A Polished Rod Transducer for Quick and Easy Dynagraphs

by

J. N. McCoy, Echometer Co.
J. W. Jennings, Consultant
A. L. Podio, University of Texas at Austin

ABSTRACT

A new polished rod transducer (PRT) for the quick and easy capture of dynagraph data has been developed. The purpose of this development was to provide the analyst with a transducer that could be quickly and safely installed by one technician for the acquisition of dynagraph data. The device is a polished rod clamp-on unit which collects both the position and load information necessary for a dynagraph. The device uses sensitive strain gauges to obtain the load information and an accelerometer for obtaining the position information. Tests have shown that the device will provide data suitable for the analysis of down-hole pumping problems.

INTRODUCTION

We have observed that dynamometer technicians operate alone many times, especially when there appears to be a problem with the downhole pumping system. In addition, they usually want to spend a minimum of time necessary to identify any problem that might be present with the system. These factors prompted the development of the transducer described in this paper.

The goals sought by this design are:

1. Quick and easy transducer attachment to the well.
2. Safe implementation (No need to place transducer between the polished rod clamp and the carrier bar).
3. Data of accuracy suitable for down-hole analysis.
4. Minimum of calibration done by user.

It has become state-of-the-art for those responsible for the efficient production from rod pumped well to obtain and utilize dynamometer information for the diagnosis of down-hole pumping problems, see Figure 1. The work by Gibbs and Neely[1] paved the way for this technology. Jennings, et. al.[2] described the specific data acquisition system used in this study. There is also the need for analyzing the surface installation, but that is not the central issue of this paper. The analysis of the down-hole situation is necessary if the operator is to determine the nature of equipment problems, if they do exist. Generally, down-hole problems may be put into one of the following two categories:

1. Down-hole equipment failure of malfunction.
2. Mismatch between the productive capacity of the formation and the pumping system.

The analysis of the first is usually possible with only dynamometer information and a calculated bottom-hole dynamometer card. The analysis of the second will require additional information, preferably fluid level, casing pressure, and static reservoir pressure.

THE TRANSDUCER

As shown in Figure 2, the transducer is a C-clamp sort of device that is lightly clamped to the polished rod about 8 inches below the carrier bar and high enough to not hit the stuffing box on the down stroke. There is a hole in the center of the arm of the "C" where the strain gauges are placed. In addition, an accelerometer and suitable electrical connections are provided as shown.

The transducer measures the change in rod loading by measuring the change in diameter of the polished rod. At first, this may seem like an extremely difficult measurement to make, but with sensitive solid state strain gauges it is quite possible and practical to do. If we look at the generalized form of Hooke's law for homogeneous isotropic materials, we can see that the strain in the radial direction resulting from a stress in the axial direction for the polished rod is:

$$\varepsilon = \mu \sigma / E$$

Where:

ε = radial strain
μ = Poisson's Ratio
σ = axial stress
E = Young's Modulus

Since the Poisson's ratio for steel is about 0.3, the radial strain is about 30% of the axial strain. So the device only has to be about 3 times more sensitive than a normal strain gauge measuring axial strain.

The PRT generates a change in output signal which is proportional to the load on the polished rod. The transducer is said to be linear as the output is a linear function of load. However, when the device is first installed on the rod a preexisting load is present. The transducer is calibrated to account for this preexisting load as described in the next section.

TRANSDUCER CHARACTERISTICS

There are three transducer operating characteristics that will be discussed in this paper: the linearity and sensitivity of the output, hysteresis, and temperature effects. It is very desirable that any transducer in a data acquisition system have a linear output, that is that the output signal is linearly related to the measured quantity.

Figure 3 shows the calibration measurements on a typical PRT. The output plotted is millivolts of transducer output. A gauge excitation voltage of 8 volts was used as is normally the case. These data were obtained by placing the transducer on a short piece of polished rod material, placing the assembly in a hydraulic press, and measuring the output which results from the compressive load applied. The curves shown are a plot of the actual data points, which is very close to a straight line in each case. In practice the best fitting line is used to determine the sensitivity of the transducer. Notice that the output is linear in all cases, although the slope of each line is different for each size polished rod as expected. Further notice that the sensitivity of the instrument is about 1 mV/Klb. For the 8 volt excitation voltage applied, a 1 lb change in load on the polished rod will result in a change of approximately I micro volt on the output. This voltage change is easily measured with the data acquisition system which has a resolution of 0.2 micro volt.

