REAL-TIME DISPLAY OF SUCKER ROD PUMP PERFORMANCE FROM DYNAMOMETER DATA

J. N. McCoy, Lynn Rowlan and Dieter Becker
Echometer Company
A. L. Podio, University of Texas at Austin

ABSTRACT

The experience gained from many years of computerized analysis of dynamometer records combined with very powerful portable computers, advanced modeling software, advanced graphical user interface and wireless data acquisition systems allow the visualization of the operation of the rod pump in real time. The operator directly observes and determines at a glance whether the pumping system is operating efficiently or requires modification or remedial intervention. The majority of the analysis is performed automatically and does not require evaluation of numerical results by the user. When unusual conditions are observed the user has access to advanced tools that facilitate detailed diagnostic analysis.

OBJECTIVES OF DYNAMOMETER ANALYSIS

Ever since the development of dynamometer instrumentation over 70 years ago the objective has been for the operator to be able to answer the following basic questions:

- What is the pump pumping in terms of liquid volume?
- Is the pumping system overloaded and something is about to fail?

The first question is generally triggered by a mismatch between the volume increase in the tank and the theoretical displacement of the pump based on pumping speed, stroke length and plunger diameter. The mismatch may be caused by several factors such as:

- The reservoir provides insufficient liquid to fill the pump; well is pumped off.
- Mechanical failures of the rods, valve leakage, plunger slippage, inadequate design, improper operation, etc. are reducing the volumetric efficiency of the pump.
- The fluid at the pump intake consists of a mixture of gas and liquids: gas interference.
- The pump intake is blocked so that fluid entry into the pump is restricted.
- Other factors

The second question is always present in the operator's mind and more prominently when the mean time between failures for a certain well has been much less than it should be.

Although the tools available to the operator's for analysis of dynamometer records have improved greatly over the years, as briefly noted in the following section, they generally still focus on providing numerical results that the user has to interpret to obtain an answer to the main questions listed above.

EVOLUTION OF DYNAMOMETER ANALYSIS

When dynamometer records were first introduced the analysis consisted of qualitative evaluation of the shape of the surface card by comparing the shape and loads of the current recording to type shapes or to dynamometer records obtained when a new pump was installed and flow stabilized. Deviations from the baseline shape and loads were indications of potential problems.

Subsequently, as more experience was gained and thanks to the development of quantitative recording dynamometers[1], the analysis was based on comparison to type dynamometer shapes and comparison to allowable surface loads. Figure 1 shows a typical "library" of surface dynamometer card shapes.
This type of analysis required significant experience and often was confusing and inaccurate as far as establishing how the pump was actually operating and the cause of unusual results. A major difficulty was caused by the

dynamic loads that are purely dependent on pumping speed and cause oscillations of the surface loads that are not directly caused by pump operation.

The development of the “Downhole Dynagraph” by W. E. Gilbert[2] was a major factor in providing better understanding of the operation of the pump and valves by directly recording downhole the load applied to the plunger as a function of its position during a stroke. Figure 2 shows a typical downhole dynagraph recording and an illustration of the barrel pressure variation during a plunger stroke. This tool however remained primarily a research tool and was never commercialized.

Many years of study of mechanics of vibrating strings and broad experience in analysis of surface dynamometer cards by Slonneger[3] culminated in the publication of a book that describes graphical procedures that allow calculation of the effective displacement of the pump based on determining the pump plunger travel and the tubing movement. The analysis is time consuming and requires accurate calibrated load data and mechanical description of the pumping system. Figure 3 shows an example of the graphical solution that yields an effective plunger stroke of 68 inch a tubing stretch of 5.5 inch and polished rod load variation from a maximum of 18,500 Lb to a minimum of 3,200 Lb. The points of opening and closing of the traveling valve and standing valve are also inferred by the analysis thus indicating the mechanical aspects of pump operation. The results of the analysis gave the operator the information required to answer the two main questions listed above but required a significant effort.

The introduction of portable solid state instrumentation provided new tools for acquisition of dynamometer record as shown in Figure 4. Analysis required calculations and interpretation of computed results that were facilitated by guidelines and calculation forms and generalized dimensionless graphs developed by the American Petroleum Institute and published as the well known RP11L. This publiucation included type dynamometer cards as shown in Figure 5, but was mainly a tool for design of pumping systems to satisfy specific flow rate requirements and selection of adequate rod and pumping unit capacities.

The API RP11 was based on analog computer simulation of the rod string to translate the loads at the pump plunger to the equivalent loads that would be measured at the surface accounting for the rod string weight and including the dynamic forces due to acceleration and rod vibrations.

This analytical method used in the reverse direction, that is measuring the surface loads and position at the polished rod and calculating the loads at the pump was implemented in real-time using electronic circuits as described in the Yew et al. patent[4] illustrated in Figure 6 that shows a pump dynamometer card generated from analog recording of polished rod load and position as a function of time.

The advent of portable digital minicomputers with greater flexibility in terms of programming, compared to analog computers, precluded widespread application of the Yew system in favor of digital processing of the surface dynamometer data[5]. However, since the majority of dynamometer records at that time were still in some type of graphical format, the processing required digitization of the recorded graph or card. Thus the processing and analysis was somewhat cumbersome and labor intensive and so was primarily limited to major companies and large independent operators. Processing of the data was undertaken at the engineering office after acquisition was completed at the field and resulted in printed reports and graphs of the surface and downhole parameters.

Availability of low cost, battery powered laptop computers with fast processors and high resolution graphics, outfitted with integrated circuits for analog to digital conversion and advanced analysis software was instrumental in extending the benefit of digital dynamometer analysis technology to all operators. Figure 7 illustrates a state of the art dynamometer data acquisition and analysis system. Acquired data consists of digitized load and acceleration, measured at the polished rod during an extended period of time to ensure that the operation of the pump has stabilized and data is representative of the normal operation of the pump. Processing of the surface data to generate the corresponding pump dynamometer cards is undertaken after acquisition of several strokes has been completed.

Figure 8 shows the results of detailed calculations for a specific pump stroke that gives a very complete analysis of the pump operation and the loads experienced at the surface. Pump displacement is computed at 119 bbl/day based on the current pumping speed of 8.411 strokes per minute. The effective plunger stroke is 54.2 inches that corresponds to 62.65% of the total plunger stroke of 86.5 inches. Since the surface stroke is 100 inches there are 13.5 inches of stroke loss due to rod and tubing stretch. The shape of the pump dynamometer indicates that the pump barrel is filled with a mixture of liquid and gas at an initial pressure of 130.1 psi. The gas is compressed during the down stroke to a pressure that exceeds the pump discharge pressure at which point the traveling valve opens as indicated by the vertical dashed line. The minimum pump load is calculated as a negative 470 Lbs which shows that the bottom rods are loaded in compression.

