Well Performance Visualization and Analysis *

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Abstract

A system has been developed based on a powerful portable microcomputer and an integrated data acquisition package, connected to the computer's expansion slot, that allows real-time analysis and visualization of pumping well performance. The system integrates all the necessary elements to obtain a complete analysis of the performance of the pumping system which includes the pumping unit (beam or submersible), the wellbore, and the reservoir.

The data acquisition package consists of the necessary analog and digital inputs to process data from standard transducers such as pressure, temperature, rod load, displacement. etc. so that detailed surface unit performance curves such as dynamometer, speed, acceleration, power etc. can be obtained and analyzed. When the instrument is used in conjunction with an acoustic pulse generator and receiver, it digitizes (1 KHz rate) and records the reflected acoustic signals which are digitally filtered and automatically processed to determine the liquid level. This is undertaken under program control so that a continuous recording of fluid level vs. time is obtained with the pumping performance parameters. Fluid level data is processed by the software to calculate bottom-hole pressure as well as flow into and out of the well bore. Changing the well from flowing to shut in conditions allows recording of pressure buildup data which is then interpreted in terms of reservoir parameters. Alternatively, pump start-up after shutting in the well in for stabilization, provides draw-down testing capability. The analog/digital electronic system contains output of a 12 volts relay driver for external control of a gas gun valve.

Graphic display of the various diagnostic parameters allows complete visualization of the performance of the pumping system as a whole including the reservoir, wellbore and pumping unit. The system can be used as a diagnostic tool to optimize pumping well performance on a periodic basis. The present performance of the well is compared to the performance recorded previously and in the case where significant changes are noted a more detailed analysis is undertaken.

Well Performance Visualization

Figure 1 is a schematic diagram of the well performance Visualization System. This system is the integration of various surface measurement systems with well data base information and with software packages designed for diagnostic analysis of well performance. The system's objective is to yield an accurate and timely analysis of well performance for the present operating conditions and to predict the effect of operational changes on the well performance.

Integration of these elements has been made possible only recently through the development of powerful microcomputers, portable digital data acquisition electronics, improved low cost sensors and transducers, PC-based analysis,data base management and graphics software.

Well performance in the context of this paper addresses the complete well system including: the reservoir, the wellbore and the pumping components. Visualization of well performance then involves the ability to understand how these elements interact to yield the present conditions of pressure, flow rates, loads, efficiency, etc. and to be able to forecast the effect of changes in the variable operating parameters such as speed, stroke, surface pressure, on/off time, etc. and changes in the well configuration such as pump depth, rod sizes, surface unit geometry, well stimulation, etc. on the performance of the system.

For many years, the industry has had access to the individual components of the system: acoustic liquid level measurements, dynamometer measurements, well test data, pressure recorders, transient well test data, etc. The present system provides the means to integrate all these elements in a single system capable of

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providing the complete picture of the performance of the well. Figure 2 is a block diagram representation of the hardware and software configuration that implements the well performance visualization system.

Acoustic Well Soundings

Acoustic echo-ranging techniques to generate well soundings have been in effect for over fifty years to aid in the analysis of pumping wells [1]. Early application was limited to determining the presence of liquid in the annulus above the pump. If liquid was found over the pump then the operator knew that additional production was available if a larger pump was installed; or, if the pump were not operating properly, that the pump should be pulled and repaired.

Soon after the development of these instruments, some operators realized that proper interpretation of the records could yield additional information. In particular bottom-hole pressure was calculated from the summation of the surface casing pressure plus the gas column hydrostatic and the liquid column hydrostatic pressures. This presumed some knowledge of the density and distribution of the oil and water in the liquid column especially in the case of shut-in wells where relatively high liquid columns were observed. Operators also observed that in those instances where gas was vented from the annulus the calculated bottom-hole pressure was excessively high. This was attributed to the lowering of the effective liquid gradient by the presence of gas bubbles in the liquid column above the perforations. C. P. Walker [2] patented a method for determining the density of annular liquid columns which are areated by gas bubbling upward through the liquid. Walker presented a technique whereby a back-pressure valve is used to control and increase the casing-head pressure causing the annular liquid level to fall a distance corresponding to the pressure increase. The gradient of the gaseous liquid is calculated by dividing the change in pressure at the top of the gaseous liquid column by the corresponding drop in liquid level. This gradient is then used to calculate the bottom-hole pressure. If the back-pressure valve setting is further increased until the the top of the gaseous liquid column is stabilized in the vicinity of the pump intake, which generally is near the perforations, then the producing bottom-hole pressure can be estimated quite accurately since the contribution of the hydrostatic pressure from a short gaseous-liquid column is small in relation to the casing-head pressure, and errors in the gradient estimate will not significantly affect the resulting total pressure. In the majority of producing wells in the United States, the liquid level is near the pump inlet and the casing-head pressure plus the gas hydrostatic will yield a very close estimate of the producing bottom-hole pressure. This method which was presented over 50 years ago is still one of the most useful methods of obtaining accurate producing bottom-hole pressure.

Recent studies by Podio, McCoy, et al [3] have presented a technique of obtaining the casing annulus gas flow rate by measurement of the casing annulus gas pressure buildup rate. Utilizing the casing annulus gas pressure buildup rate and the void volume in the casing annulus, a reasonably accurate casing annulus gas flow rate can be obtained. If the casing annulus gas flow rate is known, an estimate of the liquid column gradient is made using a field data correlation. This permits a reasonably accurate producing bottom-hole pressure even when gaseous liquid columns exist above the pump. In addition to the casing annulus gas flow rate, the operator can determine the specific gravity of the gas if an acoustic well sounding is made since the acoustic velocity and the pressure are known and the temperature can be estimated. Determination of the annular gas specific gravity permits a more accurate calculation of the gas column pressure.

Further refinements in obtaining bottom-hole pressures by improvements in determining the gas column pressure and the liquid column pressure along with electronic and mechanical improvements in processing and automation devices resulted in the development of equipment to obtain acoustic liquid level data and casing pressure data automatically without the need of operator assistance. Such a system is described by Godbey and Dimon [4]. This further refinement of automatically obtaining acoustic liquid level data and surface pressure measurements from which bottom-hole pressures can be obtained offered a new analysis technique to operators of pumping wells since this data can be obtained relatively inexpensively. Pressure buildup data permits the operator to obtain reservoir properties such as permeability, skin damage, reservoir pressures and numerous other parameters at a relatively low cost.

Advances in signal processing which are utilized so extensively by the geophysical industry and the availability of small lap-top computers offer significant advances and improvements in acoustic well sounding. Three important achievements are possible by utilization of a microcomputer. First, the computer can utilize digital processing of the acoustic data to obtain more accurate liquid level depths, automatically. Second, the determination of bottom-hole pressures from the acoustic liquid level measurement, the surface pressure, and properties of the produced fluids is automatically available. Third, the computer offers automatic operation of the equipment in that the computer can be programmed to perform well soundings and obtain casing pressure measurements on command, without operator attention.