Figure 4 shows the results of a test on the hysteresis of the system when the polished rod load is cycled first up then back down. While there is a slight hysteresis present, we believe that most of the hysteresis is associated with the properties of the polished rod itself and not the properties of the transducer. While the rod is not stressed to beyond it's elastic limit, the polished rod material is not picked for ideal elastic properties and therefore exhibits some hysteresis.

Temperature has an effect upon the dimensions of the transducer. If the transducer and polished rod are at different temperatures when the transducer is installed, the temperature of the transducer will drift towards that of the polished rod. Let us say that the transducer is cooling, in which case it will be getting smaller. The electrical output which results will be similar to a decrease in polished rod axial load. A temperature compensation circuit is employed in the transducer to eliminate all the practical effects of this temperature change. This temperature compensation is easily accomplished since the transducer output is linear.

The effect of temperature is to change the size of the PRT relative to the polished rod. Figure 5 shows the effect of a change of 40^{o}F on both a compensated and uncompensated transducer which is clamped to an INVAR rod. Actually, we have found that the effect of temperature is only important when you are looking for changes in load over a period of several cycles. Since the effect of temperature is just a constant offset, this is automatically taken out during automatic calibration on a cycle by cycle basis. The figure also shows that one should allow about 15 minutes for the system to stabilize if maximum accuracy is desired. The pumping unit may be operated during this stabilization period if desired. Tests have shown that accurate downhole cards can be obtained without any waiting period however. A high tensile strength (15-5) alloy is used to make the transducer instead of aluminum for better temperature behavior even though aluminum is less expensive and easier to machine. The temperature drift effect is much more pronounced on shallow, low load wells than on deep, high load wells.

TRANSDUCER CALIBRATION AND ANALYSIS

When the transducer is first placed on the polished rod, the operator must be careful not to over stress the device. A simple display, similar to that shown in Figure 6, is shown on the data acquisition computer screen to assist the operator in properly attaching the

transducer. The screw on the transducer is adjusted until the triangle is approximately centered on the ruler. This assures that the transducer is operating near the midpoint of its range. The PRT has an output of approximately 15 mV/V depending upon the temperature at no load conditions. The adjusting screw is tightened to hold the PRT to the polished rod which is indicated by a zero voltage output.

The sensitivity of the transducer, change in output per unit change in polished rod load, is determined at the factory and should not change throughout the life of the transducer. The transducer should be protected from dropping to hard surfaces and other mechanical shocks as the accelerometer can be over stressed at about 40 g. Since the transducer is a linear device, a second calibration constant is needed, the offset. This value must be obtained for each test. There are 4 options for doing this:

1. Automatically, where the computer determines the offset by calculating the down-hole card and then determining the offset that causes the minimum value of the pump card on the down stroke to be zero.
2. From a previously measured buoyed rod weight.
3. From a calculated buoyed rod weight.
4. From an operator entered buoyed rod weight.

The automatic technique for determining the offset is normally used. First, the polished rod is stopped at the bottom of the stroke. The PRT is installed on the polished rod using the adjustment screw to zero the PRT output which is displayed on the computer screen. The pumping unit is started and data acquisition begins. The operator views the displayed data to determine if excessive drift is occurring which is manifested by varying maximum loads on the upstroke of successive cycles. When the drift is acceptable, which normally occurs immediately, the data is accepted by the operator for processing. The position of the polished rod is calculated first. Then, the operator selects a stroke for analysis. The computer analyzes the surface data which generally has positive and negative loads with well file rod data to obtain a down hole pump card. The down hole pump card will generally have large compressive forces. The bottom of the pump card is set to zero utilizing an offset. This assumes that the minimum load on the pump on the down stroke is zero, which is a practical value assuming minimal frictional forces. The surface card which contains both positive and negative load values is adjusted by the same offset that was utilized to shift the bottom of the pump card to zero. Software guides and prompts the operator during this simple acquisition and analysis phase.

The offset can also be obtained using manual entry of the buoyant rod weight by the operator. For the manual mode of operation, the polished rod is stopped at the bottom of the stroke. The transducer is installed. The pumping unit is operated for one minute to allow seating of the transducer to the polished rod. Again, the polished rods is stopped near the bottom of the stroke while the traveling value is open. The computer presents the operator with a drift screen which continuously monitors PRT output while the rod is stationary. When the drift is within acceptable limits, the operator continues with load selection. With the polished rod stopped near the bottom of the stroke and the traveling valve open, the buoyant rod weight exists on the polished rod. The operator has three choices of manual load selection. First, a computer calculated buoyant rod weight from data in the well file can be utilized to determine the offset. Second, if the operator desires more accurate data, the operator has the option of pre measuring the buoyant rod weight using a horseshoe transducer and entering this weight into the well file. The software allows the operator to utilize this pre measured buoyant rod weight if desired. For special conditions, the operator may also enter a zero or an assumed rod load if he is performing special tests such as measuring loads in an anchor line.

