid level in the casing annulus of a well. This paper mainly discusses this technique. However, an acoustic liquid level instrument can be used to measure the distance to the liquid level inside the tubing. It can also be used during work-overs or in drilling to determine the distance to the mud level. The acoustic instruments can be used to measure the distance to any change in cross-sectional area inside a pipe or in the annulus of a casing/tubing combination.

DUAL CHANNEL MICROPROCESSOR CONTROLLED AMPLIFIER/RECORDER

The dual channel recorder permits better interpretation of reflections from downhole anomalies since two different filters are used to improve the signal. The response from the liquid level (or reduction in annulus area) is opposite to the response from an enlargement such as a hole in the casing. Processing and simultaneously recording the reflected signal with two different amplifiers having different frequency responses improves the ability of the operator to distinguish downhole obstructions from enlargements. This aids in the interpretation of the strip chart. Formerly, dual-channel instruments were heavier, bulkier, more expensive and required larger batteries than single channel devices. Use of modem electronics and a thermal printhead allows dual channel response from a compact and lightweight system.

The newly developed dual channel microprocessor controlled instrument accents and records collars on the upper channel and the liquid level response on the lower channel. The collar channel can be selected to record sharp upper collars or deep collars. Selecting the proper collar filter will result in more accurate determination of the number of tubing collar reflections from the surface to the liquid level. The liquid level channel accents signals from the liquid level, tubing anchor, gas lift mandrels, casing perforations, and other major anomalies.

A microprocessor is used with an analog to digital converter, memory chip, amplifiers, clock, timing circuit and other electronic components to improve the performance and utility of the instrument.

When an acoustic pulse is generated in the well, the reflected signals from collars at the top of the well are large but rapidly attenuate. The microprocessor is programmed to evaluate the collar signal level and increase or decrease gain in the collar amplifier as desired. The automatic gain control causes the collars and other signals to be recorded at a predetermined width of approximately 0.5 inch (12 mm). This automatic gain control simplifies the manual counting of the collars as the collar signal level would rapidly attenuate or fade unless increased gain is applied to the signal. Automatic gain control is not used with the liquid level amplifier.

In order to adapt to the specific conditions of a given well, before initiating the acoustic pulse, the maximum collar amplifier gain should be preset to a level which causes the background noise to be recorded at a minimal level of 0.05 inches (1 mm) or about 1 / 10 of the collar recording level. Then, the automatic gain control will cause the large collar reflections to be recorded at a distinguishable level of 0..5 inch (12mm) with gain being automatically applied as the signal attenuates. Since the background noise level was preset to be recorded at a minimal level of 0.05 inch (1 mm) on the strip chart, when the collar signal fades and becomes less than the background noise, the background noise will be recorded at a minimal level and will not be misinterpreted for collars, perforations, liquid level or other anomalies.

The collar and liquid level amplifier gains should be preset so that background noise is recorded at a minimal level before the pulse is generated. A collar gain control knob on the panel controls the maximum amplifier gain in the collar channel unless it is in the automatic mode. The liquid level gain control knob controls the amplifier gain in the liquid level channel unless the control is in the automatic mode. When the gain controls are set to the automatic position, the microprocessor and related electronics measure the background noise level before the pulse is generated and preset the collar and liquid level amplifier gains so that the noise level will be recorded at a minimum level of approximately 0.05 inch (1 mm) on both channels. Collars, gas lift mandrels, perforations, liquid level reflections and other signals greater than noise will be recorded while the noise will be minimized.

The microprocessor is used in conjunction with a timer. Since the instruments are used throughout the world, the universal coordinated time and date are printed on the strip chart. The timing capabilities of the microprocessor, clock and timing circuit also allow one second markers to be placed on the strip chart. When the pulse is initiated, zero time is recorded on the strip chart. Each second thereafter, a marker is placed on the strip chart. This allows the operator to determine roundtrip travel time precisely. Roundtrip travel time can be used in conjunction with distance, pressure and temperature to calculate acoustic velocity and determine the specific gravity of the gas from which downhole pressures can be calculated more accurately. [3,8,9] Also, knowledge of the gas specific gravity is useful in CO_2 content in the produced gas.

In addition to recording both collar and liquid level signals simultaneously, the digital printhead generates a header, an analysis form, and prints the values of background noise, battery voltage and special instructions on the strip chart.