This new computerized system has considerable flexibility. It can be operated with a manual-firing gun, a remotely fired gun with pressure sensor or it can be operated as a fully automatic system. In the automatic mode, the computer controls the gas gun and the casing pressure measurement so that automatic data acquisition will occur on command and a pressure buildup can be obtained without operator assistance. A discussion of these three systems follows.

Manual Acoustic Liquid Level Instrument

The computer and A/D converter can be used in conjunction with any modern manually operated acoustic gas gun and microphone. The gas gun generates an acoustic pulse. The microphone converts the reflected acoustic pressure pulses to electrical signals. These signals are digitized in the analog to digital (A/D) converter and fed to the computer. This configuration is illustrated in Figure 3. The computer can display these signals and/or process the signals as instructed by software. The computer automatically determines liquid level depths by signal processing. Modern analysis includes not only the distance to liquid level, but also a producing bottom-hole pressure, therefore, the casing pressure must be measured at the time of liquid level determination. A conventional pressure gauge is used with this manual system and data entered via the keyboard. If liquid is present above the formation and gas is flowing upward in the casing annulus, the casing vent valve should be closed and another casing pressure measurement should be made manually after approximately 10-15 minutes so that the casing pressure buildup rate can be obtained. From this and the annulus void volume, the casing annulus gas flow rate is calculated. This allows determination of the gaseous liquid column gradient if liquid exists above the pump.

Operation of the equipment is different than analog recorders. With the digital system, the computer and A/D are programmed to monitor the microphone output. The operator manually fires the gun. The computer automatically stores the digitized data immediately preceding the shot and the signals during the time when collars are reflected and the liquid level reflection occurs. This data is processed to determine the distance to the liquid level. The operator then inputs the initial casing pressure and the later casing pressure as well as the time between the two casing pressure measurements.

Software performs various functions in this analysis. First, well data is recalled from data which is stored into a database. This includes the well depth, pump depth, average tubing joint length, formation fluid properties, formation temperature, well test data and other parameters. This data is necessary for accurate bottom-hole pressure determination. Software also processes the signal echoes from the well and determines the distance to the liquid level. The operator is alerted if liquid exists above the formation and a computer analysis of the background noise indicates the probability of a gaseous liquid column. Further analysis based on inflow performance includes an estimate of the maximum production rate of the well if the producing bottom-hole pressure were reduced to a minimum value. The previously calculated value for casing annulus gas flow rate, casing annulus gas specific gravity and other computed well conditions are displayed. The above analysis is available on hard copy.

Figure 4 shows the display observed by the operator after an acoustic pulse has been generated at the surface of the well and reflected signals are received by the microphone. The reflected data is digitized by the A/D and stored in the computer. Then the data is displayed. The top insert shows the raw data. The beginning is at the left. The background noise, the initial acoustic pulse and the reflected signals are shown. Data are recorded past the time at which the liquid level reflection is expected. The vertical line at the liquid level kick indicates the exact time which the software selected as the onset of the liquid level signal. The lower right hand inset shows the detail of this liquid level signal. Two vertical lines are shown midway between the initial pulse and the liquid level pulse. Data for this time interval are shown as raw signal on the lower left hand insert. The raw signal after processing to accent collar reflections is displayed immediately above the raw signal. The software determines the total number of collars from the surface to the liquid level using the processed signal.

Using the PAGE-UP/PAGE-DOWN keys the operator controls the signal scale for the top presentation of the data. This allows detailed examination of the raw signal as a means of quality control and to insure that the proper kick has been selected for the liquid level response.

Observation of this display allows the operator to visualize the background noise present in the well before the shot, the transmitted pulse, the reflections from the collars and the liquid level kick. In general the software selection of the liquid level which is based on the amplitude of the signal, will correspond to the correct determination. However, if a tubing anchor, upper perforations, a paraffin ring or other obstructions exist in the annulus, the program may select one of these signals as the liquid level. In these instances the operator can use the arrow keys to displace the liquid level marker to the proper time. After this is done in subsequent tests the software will not accept the earlier signal arrivals. In some extremely difficult conditions, identification of the proper liquid level reflection may necessitate artificially moving the liquid level either by shutting down the well or increasing casing pressure in order to verify that the proper signal has been selected as the liquid level reflection.

After the raw data has been displayed the operator has the choice of a display of the well analysis sheet, a display of the acoustic data which was processed to accent and count the collars, or a display of the raw signal and processed signals from which the operator can count joints and analyze the signals. When the operator acknowledges that the raw data and selected liquid level kick and indicated collars are satisfactory for analysis, the software processes the raw data and counts the number of joints to the liquid level. The operator can display these processed data if desired, so as to visualize the quality of the signal obtained from the well and the accuracy of the count of tubing joints to the liquid level. If the display of the processed signal showing tubing joints is not satisfactory to the operator, he has the option to request a sideways printout of the raw signal and processed signals including a band pass filtered signal to accent the deep collars and a high-pass filtered signal to accent all of the tubing collars in the well. This display and printout of the raw data in conjunction with filtered data allows the operator to perform a detailed study of variations in cross sectional area of the annulus. The printout will show anomalies such as different tubing joint lengths, salt rings, paraffin deposits, submersible pump cable splices, casing holes, casing leaks, tubing leaks, multiple tubing strings, gas lift valves, upper perforations, changes in tubing and casing diameters, and any other condition which affects the area of the annulus. An example is shown in Figure 5. Raw data are plotted at the bottom of the graph. The middle graph displays data which has been processed to accent deep collars by filtering so as to obtain sinusoidal signals which are easily counted in terms of number of collars. The upper chart shows the raw signal processed with a high pass filter to remove the DC and low frequency components. The collar reflections and signals from small anomalies are accented in this presentation. Note in Figure 5 that the filtered signal greatly improves the ability of the operator to recognize and count the collars which are hardly visible in the raw signal.

The operator thus uses these screens and printouts to insure that the data is satisfactory and further computations can proceed and will yield accurate results. Acceptance of the data results in the well analysis display is shown in Figure 7. The objective of this display is to provide complete visualization of the well conditions at the time of the measurement. The figure is divided in two sections: on the right is a schematic diagram of the wellbore and reservoir configuration, on the left are several blocks containing quantitative information about the well and its past performance.

The well schematic includes important parameters such as tubing depth, perforation depth and other characteristics. The currently measured casing pressure, casing pressure buildup rate and the calculated casing annulus gas flow rate and gravity are printed opposite the gas portion of the well. Just below are printed the depth to the gas-liquid interface and the percentage of liquid present in the gaseous liquid column. At the bottom of the well are printed the calculated bottom-hole pressure and the most current value of static reservoir pressure.