Figure 7 shows the load data for 4 complete pumping cycles taken from a typical well using the PRT. Figure 8 shows similar data from the same well taken with a horseshoe type of transducer. Notice that the data for the two transducers have the same shape and amplitude, the data for the PRT is simply shifted down by a constant. The automatic calibration procedure determines the offset necessary to make the PRT data equivalent to the horseshoe data. If during the examination of the load data as shown in Figure 7, the operator sees that a change from cycle to cycle is occurring (drift) additional data should be taken until the drift is at a minimum. Actually, it is only necessary that the drift over one pumping cycle be minimal in order to obtain good results. With the last 3 methods, the known buoyed rod weight is used to determine the offset of the transducer.

The down-hole card associated with the PRT data in Figure 7, before calibration, is shown in Figure 9, after calibration, in Figure 10. The down-hole card calculated from the horseshoe transducer data shown in Figure 8 is shown in Figure 11. Notice that the card shape, which is the primary diagnostic tool, is the same in all instances. Also, the load values for the calibrated PRT and horseshoe transducer are very similar.

A plot of the surface card for several successive strokes of PRT data is shown in Figure 12. Again, notice that the cards lay over one another, indicating little or no drift. Finally, Figures 13 and 14 show PRT surface and down-hole cards for a fluid pounding situation. These data are very similar to the corresponding data from the horseshoe transducer.

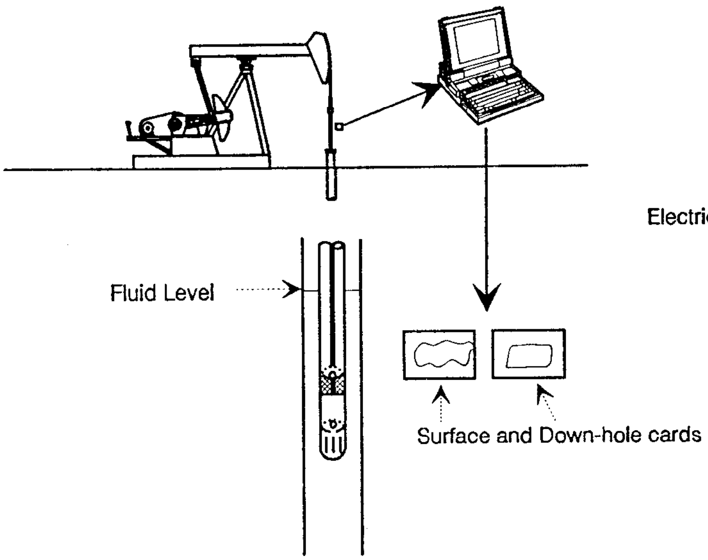
SUMMARY

The results presented show that the PRT can be a very useful tool in the diagnosis of rod pumping problems when used with down-hole dynamometer card calculations and fluid level determination. The speed and ease of use of the device lend itself to safe use by a technician in gathering the data for a diagnostic study.

REFERENCES

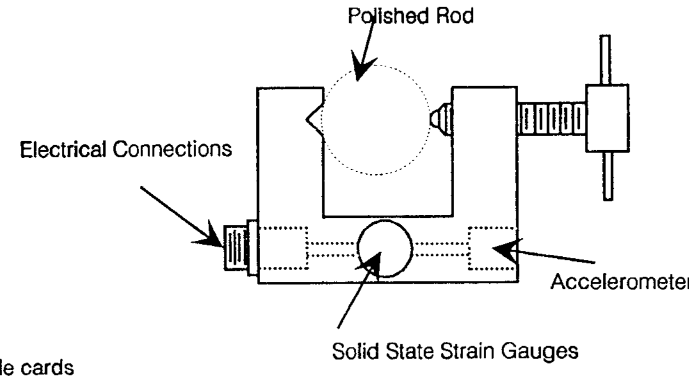
1.Gibbs, S. G. and Neely, A. B. : "Computer Diagnosis of DownHole Conditions in Sucker Rod Pumping Wells, "JPT (Jan. 1966) 91-98.