OPERATION OF THE DUAL CHANNEL AMPLIFIER/RECORDER

Operation of the instrument is simple. First, the acoustic wellhead should be attached to the casing annulus valve, and the cable connected between the microphone and the instrument. The valve between the casing annulus and flow line should be closed to prevent the casing annulus gas from venting into the flow line which could be a source of noise. The instrument panel is shown in figure 2. A 2.5 amp-hour 12v rechargeable lead-cell battery is contained at the back. The chart drive is at center left. The chart drive utilizes a thermal printhead and constant speed chart drive motor. The master power switch and LED battery indicator, battery charger connector, test output, and remote fire gun connection and switch are located at center right. The instrument can be used with a 12-volt solenoid operated gas gun if desired. The lower panel allows the operator to accent upper or lower collars, and set the gain controls of both amplifiers. The chart drive power switch is also on the lower panel along with the microphone input connector. All of the instrument is contained in a waterproof plastic housing having inside dimensions of 5 by 10 by 10 inches (12x25x25cm.)

When the amplifier is turned on, a red LED light indicates that the battery is powering the electronics. A header is recorded. Refer to figure 3. Next, a system test is performed which also displays the battery voltage. If the battery voltage is low, a message to charge the battery is displayed. Then, the message is printed to turn on the chart drive when ready to test the well. The chart drive stops until the chart drive switch is turned on. The operator then selects the type of collar response desired. Sharp upper collars can be selected for special applications such as shallow wells, irregular tubing length, dual tubing strings and other special applications. The deep collar position is selected for most deep wells especially at low pressure. The operator normally sets both gain controls to the automatic position and only changes the settings from the automatic positions for special cases in which satisfactory recordings are not obtained in the automatic mode. When the chart drive switch is activated, figure 4 is recorded on the strip chart. A form for manual recording of the well designation, casing pressure, casing pressure buildup rate and, production rate is printed. The universal coordinated time stamp is beneficial for tracking the sequence of shots and the exact time interval between shots. Next, the acoustic analysis form is printed on the strip chart. The instrument then records the background noise on both channels for one second and analyzes the noise in terms of peak to peak amplitude. If the well is excessively noisy, a large charge in the gas gun volume chamber is recommended. Then, a message to generate the pulse is printed on the strip chart. As shown in Figure 5, when the shot is generated, the instrument detects the large signal and marks the zero time mark on the strip chart. Each second thereafter, another mark is recorded. The electrical signal from the microphone is filtered, amplified and recorded on both channels. After the liquid level response is obtained, the operator turns off the chart drive. Another liquid level test can be performed by switching the chart drive on and generating another acoustic pulse. Figure 5 is a record accenting upper collars. Figure 6 is a record accenting lower collars. If the operator desires to manually select the amplifier gain, after the chart drive is turned on and the background noise is recorded, the gain controls should be set so that the noise level on both channels is recorded at a minimum level of 0.05 inch (1 mm) or less as desired.

The number of joints to liquid level is counted and entered in the acoustic analysis form. The producing bottomhole pressure and static bottomhole pressure are determined as described in references 2 and 3. The producing rate efficiency and the maximum production rate can be calculated from the above information using reference 3 or the software programs AWP, IPA-DOS or IPA-WIN II which are available free from Echometer Company or Echometer Sonolog, Inc. An example of the AWP analysis is shown in Figure 7.

Calculation of the bottomhole pressure at producing and static conditions requires the determination of the casing pressure and the casing pressure buildup rate. Conventional pressure gauges can be used for measuring the pressure. If the well produces gas up the casing annulus and the gas aerates the liquid column, a casing pressure buildup test should be performed. A sensitive pressure gauge having a range such that the casing pressure is indicated at half scale or greater is recommended. Special portable hand-held, high resolution digital readout pressure instruments are available for acquiring this data. The buildup rate is critical in calculating the casing annulus gas flow rate and the gradient of the gaseous liquid column.

SUMMARY

The dual channel microprocessor-controlled strip-chart amplifier/recorder offers more accurate acoustic liquid level depth measurements in a rugged, compact, waterproof, easily portable case. The microprocessor controlled automatic setting of collar and liquid level amplifier gains offers simpler operation. Modem filters improve collar and liquid level response. The printhead records headers, analysis forms, date and time markers on the strip chart for improved analysis. The dual channel instrument allows the operator to analyze the collar accented reflections and liquid level channel response simultaneously which results in a more accurate liquid level depth measurement and a better understanding of the well's behavior, performance and downhole configuration.