The polished rod power is computed as 6.3 HP from the area enclosed by the surface dynamometer card while the power expended at the pump equals 4.8 HP. The energy losses correspond to frictional forces between rods and fluids and rods and tubing. Additional analysis of the rod loading (not shown in this figure but presented in the detailed performance report) indicates that the rod string is loaded to 52% of the allowable loading, the pumping unit beam is loaded to 50% of its capacity and the gearbox is operating at 55% of maximum torque, and the prime mover are not overloaded.

The extensive report contains a large number of results that must be interpreted and analyzed by the operator to arrive at a conclusion whether the pumping system is operating as intended and produces the desired rate in the most efficient manner.

THE NEW DYNAMOMETER REAL-TIME VISUALIZATION SOFTWARE

The objective of the new software is to show to the user, at a glance, how the downhole pump is operating. This is accomplished by acquiring the surface load and position data while computing "on the fly" the plunger displacement and load, determining the pressure in the pump barrel and calculating the percentage of gas and liquid as a function of plunger travel. The results are presented on the laptop screen in a graphical format as shown in Figure 9.

The data acquisition system[7] is designed to allow simultaneous recording of dynamometer and fluid level so that on the left of the screen is also presented the real time visualization of the fluid level and fluid distribution in the wellbore. This complements the visualization of the pump operation and shows to the user the interrelation between the pump operation and the fluids and pressures that exist in the well and at the pump intake thus providing complete monitoring of the artificial lift system.

Visualization of the fluid distribution inside the pump requires analyzing the behavior of the gas liquid mixture as a function of pressure, considering the solubility of the gas phase into the hydrocarbon liquids. In general terms the calculations are based on the PVT behavior of the hydrocarbons, as obtained from generalized correlations as a function of fluid specific gravities, pressure and temperature. The origins of the gas inside the pump barrel include free gas that may be present at the pump intake and/or gas that evolves from the liquid due to pressure drop caused by flow through the pump intake.

The rate of gas evolution from or dissolution into the liquids is considered to occur within the timing of typical pumping speed, which is in the range of several seconds. This is substantiated from results shown in Figures 10 and 11 from a detailed laboratory study[8] performed under conditions of vigorous agitation similar to what has been observed in two-phase flow video recordings of flow through rod pump valves and inside the pump barrel as illustrated in Figure 13.

Pressure inside the pump barrel is controlled by plunger position and compressibility of the gas-liquid mixture. Compressibility increases as the input gas to liquid ratio increases and as gas evolves from the liquid. Figure 13 shows a typical record of the pressure inside the pump barrel filled with a gas and liquid mixture consisting of 60% liquid. Comparison of the barrel pressure with the pump intake and discharge pressures determines the position of the plunger when the traveling and standing valve change status from closed to open and vice versa.

Figure 14 is a detail of the pump visualization and dynamometer records. During acquisition the current load and position point, represented by the red dot, is moving in real time on both dynamometers and "writes" the new dynamometer record overlaid on the immediately previous dynamometer card. At the particular instant for this frame, notice the difference between the position of the polished rod at 39.89 inch on the upstroke and the position of the plunger at 24.13 inches. The 15.76 inch difference corresponds to the dynamic rod stretch due to the elasticity of the rods and the unanchored tubing. At the left, the schematic figures show the corresponding positions of the polished rod (carrier bar) and pump plunger inside the pump barrel at the bottom of the tubing. The pump barrel fillage is displayed with quantitative representation of the liquid and gas fillage. The plunger positions where the valves open and close are clearly shown on the pump dynamometer graph. The balls inside the valve cages, which are illustrated in the pump schematic, move of or on the seat when the plunger traverses those specific points.

Based of the net volumetric displacement, the pumping speed and the run time, the program computes and displays the corresponding volume pumped per day as shown at the lower right in Figure 9.

SUMMARY

The new software represents the latest generation of dynamometer data acquisition and analysis that includes:

- Real time processing of polished rod load and acceleration to generate the corresponding pump dynamometer.
- Continuous display of the motion the polished rod and the pump plunger.
- Quantitative representation of pump liquid fillage and valve operation.
- Calculation of net pump displacement and equipment loading

From these results the operator can see in real time what is happening inside the pump, how much fluid is being displaced, how valves are functioning and the dynamics of the rods that cause oscillation and delays of the plunger motion. Immediate indication of pump displacement and rod loading answers the main questions regarding pumped fluid and equipment loading. The operator can view detailed quantitative analysis when needed and has powerful software tools for refining the analysis if desired.

REFERENCES

1-L.W Fagg: “Dynamometer Charts and Well Weighing”, SPE, 1950
2-W. E. Gilbert: “Downhole Pump Dynagraph”, API Production Practices, 1936
3-J.C.Slonneger “Dynagraph Analysis of Sucker Rod Pumping”, Gulf Publishing Co., 1961.
4-Yew, C. H. Gibbs, S. G. and E. A. Ripperger: “Apparatus for Analyzing Sucker Rod Wave Motion”, US Patent 3527094, Aug 4, 1967.
5- Gibbs SG, Nolen K. B.: “Wellsite Diagnosis of Pumping Problems Using Minicomputers, ”Journal of Petroleum Technology, November 1973, pp. 1319–1323.
6 – Podio, A. L., McCoy J. N., D. Becker, O. Lynn Rowlan and Bill Drake: “Total Well Management II ,SPE 67273, Production and Operations Symposium, Oklahoma City, Oklahoma, U.S.A., 24–27 March 2001.
7 – McCoy, J. N. et al.: “Wireless Simultaneous Acquisition of Dynamometer and Fluid Level Data Facilitates Rod Pumped Well Optimization”, proceedings SWPSC April 2011.
8 – Tebourski, H.: “Two-Phase Volumetric Efficiency in Sucker Rod Pumps”, MS Thesis, University of Tulsa, 1993.
9 - Adisoemarta, P. S. et al.: “Downhole Pump Visualization and Data Acquisition”, proceedings SWPSC, 2001.