2.Jennings, J. W., McCoy, J. N., and Drake, B. "A Portable System for Acquiring and Analyzing Dynamometer Data." Proceedings of the Thirty-eighth Annual Meeting,SWPSC (Apr. 1991) 314-323.



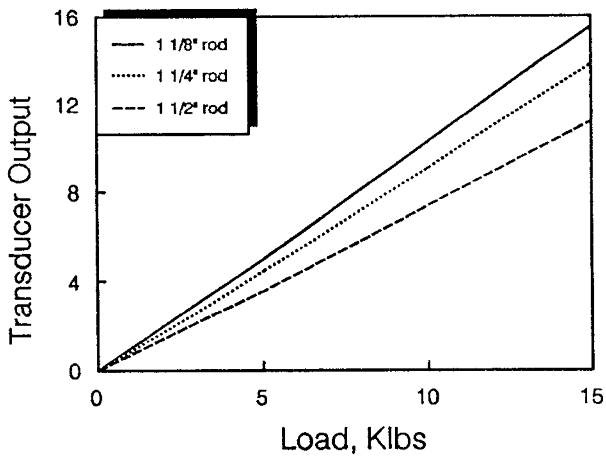
Down-hole Analysis System

Figure 1



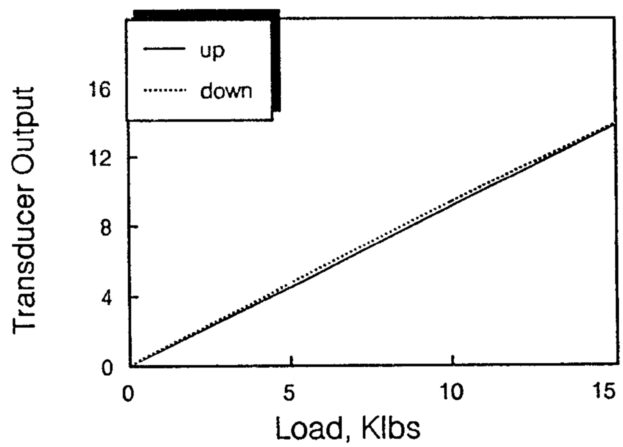
Polished Rod Transducer

Figure 2



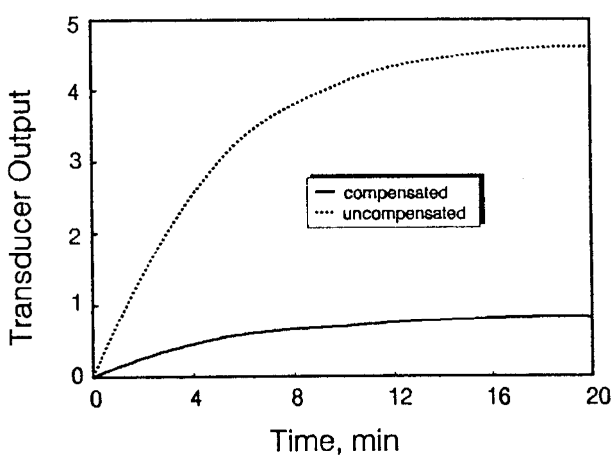
Calibration Curves;' PRT