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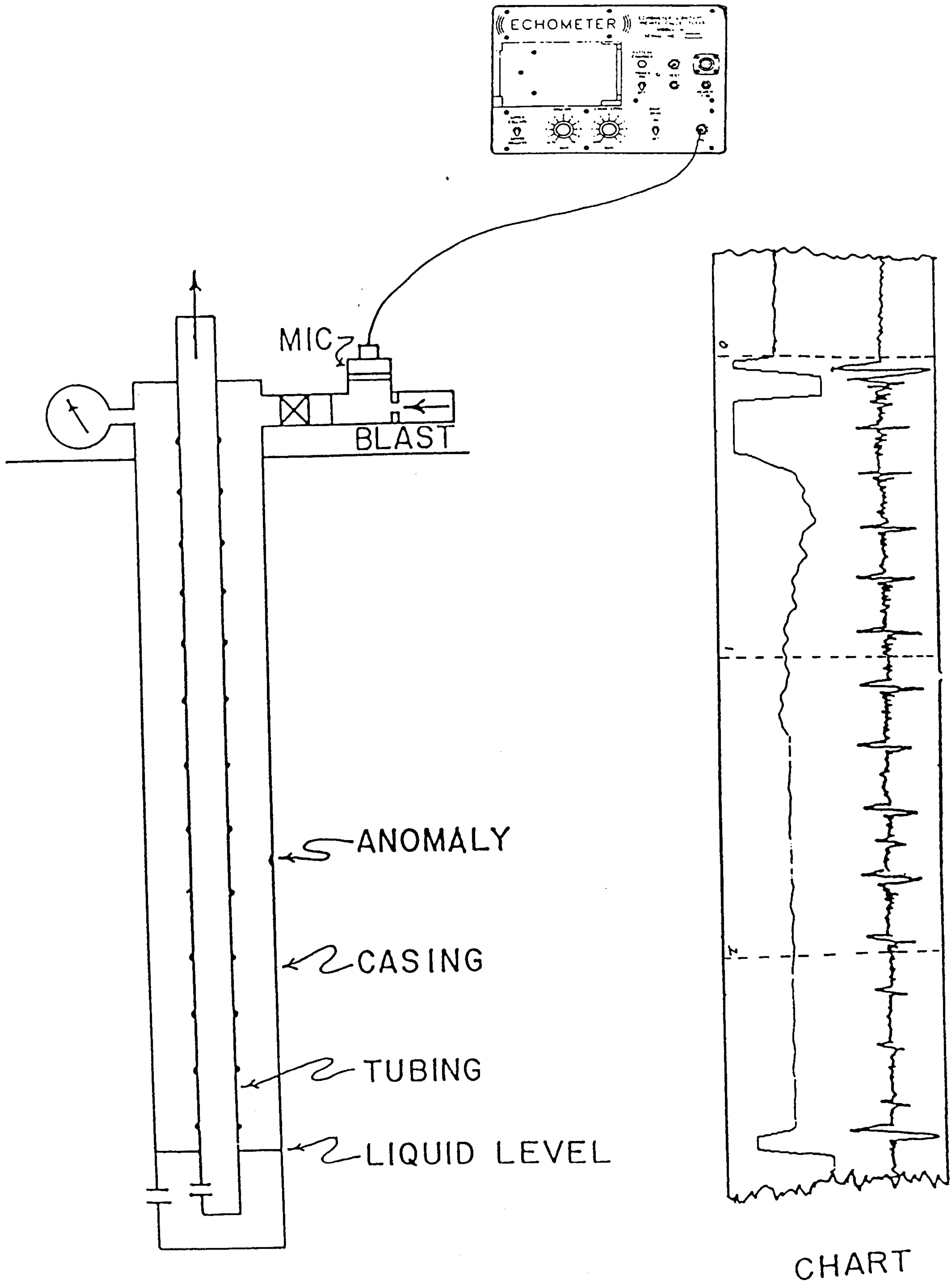