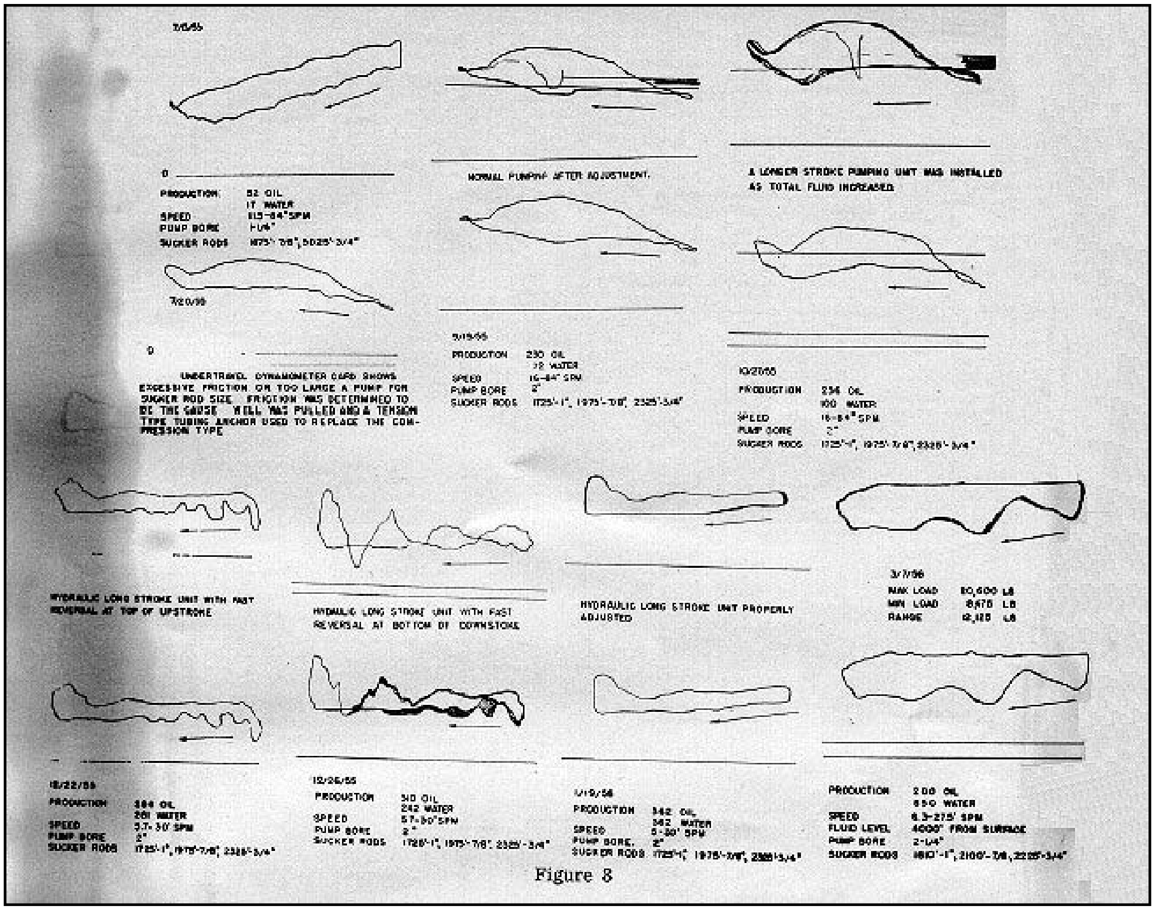


Figure 1 – Type surface dynamometer cards used for analysis of downhole problems. (Fagg 1950)

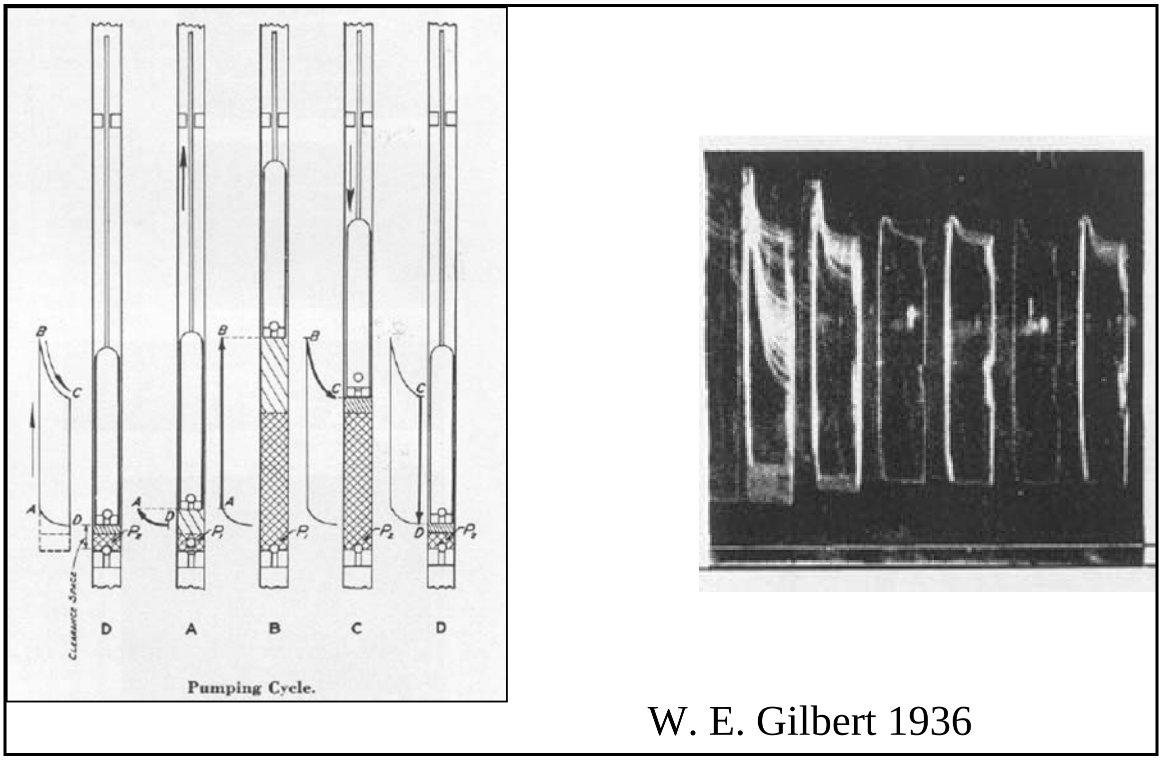


Figure 2 – Downhole Pump Dynagraph Record and Schematic of Pump Operation during a pumping cycle.