The quantitative data on the left half of the figure is designed to present vital information about the well. In the upper left hand block, the well, company, operator and data are shown. Well data are shown in the block immediately below. In the bottom block recent BHP measurements are summarized. In the upper right block, the results from the latest production test are included. The central block is used to present the results of well performance analysis based on a Vogel-type IPR relationship. This includes the current producing rate efficiency and the maximum potential production achievable by reducing bottom-hole pressure to a minimum value.

This system of combining the distance to the liquid level, the casing pressure and the well parameters into a well performance analysis report in which the operator is informed of the producing bottom-hole pressure, the producing rate efficiency of the well and the maximum production rate is a large step toward improving the production efficiency of pumping wells with a minimum of effort by the operator.

Remote Acoustic Liquid Level Instrument

The remote acoustic liquid level instrument consists of the same computer and A/D system with a different wellhead. The remote acoustic liquid level wellhead consists of a remote operated gas gun valve which can be fired by the operator from the computer. This saves time and is somewhat safer in that the operator is not near the wellhead. The wellhead also contains a pressure transducer. This configuration is shown in Figure 8.As discussed previously, a casing pressure buildup rate is necessary if gas is produced from the casing annulus before the acoustic liquid level test is obtained.

The operator commands the firing of the gas gun in order to obtain the acoustic liquid level data from the well. Software stores the digitized signal from the microphone. Again, this signal is processed to determine the distance to the liquid level. With the remote wellhead, the software obtains periodic readings of the casing pressure, after the casing gas vent valve has been closed, in order to determine the casing pressure buildup rate. Since the pressure transducer is temperature sensitive, temperature measurement of the transducer is also performed to correct for temperature variations. These data are displayed to the operator as shown in Figure 6. The operator selects termination of the casing pressure buildup test when desired. The test can be terminated earlier than in manual testing due to better gage resolution and display of the pressure transducer data. Software then computes casing annulus gas flow rate, casing annulus gas specific gravity, the gradient of the gaseous liquid column and the producing bottom-hole pressure. Again, this data is stored for later recall by the operator if desired. Also, a hard copy is available.

Automatic Acoustic Liquid Level Instrument

The automatic acoustic liquid level instrument consists of the computer, A/D converter and the remote-fire wellhead including the gas gun, microphone, and pressure transducer. Other necessary hardware in addition to hardware required earlier is a 12-volt battery (which is similar to batteries used in automobiles) and a larger gas supply bottle for operating the gas gun.

The operator programs the computer to obtain data points. Each data point consists of the time, the distance to the liquid level and the casing pressure measurement. Data points are obtained as programmed by the operator. Data points can be obtained on a shots per hour or shots per log cycle basis. This offers considerable versatility in the acquisition of data.

The software obtains data points as programmed by the operator. This data is processed to obtain bottom-hole pressures. The casing pressure, liquid level depths and bottom-hole pressures are utilized in conventional buildup analysis plots to determine well and reservoir characterization. Software also includes type curves to aid in analysis of data. Again, all acoustic, pressure and temperature data is stored.

Data Storage

The computer and A/D converter convert the analog signal from the microphone to digitized data. These data, along with time and casing pressure are stored on a floppy disk. This data can be transported to another computer for further processing.

The digitized data from the acoustic microphone is a record of changes in the cross-sectional area of the casing annulus. By saving the floppy disk, an operator can compare a current reflected signal from the casing annulus to signals obtained previously in order to determine any change that might have occurred such as changes caused by a tubing leak, parted tubing, casing leak or any other condition which would change the cross-sectional area and the reflections from the casing annulus.

Acoustic data from some wells that have multiple downhole reflections and/or wells that have paraffin or salt deposits may be difficult for the computer to process and determine an accurate liquid level depth. The operator has the option of a sideways printout of the acoustic data on a hard copy. This printout shows the raw signal from the microphone along with a band-pass filtered signal which accents the lower collars and causes the collar reflections to appear as sine waves. This band-pass filtered signal is similar to the chart signal recorded by some analog recorders except that the signal is filtered at the precise frequency of the collar reflections thus improving the filtered signal. Also displayed is a high-pass filtered signal which accents "sharp" upper collars.

The raw data signal is best for interpreting changes in cross-sectional area and always "kicks" in the correct direction to indicate enlargements or restrictions in the casing annulus. This signal is useful for locating the liquid level, liners, perforations, tubing anchors, gas lift valves and other obstructions or enlargements which cause a change in the cross-sectional area of the casing annulus. The deep collar band-pass filter tends to accent collars and remove other reflections. The upper collar high-pass signal can be useful when different length tubing is used or when multiple strings of tubing are run in a well.

Beam Pump Performance Measurements

In The United States rod pumping continues to be the most widely used method of artificial lift. Current economic conditions dictate that maximum efficiency be maintained in these installations at all times so that new and easier methods of design and analysis are being developed almost continually. These methods are principally based on Gilbert's[5] and Fagg's[6] development of the beam pump dynamometer where the load at the polished rod was recorded graphically as a function of the travel to generate a chart which represented the work undertaken at the surface unit for every pump stroke. Modern developments have concentrated in refining the techniques for interpretation of the characteristics of this load-displacement curve so that a detailed analysis of the system can be undertaken which yields among other:

- Load distribution in the rod string
- Load- displacement at the pump
- Valve operation and leakage
- Surface torque and counterbalance efficiency
- Fatigue loading and rod buckling
- Motor performance

Recently, with the advent of high performance digital data acquisition systems, attention has been given to a more complete analysis of pumping unit performance. Lea and Bowen[7] present results from simultaneous measurements of ten dynamic parameters (Kilowatts input,power factor, motor torque, gear torque,polished rod position, velocity, acceleration and load, motor speed and unit's strokes per minute. The study concluded that this type of data was very useful in calculation of pumping unit losses needed for torque calculation and prime mover sizing. They also indicate that these data combined with simultaneous measurement of downhole pump performance and wellbore pressures would yield a complete analysis of the beam pumping system.

Dynamometer measurements

The well analyzer provides means to acquire data from load and position transducers in order to undertake conventional and/or advanced dynamometer analysis. The operator can select this mode from the Analyzer's main menu by entering the appropriate choice and following up with the necessary information regarding the characteristics of the transducers that will be used.

In this mode the system's principal objective is to provide the maximum flexibility with regard to data acquisition, so that the operator can select various types of commercially available transducers or use custom units of his own design. The analyzer provides means for acquiring and displaying the dynamometer data and to store the same information on diskette for further processing and analysis.