Figure 1 Acoustic Liquid Level System

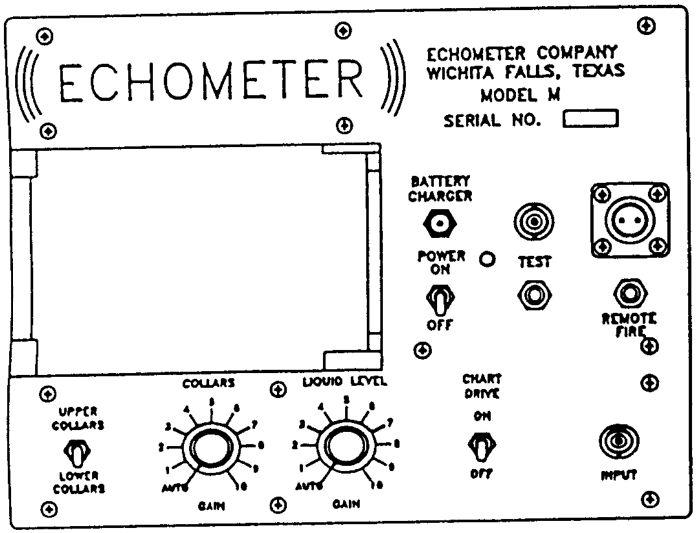

Figure 2 Instrument Panel

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EXAMPLE          WELL NAME
01-26-1997       DATE
5000             FORMATION DEPTH(FT)
5000             PUMP DEPTH(FT)
30               JOINT LENGTH(FT)
.8               GAS GRAVITY(SG)
0                  N2%
0                  C02
0                  H2S%
40               OIL GRAVITY(API)
1.05             WATER GRAVITY(SG)
70               SURFACE TEMP(F)
123              BOTTOMHOLE TEMP(F)
40               BOPD
80               BWPD
-*-PRODUCING CONDITION---
50               CASING(PSIG)
100              # JOINTS
                 dP
10               dT
---STATIC CONDITION---
                 CASING(PSIG)
                 # JOINTS

ANALYZING WELL PERFORMANCE(1.2)
ACOUSTIC BHP SOFTWARE BY ECHOMETER

F1-COMPUTE    F2-NEW DATA       F3-PRINT
F4-SAVE DATA  F5-RECALL DATA    F6-ENG/MET
Esc-EXIT

PRODUCING BHP
-------------
PBHP=  542(PSIA)
 72% LIQUID IN COLUMN
LIQUID AT   3000 (FT)

STATIC BHP
-------------
ENTERED SBHP= 1234(PSIA)

VOGEL'S IPR CURVE
-----------------
 76% EFFICIENCY
  52.8 MAX OIL RATE
 158.3 MAX LIQ RATE
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Figure 7 AWP Software Analysis