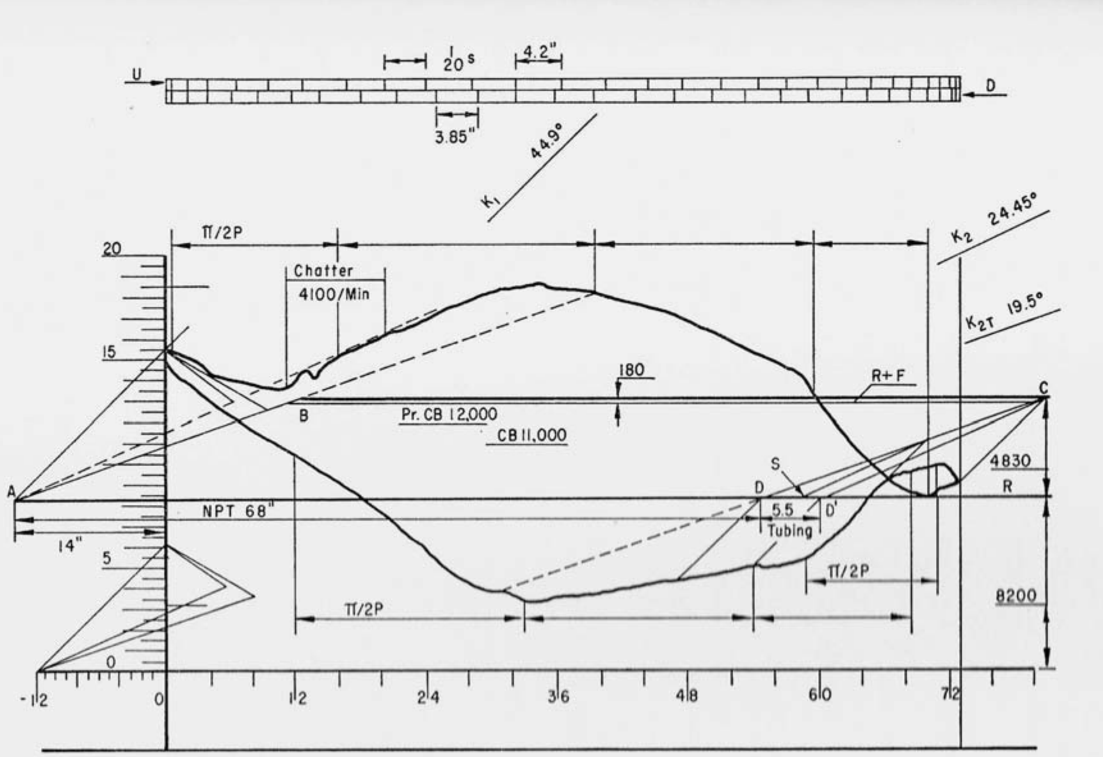
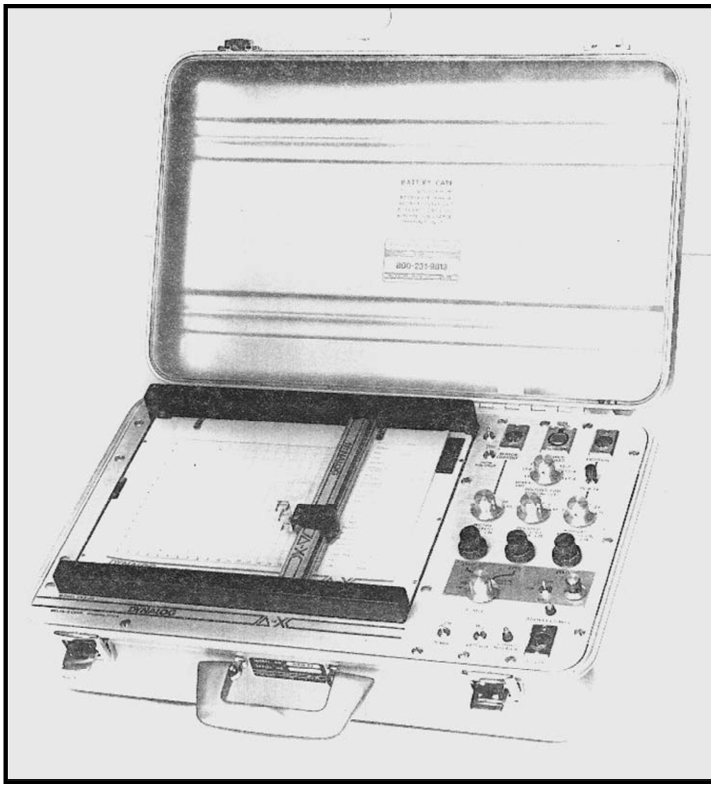


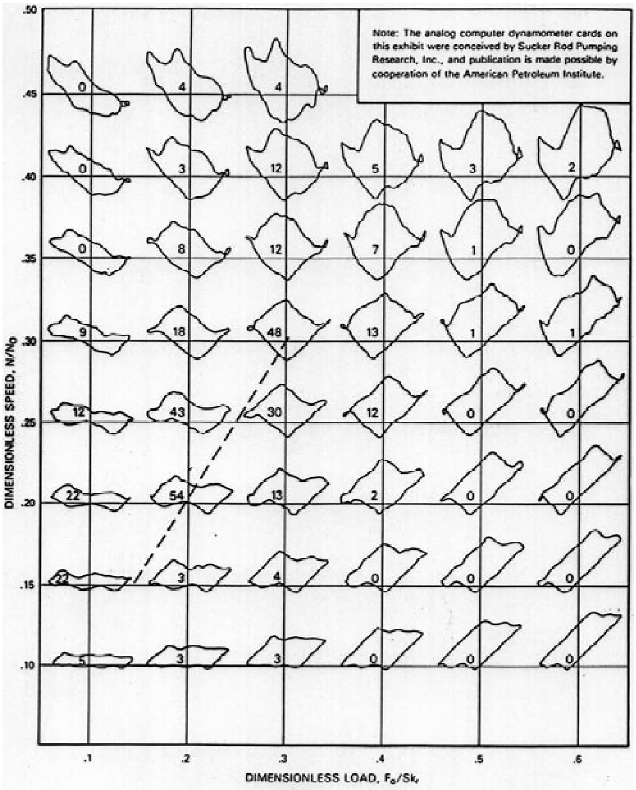
FIGURE 11.3. Graphical analysis of graph taken fr om 5,100 foot well at a 2½ order pumping cycle.

Figure 3 – Graphical Analysis of Surface Dynamometer Record,, (Slonneger 1961)



Delta-X dynamometer, 1972

Figure 4 – Portable Electronic Recording of Dynamometer Data.(Delta-X)



Polished rod dynamometer card shapes for normal operation

Design Calculations for surface unit selection.

Rod string design to allowable stress limits

Detailed design charts.

Extended to DOS programs.