Load Measurement

The accuracy required in quantitative dynamometer analysis limits load measurement to using some type of strain gauge load cell.[8] A regulated power supply is used for accurate bridge excitation.

Position Measurement

Various types of position transducers can be used. The unit provides the necessary excitation voltage for resistive type position indicators as well as for accelerometers incorporating signal conditioning and amplification. The operator selects and enters the necessary parameters through the set up menus.

Data Acquisition

The load and position input channels can be sampled at a rate of up to 1000 per second, which for normal pumping speeds will yield more data than necessary. The operator thus selects adequate sampling rates from a menu of suggested values which depend on the pumping speed. Similarly the operator has the choice of continually recording the data stream over numerous pumping cycles or for a specified number of cycles as necessary. Data is stored as pairs of values of load and position (or acceleration) as a function of time (time series). This is the preferred data set for subsequent digital processing in dynamometer analysis programs.

Depending on memory and storage media limitations the length of the data series that can be captured for a given sampling rate will be different in every case. In the continuous recording mode the most recently acquired data will be available at a given time. When the operator determines from the display that adequate data has been acquired he may then stop acquisition and the data is transferred to the diskette.

Data Presentation

Due to the speed of the lap-top computer, the dynamometer data is displayed in real time, either as separate load and displacement time series or in the conventional dynamometer presentation of load vs. displacement. When an accelerometer is used to obtain the polished rod motion information then it is also possible to monitor the velocity of the polished rod.

The operator can select special portions of the data series for display in more detail so as to study special characteristics of the signal over one specific cycle or series of cycles. The selected data can then be stored in separate data files for subsequent processing, analysis and plotting.

This is illustrated in Figure 9 which shows the computer screen during acquisition of the dynamometer data. The upper trace represent the load vs. time recording.The middle trace shows either the position, velocity or acceleration signal vs. time depending on the type of transducer used and the operator's choice. Data may be acquired for a fixed length of time (selected by operator) or continuously in a free-running mode until interrupted from the keyboard which freezes the display. Cursors (1) and (2) are controlled by means of the arrow keys and are positioned so as to bracket the portion of the acquired traces that the user wishes to display in more detail. These are shown in the lower two windows. The numeric values of the variables (load and displacement in the example) corresponding to the location of cursor (1) are printed on the screen as well as the corresponding time. The operator can thus select one pumping cycle or a series of pumping cycles or a small portion of the pumping cycle for detailed analysis. This is particularly useful in the identification of potential problems such as leaking valves, vibrations, excessive friction, etc.

When the operator is satisfied with the selected portion of the dynamometer waveforms, he branches to the dynamometer visualization display which is shown in Figure 10. The principal objective of this display is to give immediate indication as to whether the unit is operating properly or not. This is achieved by presenting the current dynamometer card as well as typical surface cards obtained previously for the particular well. The left portion of the display contains quantitative data describing the pumping system configuration, last well test results, current operational parameters and a directory of dynamometer data files acquired in the past.The right portion of the display comprises three graphic windows. The upper window shows the dynamometer card that corresponds to the section of data selected within the cursors in Figure 9 (note that if the selected data contains several pump strokes these will be superimposed in the same card). The middle window allows the operator to display any of the previously recorded dynamometer cards. The data displayed in the figure corresponds to what has been identified as a NORMAL surface card for this well. Any of the other cards in the directory could have been displayed. The bottom window always displays the surface dynamometer card that has been identified as representing partially and fully pumped-off conditions for this well. In each of the windows is also printed data for the fluid level, casing-head pressure, pumping speed and stroke which were present at the time that the data was recorded. Numeric values of the standard key parameters as defined in API RP11-L[9] (Figure 11) are tabulated for the current dynamometer card and for the type cards as a means of quantitative comparison of critical values.

The dynamometer visualization display thus gives to the operator immediate indication that the well is operating normally or that some abnormal condition is present. When further dynamometer analysis is required the current data is assigned an identifier and stored in the data base for subsequent processing.

Dynamometer Analysis

Acquiring the dynamometer data and storing it in diskette files in text format, allow the operator to feed this information to other dynamometer analysis packages so as to generate conventional or customized reports on pump performance etc. Recently developed expert systems[10] and pattern recognition software for dynamometer analysis also allow importing data in time series format. These advanced programs can generally operate in medium performance lap-top microcomputers so that some of this analysis can be undertaken in the field.

In particular, given the time series data of polished rod load and displacement shown in Figure 12, it is possible to calculate the corresponding load vs. displacement diagrams at various points in the sucker rod string and in particular at the pump, as shown in Figure 13 reprinted from Gibbs and Neely[11]. This gives accurate description of the stresses in the rods as well as definitive evaluation of the efficiency and conditions at the down-hole pump.

Several excellent seminars are available for education and training of personnel on the topic of dynamometer interpretation and analysis. Most of these firms and individuals also offer comprehensive PC software which can be used to analyze dynamometer data and predict well performance. Such organizations include: John Svinos (714-879-8951), Nabla Corporation (915-697-2228), Bob Gault (806-793-6196), and Delta-X (713-748-1184)

Integration with Fluid Level Data

From the dynamometer mode it is possible to return to Acoustic Well Sounding mode and perform measurement of the liquid level virtually simultaneously with the acquisition of the dynamometer data. This presumes that the equipment has been previously set up to perform acoustic measurements. Correlation between the acoustic and dynamometer data can then be undertaken since the system automatically records the time of day when all measurements are made. This capability allows the operator to monitor the dynamometer data as a function of varying fluid level above the pump. When this is carried out until pump-off takes place it is possible to identify accurately the features in the dynamometer card that correlate with the onset of pump-off.

A special mode of dynamometer data acquisition allows automatic continuous monitoring of the load and travel data for extended periods of time while capturing data for a given number of pumping cycles at specified time intervals or only when the dynamometer data deviates from a pre-determined base case or exceeds certain values.

Since the system is capable of automatic acoustic liquid level measurements, the operator can specify that at any time when dynamometer data is recorded then measurement of the liquid level be also undertaken. This capability greatly enhances the diagnostic potential of this system.

In addition, since liquid level data allows calculation of bottom-hole pressure, the pump intake pressure can easily be calculated and used in more accurate analysis of pump dynagraphs since knowledge of this parameter allows a better estimate of the rod system's friction and damping factors.

Conclusions

A portable, compact and complete system has been developed for acquisition of acoustic well soundings, polished rod dynamometer data and other surface measurements and for integration of these data in a series of coordinated graphic displays on a portable microcomputer. These displays allow the operator to visualize the current conditions and present performance of the well and to immediately identify existing or potential problems. Access to a data base of past well parameters and to application programs for interpretation of pressure buildup data, beam pump design, dynamometer analysis, etc. further enhances the system's diagnostic capability and permits operation at higher levels of efficiency and lower costs.