Figure 3



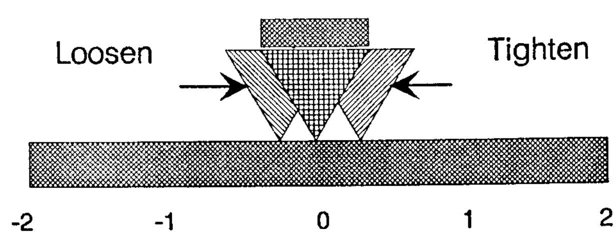
Hysteresis, PRT on 1 1/4 " rod

Figure 4



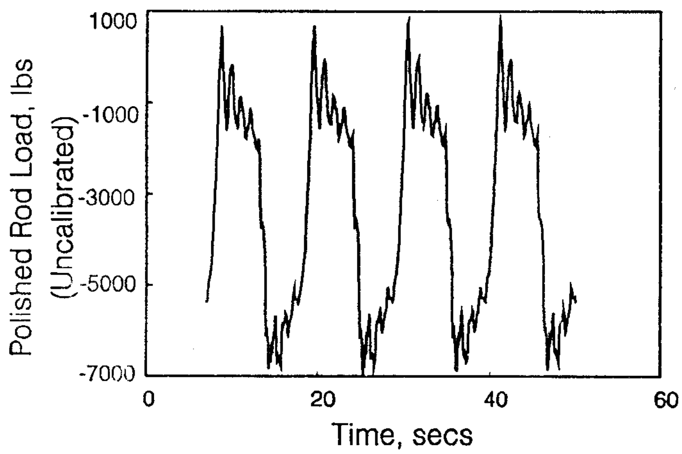
Effect of Temperature on PRT

Figure 5



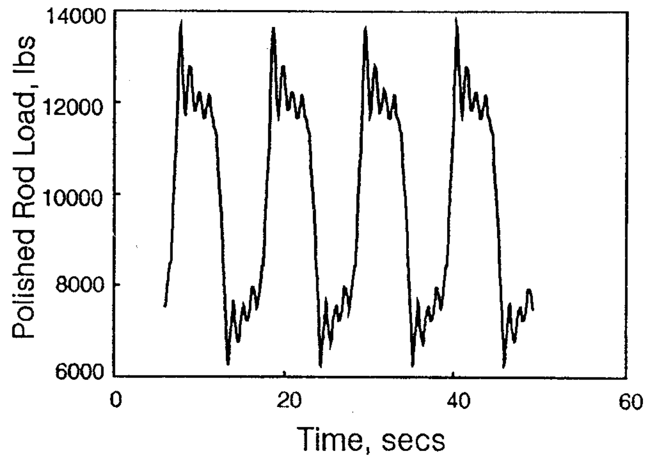
PRT Adjustment Screen

Figure 6



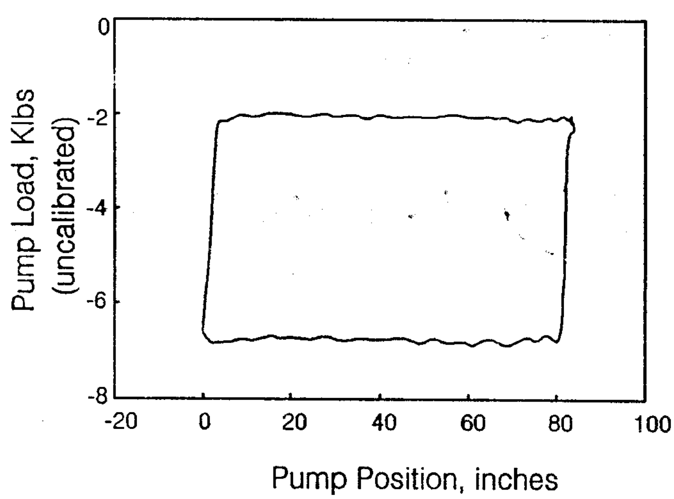
Four Cycles of PRT Load Data

Figure 7



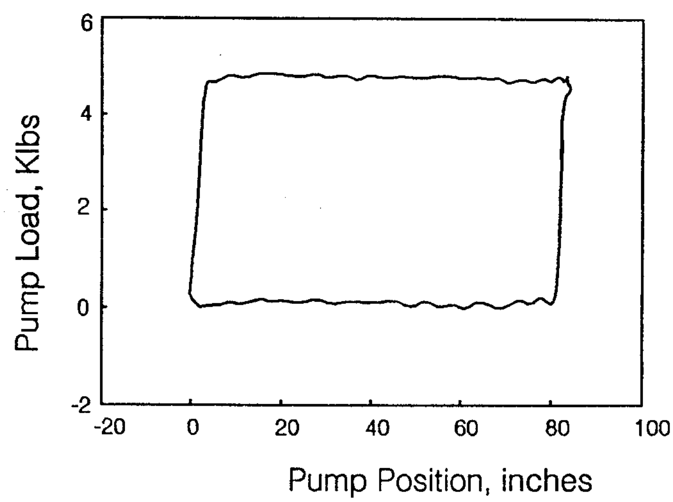
Four Cycles of Horseshoe Load Data