Figure 5 – API RP11L Analog computer modeling of pumping system

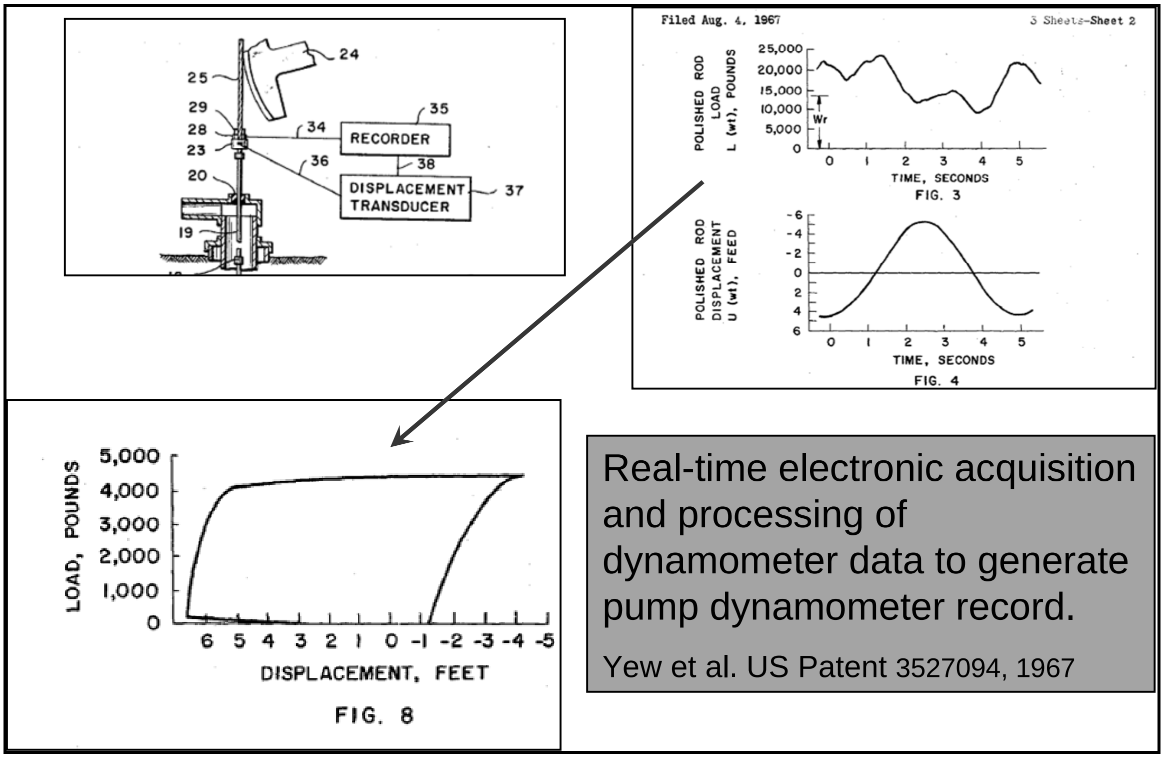


Figure 6 – Real-Time electronic calculation of pump dynamometer card.