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SPECIFICATIONS

This describes the Echometer Model F well analyzer (Patents Pending) which consists of a Toshiba T1200F lap-top computer and an analog to digital converter with associated electronics connected to the expansion slot of the computer.

Mechanical

The Model F Well Analyzer consists of a lap-top computer with well analyzer electronics connected to the computer's expansion slot. Four electrical connectors on the back of the computer provide connections to and from the external sensors.

Controls

The Well Analyzer is controlled by the computer. Operation of the system is totally under software management.

Electrical

The Well Analyzer is designed for standard applications of acoustic well sounding and dynamometer surveying as well as for general purpose functions.

Power

The analog to digital converter and related electronics are computer controlled. These circuits are powered only as needed from the computer battery. When extended operation (several days) is desired, an external 12 volt battery is used to maintain the self contained computer power. Circuit power is under software control so as to minimize drain during stand-by periods.

Fluid Level Inputs

These consist of input channels required for connection to the Echometer Compact Gas gun or the Automatic Wellhead. This includes microphone, casing-head pressure and temperature inputs. Regulated power is provided for the pressure and temperature transducers.

Fluid Level Output

A 12 volt pulse, at 1 amp, switched to ground is available for actuation of the gas valve in the Automatic Wellhead.

Dynamometer Inputs

Provision is made for strain gage load cell measurement with excitation provided by regulated power supply. Input and excitation are provided for resistive position transducers and/or accelerometer inputs for acquisition of polished rod position data.

Precision and Accuracy

The measurement precision is one part in 2000 at full scale or 0.05%. The accuracy is also + or - 0.05% of full scale for a six month calibration interval at 25 degrees Centigrade. The accuracy for annual calibration is + or - 0.08% of full scale. Temperature stability is + or - 0.1% over the temperature range.

Sampling Rate

Sampling and channel selection are under software control. The maximum rate is 1000 samples per second. The computer may command any lower rate. Anti-aliasing filters are designed for a sampling rate appropriate for the intended application.

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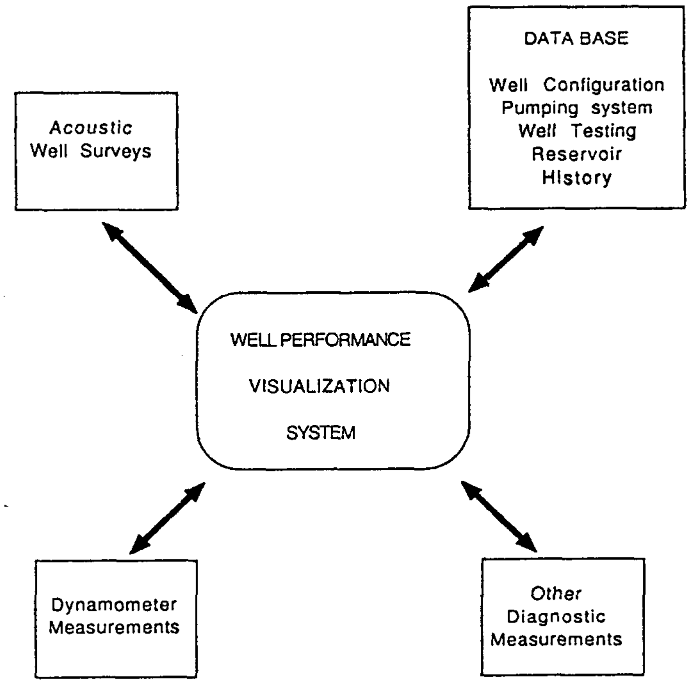