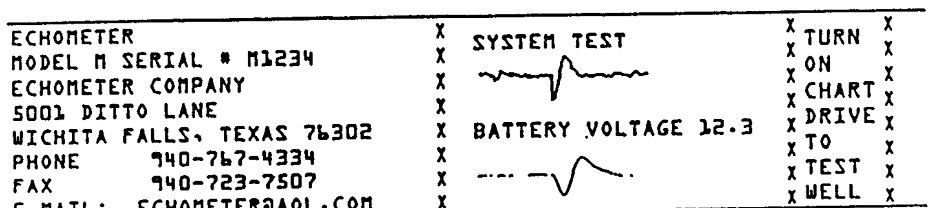

Figure 3 System Identification and Text

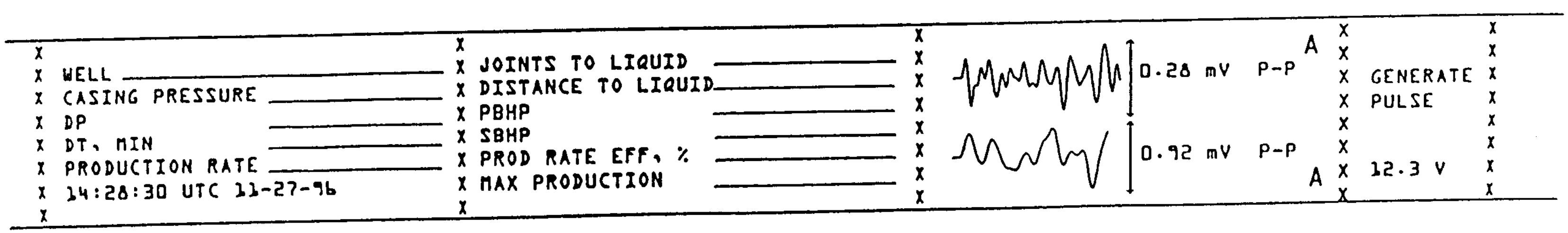

Figure 4 Data Forms and Noise Measurement

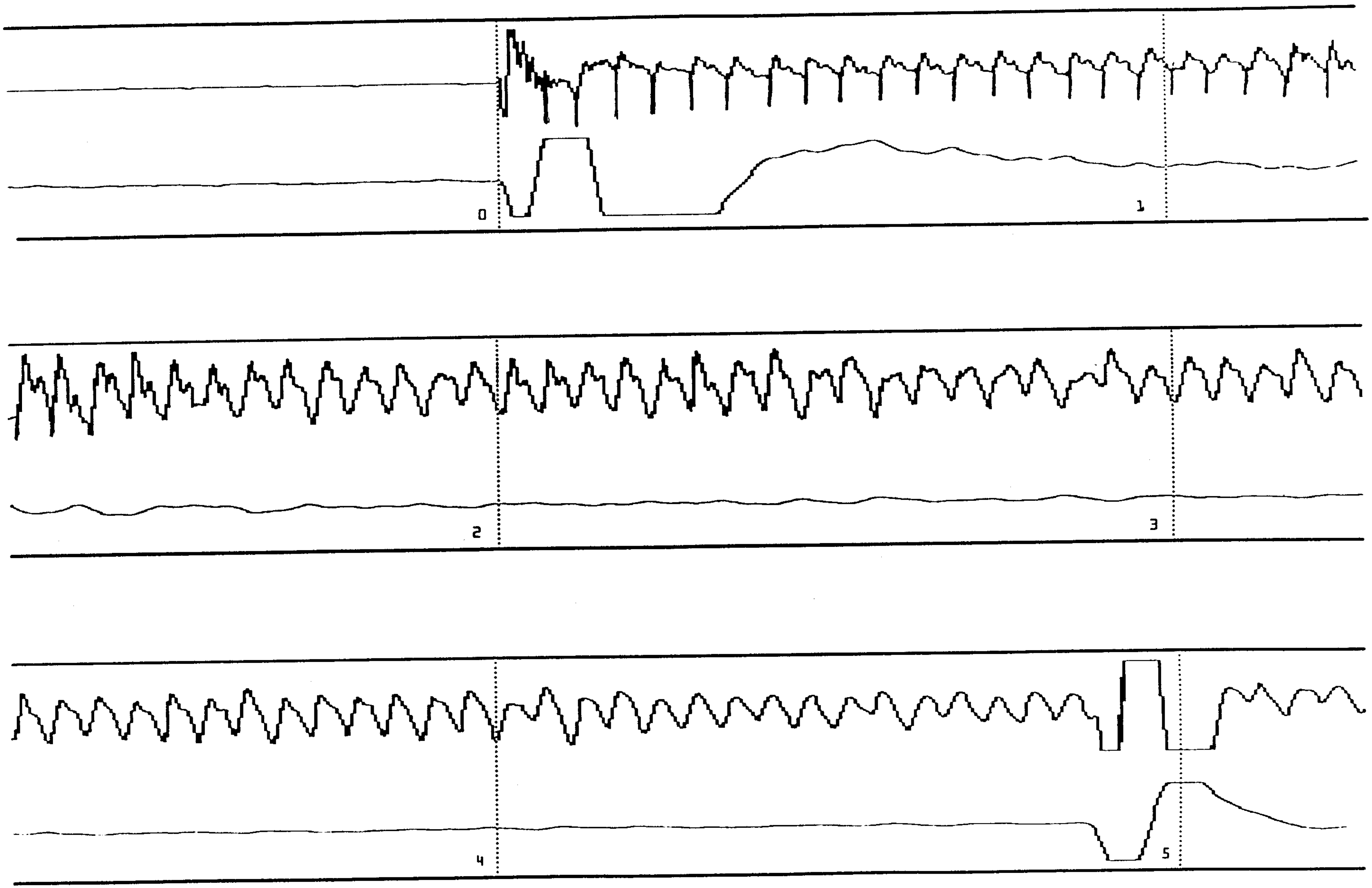

Figure 5 - Strip Chart (Upper Collars Accented)