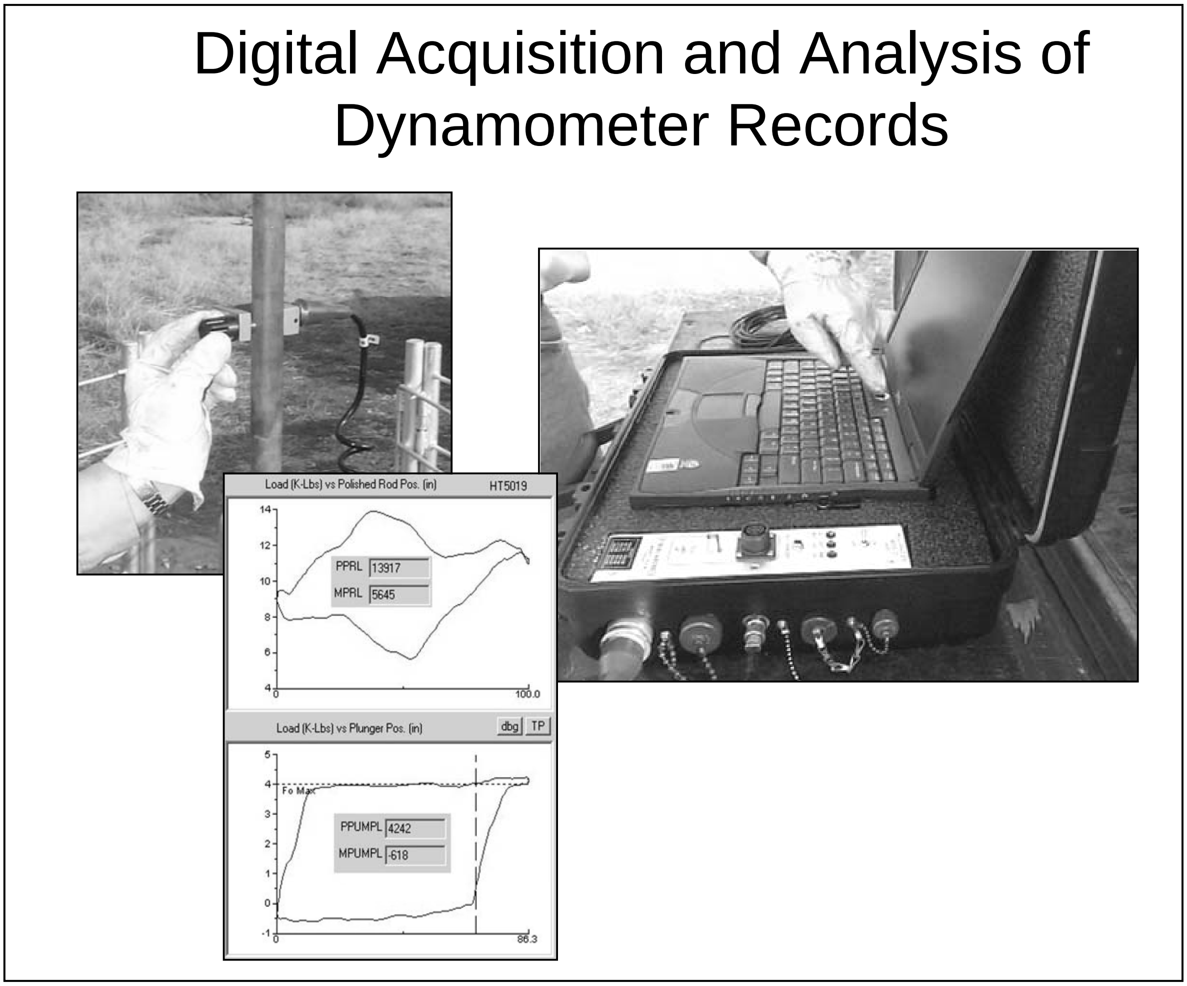


Figure 7 – State of the art dynamometer data acquisition and processing system

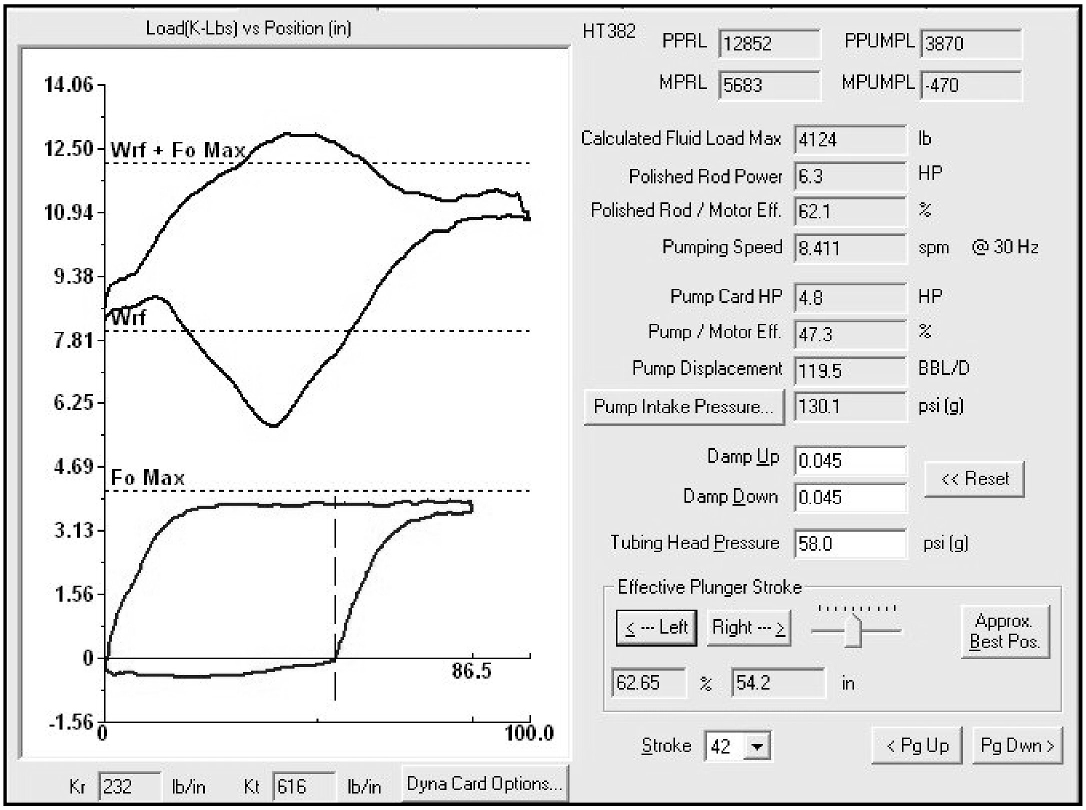


Figure 8 – Detailed analysis of dynamometer data for one pump stroke.

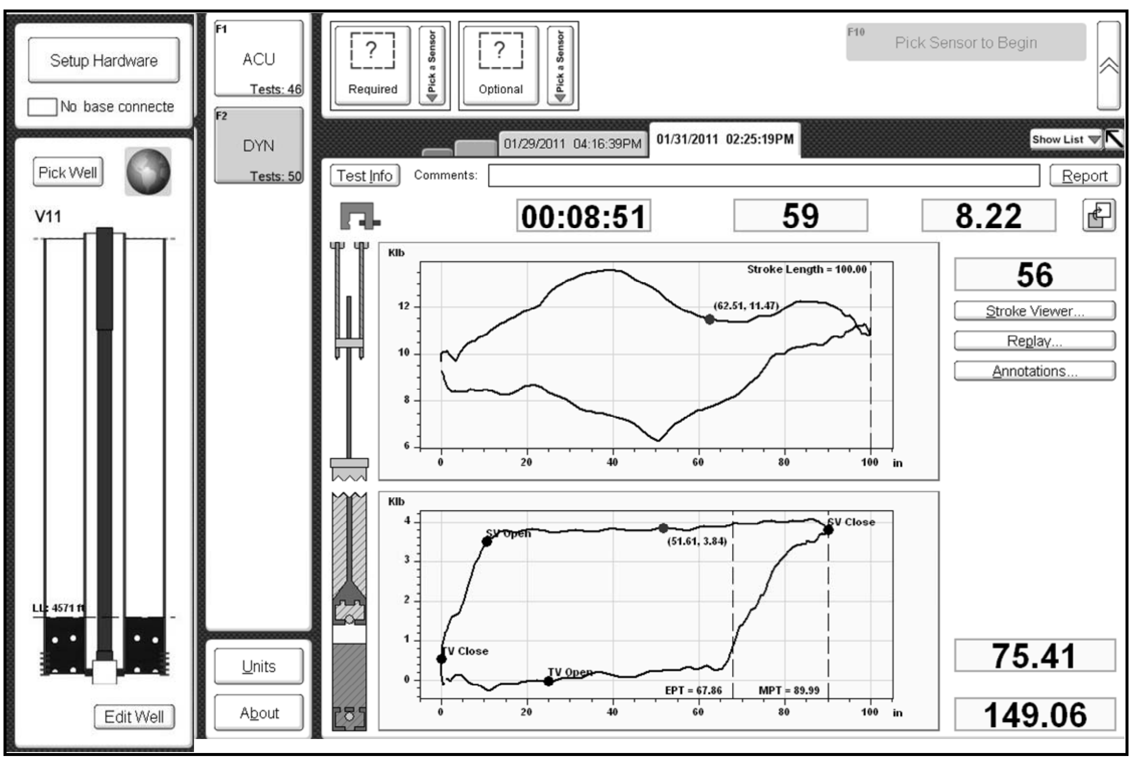


Figure 9 - Real-time Presentation of Surface and Pump Dynamometer Recording Coordinated with Fluid Level Measurement and Visualization of Fluid Distribution in Wellbore.

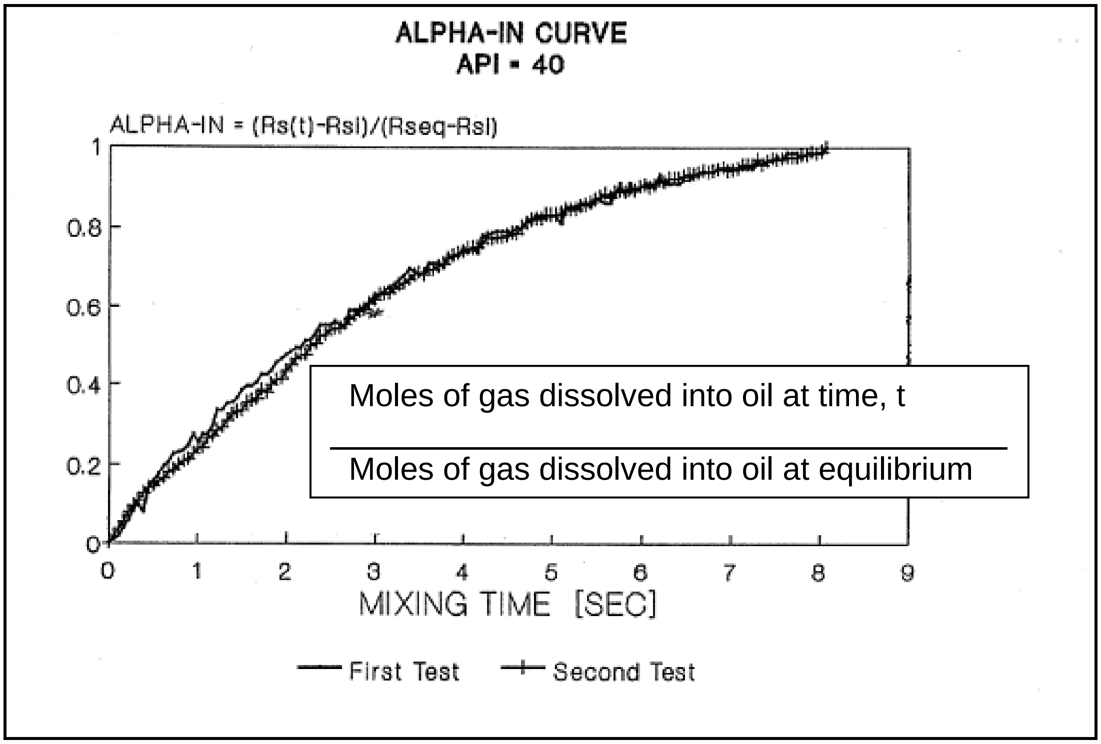


Figure 10 – Dimensionless rate of gas dissolution as a function of time. Ref 8.