Figure 1 - Schematic diagram of the well performance visualization system

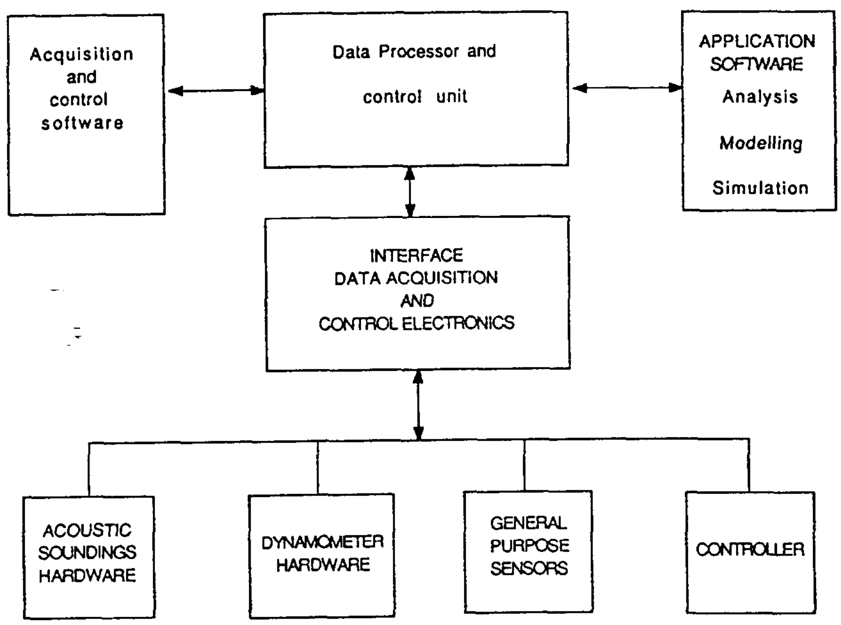

Figure 2 - Hardware and software configuration

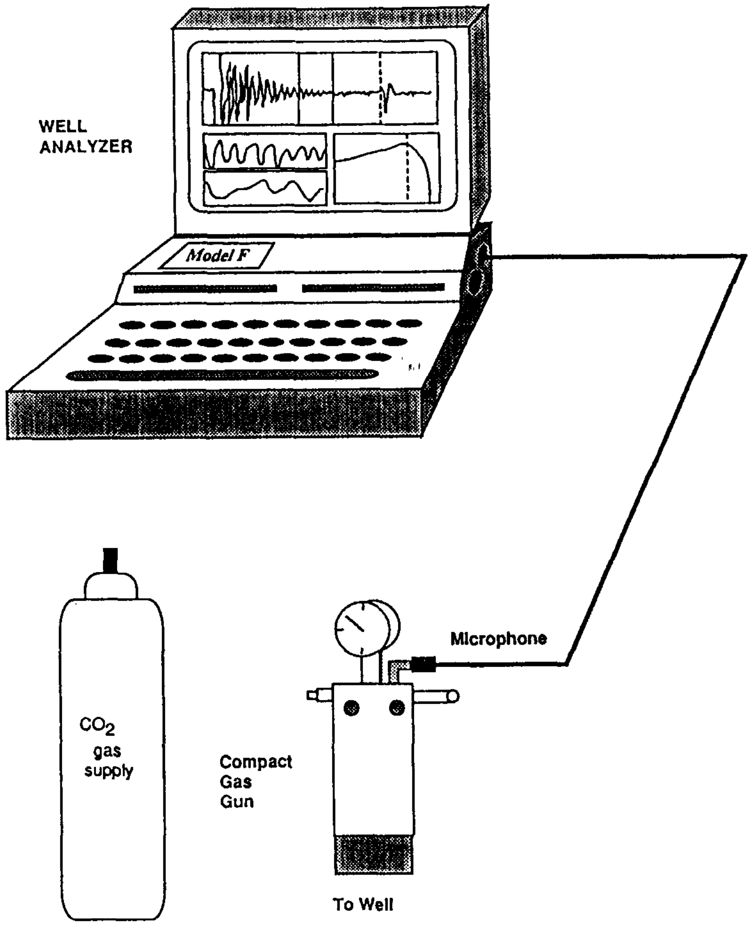

Figure 3 - Manual acoustic liquid level system

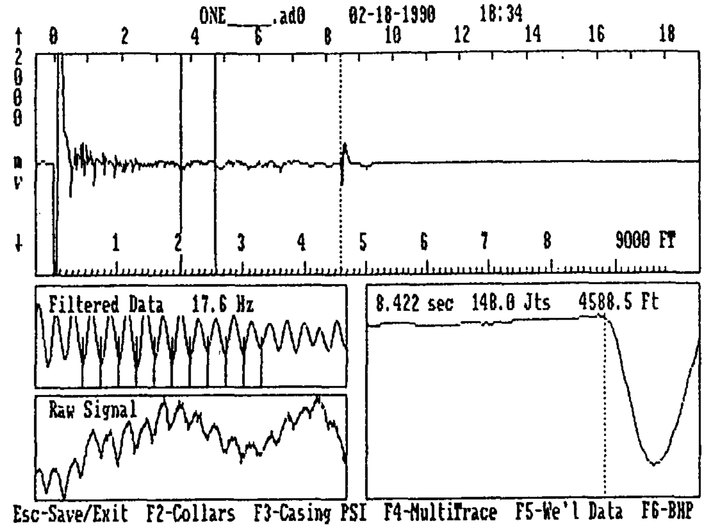

Figure 4 - Acoustic data display

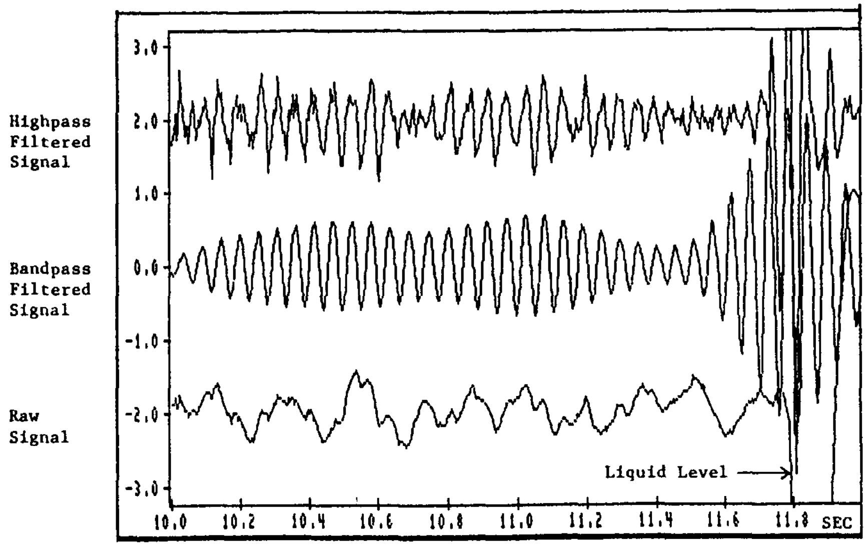

Figure 5 - Raw and processed acoustic data (10.0 - 12:0 sec.)