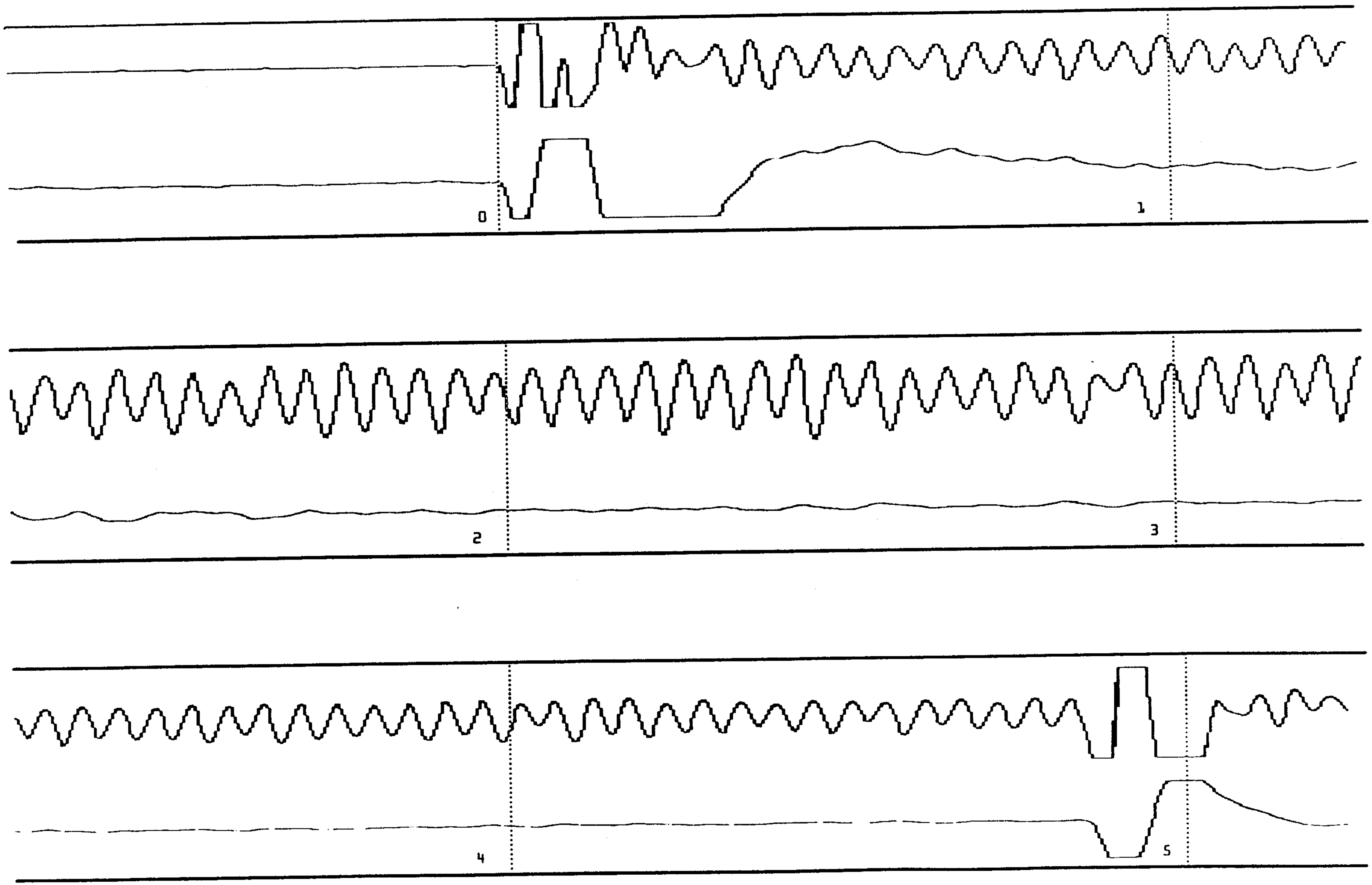

Figure 6 - Strip Chart (Lower Collars Accented)