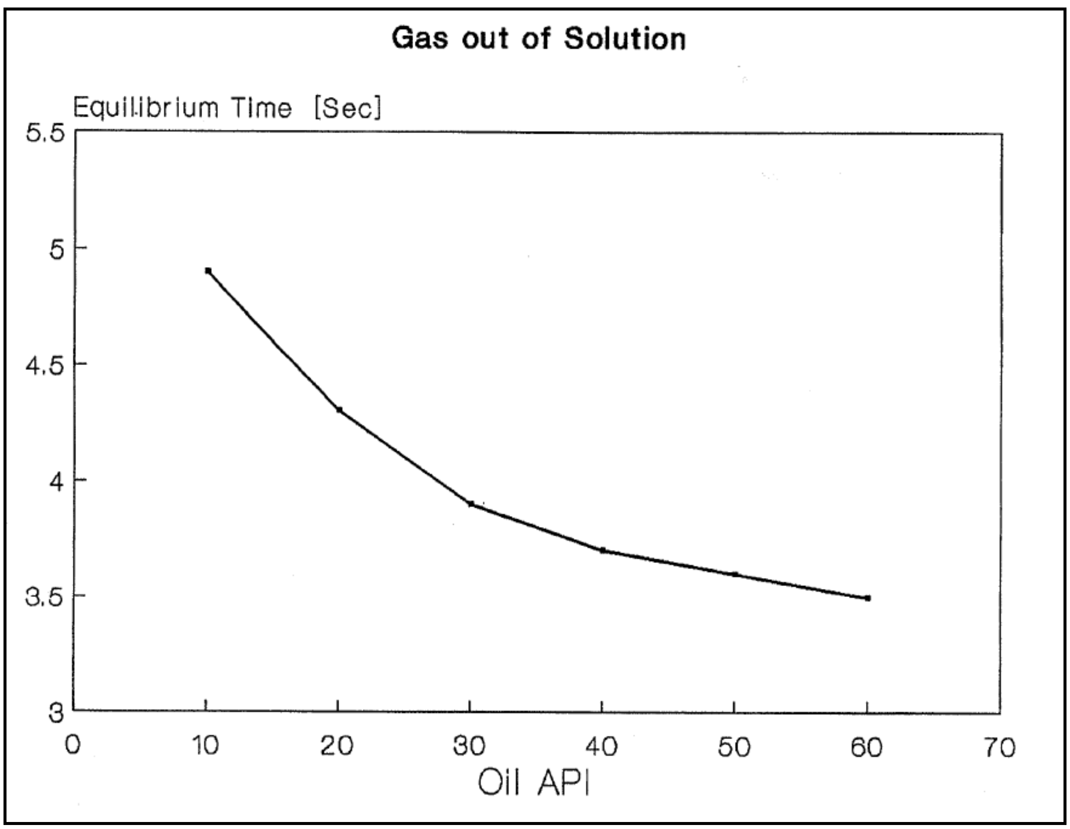


Figure 11 – Time for gas to evolve from liquid. Ref 8

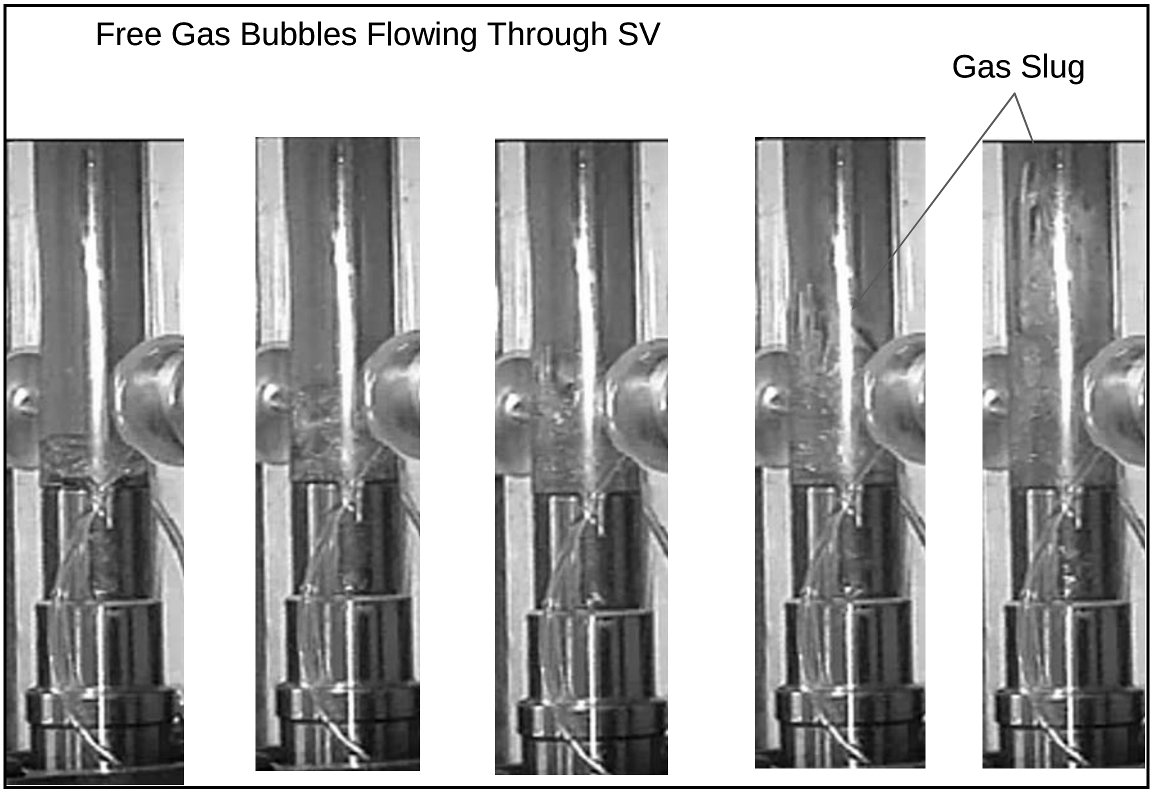


Figure 12 – Agitation and turbulence for two-phase flow through standing Valve. (Ref.9)