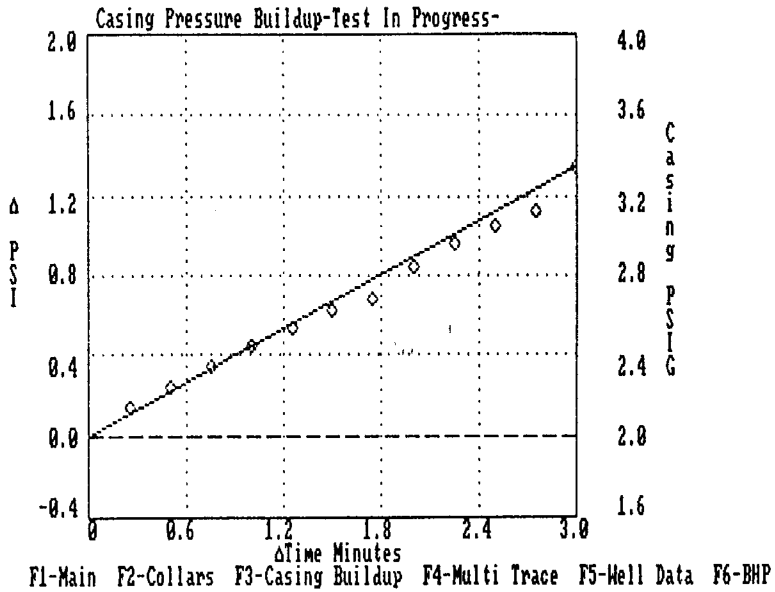

Figure 6 - Casing pressure buildup screen

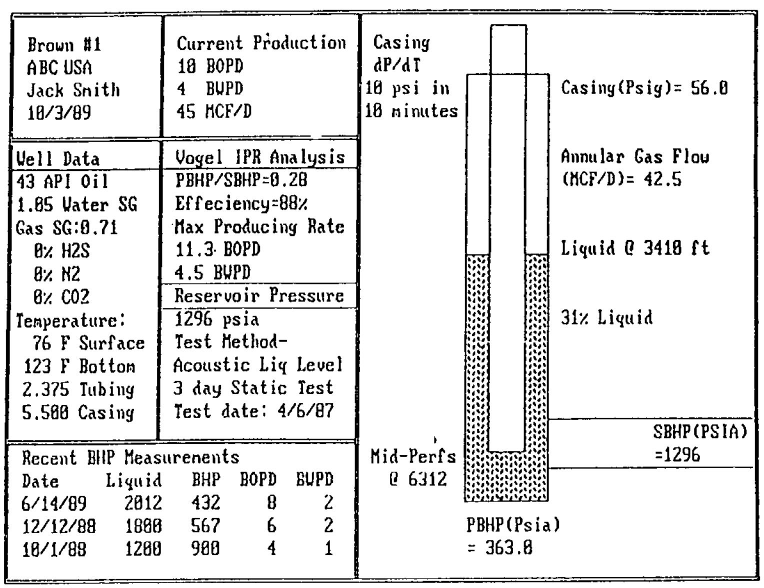

Figure 7 - Well analysis

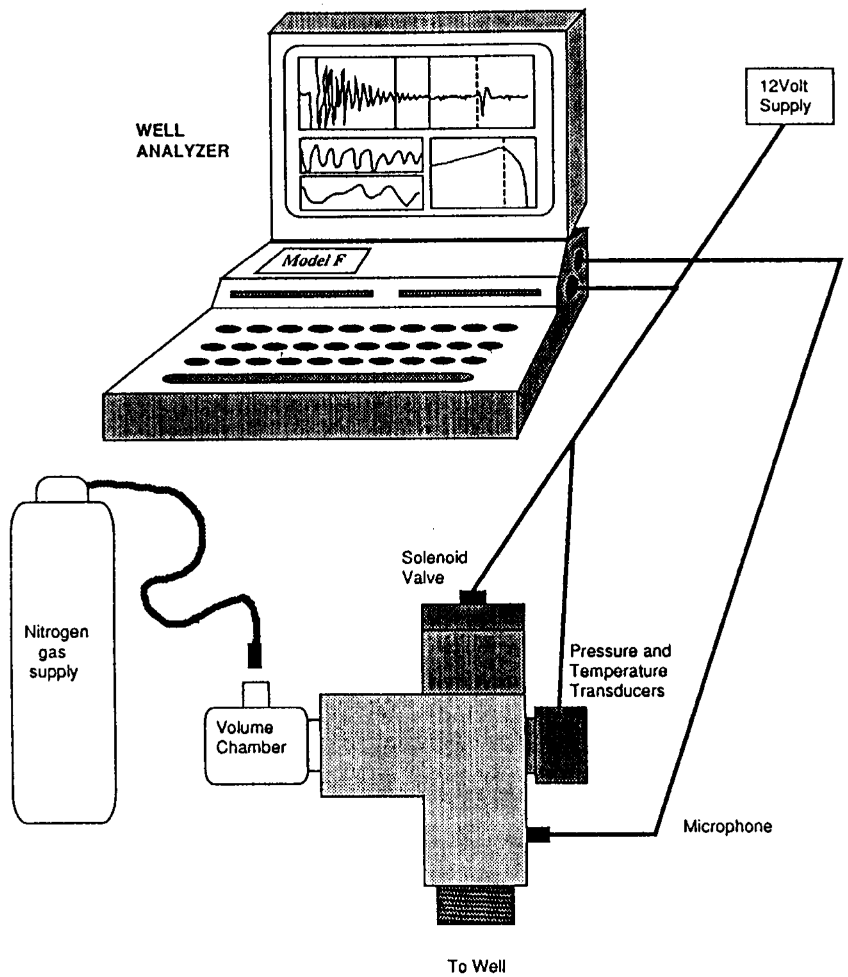

Figure 8 - Remote acoustic liquid level system

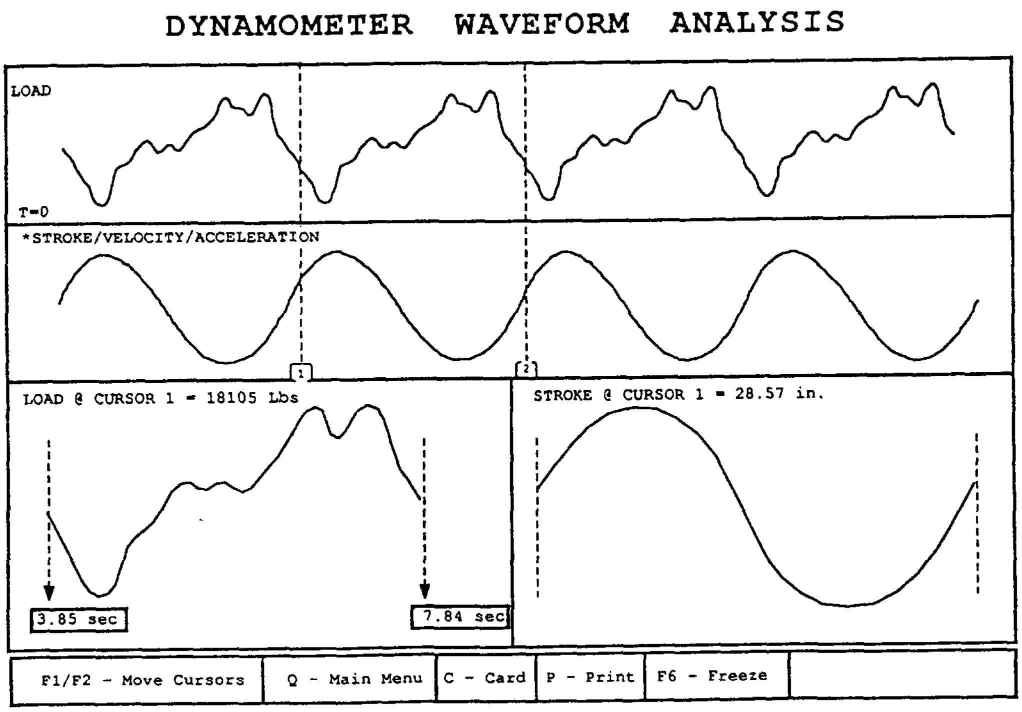

Figure 9 - Data is acquired from this screen. C=goes to visualization screen and displays dynamometer card for time interval between cursors.