Figure 8



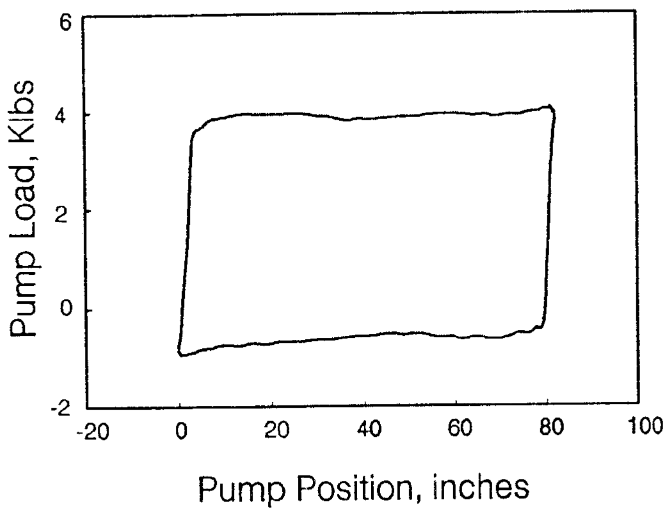
PRT Pump Dynagraph

Figure 9



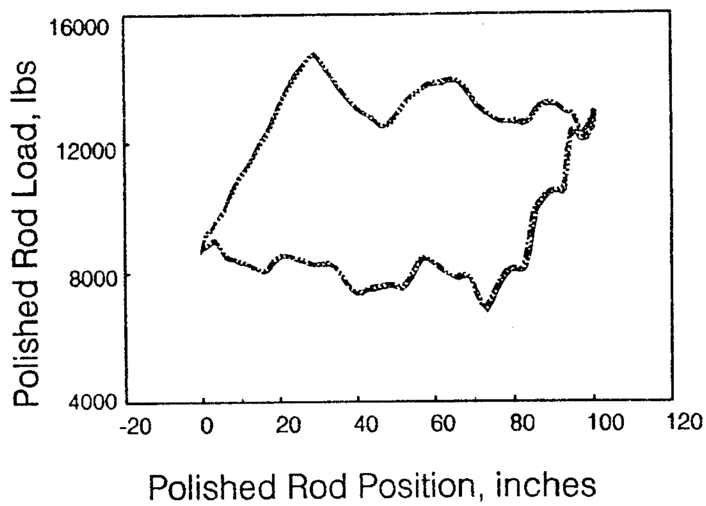
PRT Pump Dynagraph

Figure 10



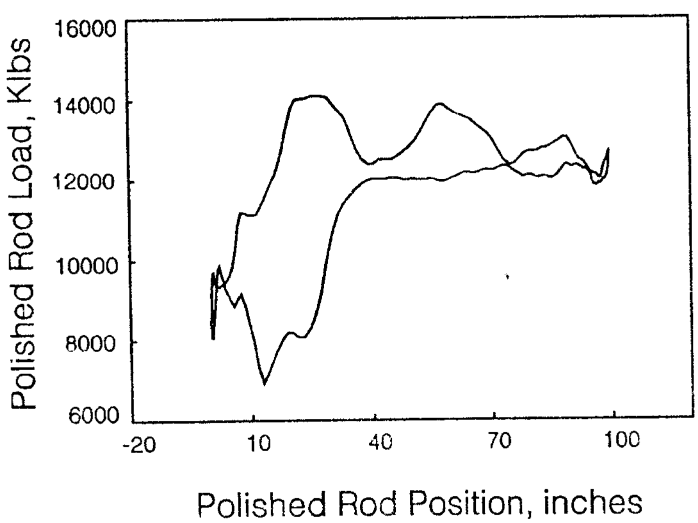
Horseshoe Pump Dynagraph

Figure 11



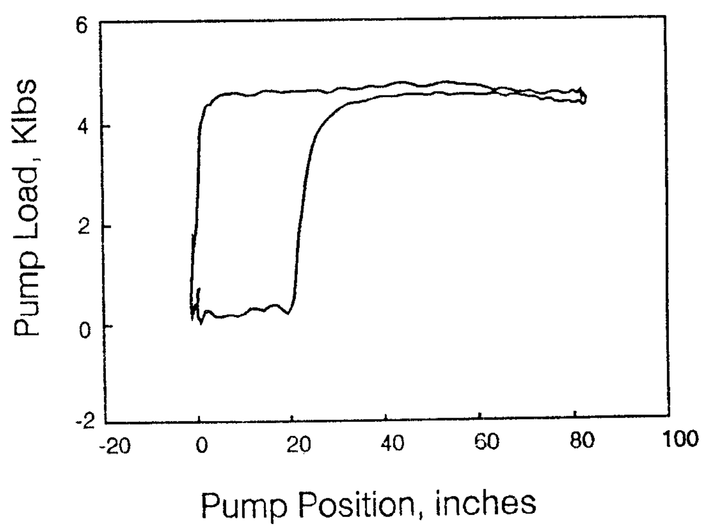
PRT Dynagraph (overlay)

Figure 12



PRT Surface Dynagraph, pounding

Figure 13



PRT Pump Dynagraph, pounding

Figure 14