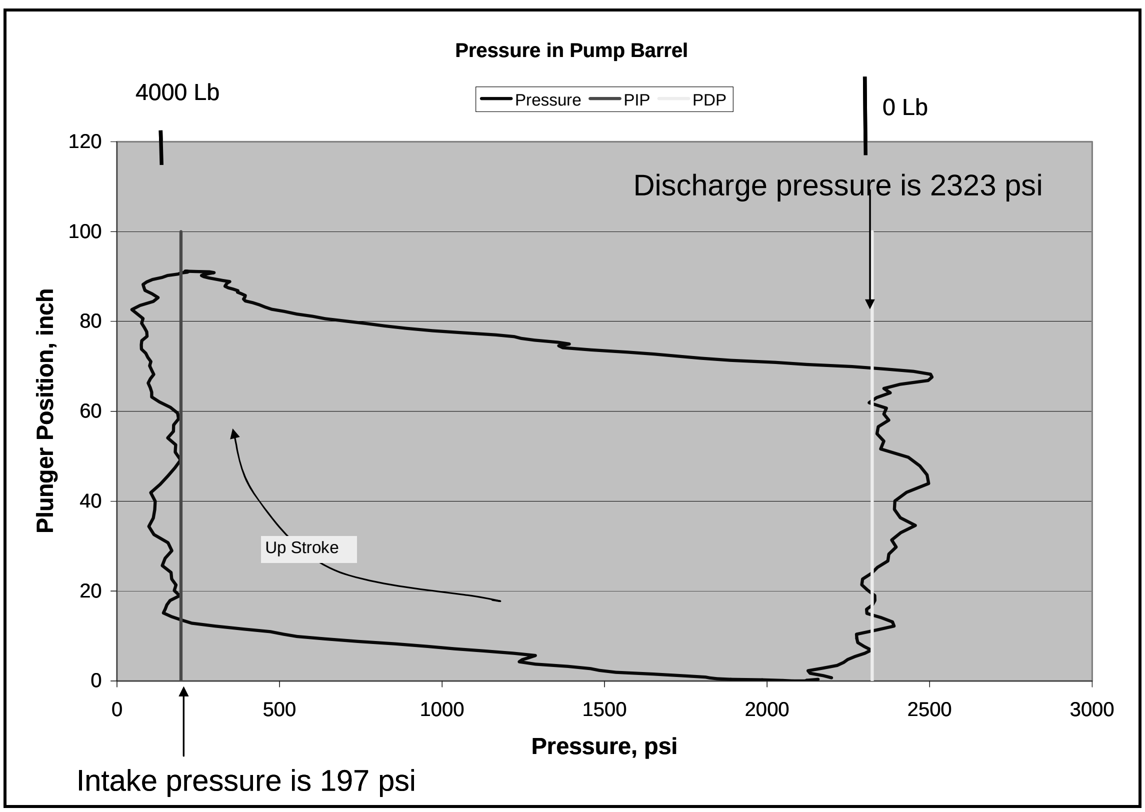


Figure 13 – Pressure Variation inside Pump Barrel during one Plunger Stroke

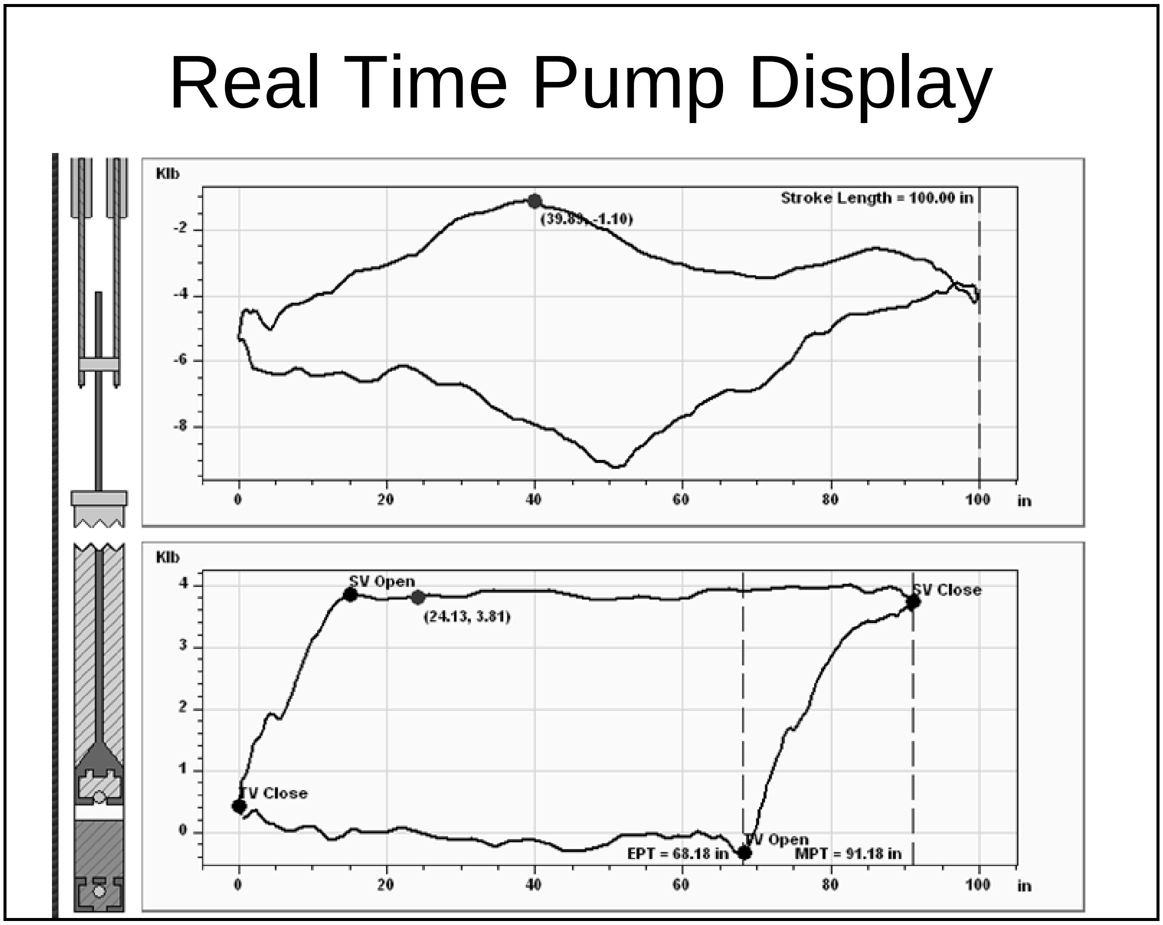


Figure 14 – Detail of Real-time visualization of pump operation with coordinated display of polished rod travel and loading.