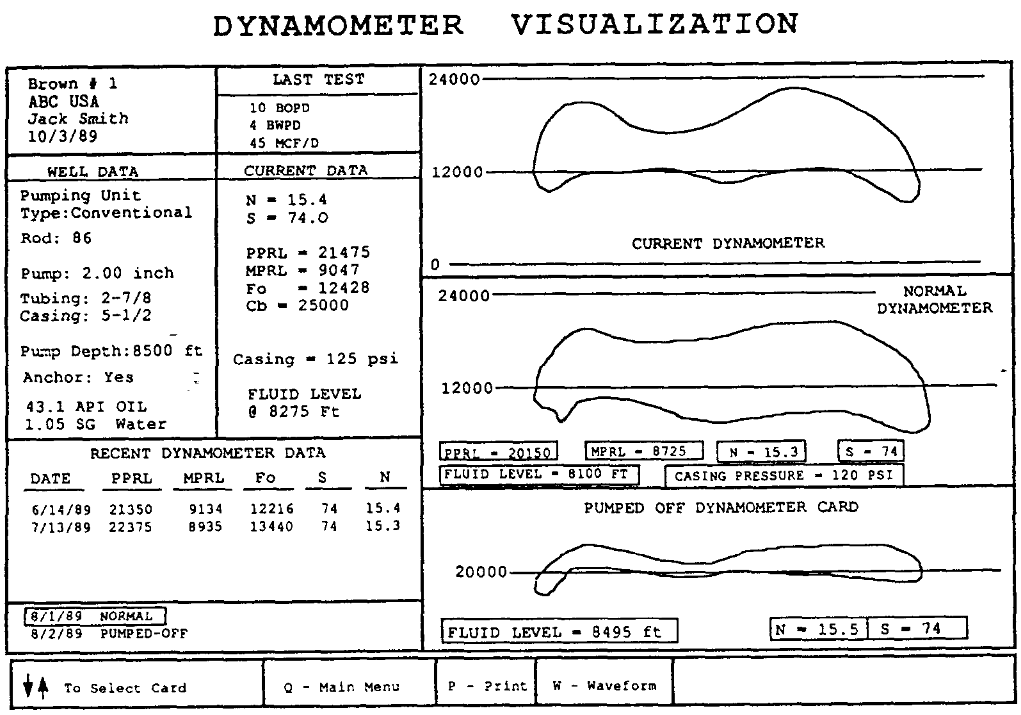

Figure 10 - Dynamometer visualization screen. The operator selects middle display from data base.

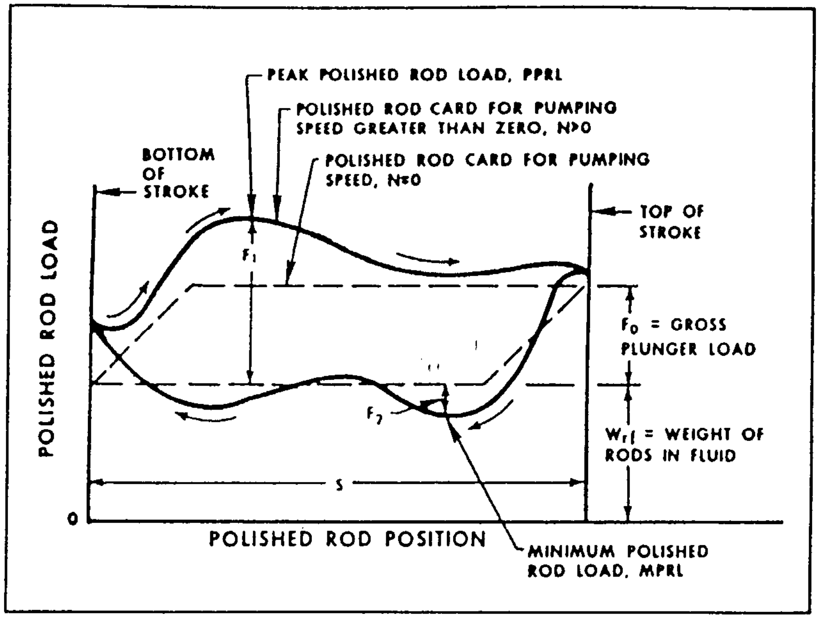

Figure 11 - Basic dynamometer card definitions (API RP 11L)

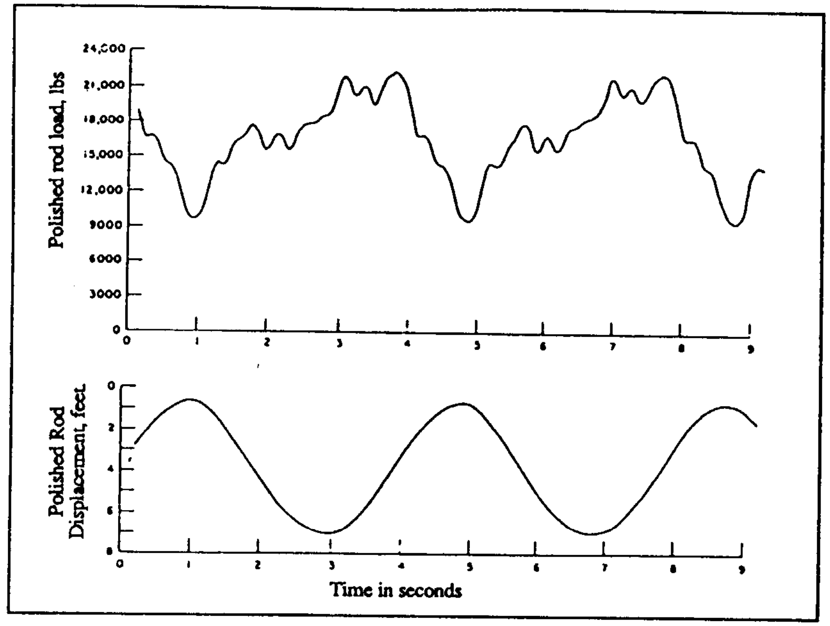

Figure 12 - Typical polished rod load and displacement time series. (Gibbs, 1966)

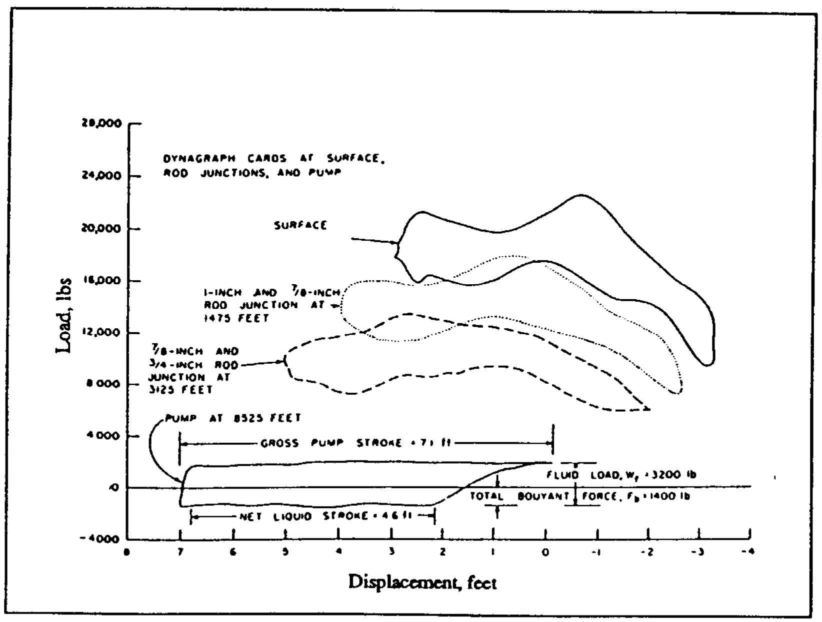

Figure 13 - Dynagraph cards calculated from time series in Fig. 12. (Gibbs, 1966)