BEYOND PUMP-OFF CONTROL WITH DOWNHOLE CARD WELL MANAGEMENT

Lindon Dugan and Lance Howard
Lufkin Automation

BACKGROUND

For years questions concerning problem wells have been answered thru well analysis. Current RPC technology can predict well problems, manage pumping wells, and control cycle times via the downhole pump card. This leap in technology goes beyond normal pump-off control to total well management. Guesses can be made viewing the surface card. Decisions are made viewing the pump card. Utilizing diagnostic software within the control providing the operator both the surface card and downhole pump card is like having a dynamometer and analyst on the well 24 hours a day. This downhole card detecting pump fillage will assist the operator in detecting problems in the well in advance of equipment failure, aid in diagnosing downhole conditions while maximizing production.

Why control a well with peak and minimum load violations when you can MANAGE the entire beam pumping system from electric motor to downhole pump. In addition, enhanced historical data and analysis capability are available.

This paper will review the anomalies of the surface card with answers provided by the downhole pump card. Actual well analysis comparisons, computer predictive comparisons, and data from Pump-off controls currently using pump card technology will be used in making operating decisions.

DISCUSSION

Many factors contribute to the shape of the surface card. Pumping unit geometry, plunger size and fit, pump design, rod harmonics, rod design, gas, friction, incomplete fillage, tagging bottom, pumping speed, pump depth, and others will influence the card shape. Indications of well problems may not be seen through the haze associated with the surface card.

Accurate interpretation can be attained through analysis of the downhole card. Many items can be detected in analyzing the pump card. This includes loose tubing anchor, traveling valve problems, standing valve problems, fouling pumps, pump leakage, pump sticking, over travel, under travel, fluid load, friction, gas interference, pump-off, tagging, inoperative pump, etc.

Simple answers to obvious questions may surprise you when considerations are made about what is occurring 5000 to 12.000 feet below surface. For instance:

1. Which provides the greatest production?
   A). 1 ¼” x 9.5 SPM **x** 120” SL or
   B). 1 ¾” **x** 9.5 SPM x 120’ SL
2. What does a horsehead appearing in the surface card indicate?

Overall well management can be accomplished by utilizing certain methods of attaining load and position. Obviously the better the end devices the better the data will be.

LOAD TRANSDUCERS

Two options are available. Beam Transducer and Polished Rod Load Cell. With enhancements to beam transducers good data is available. However, the Polished Rod Load Cell provides quantitative data which is invaluable in rod pump analysis.

POSITION IS CRITICAL

Many different technologies have been used over the years to determine polished rod position during the stroke. These include string transducers, Hall-effect sensors, inclinometers, angle transducers, reed switches and proximity switches.

For simple Pump-off control all of these technologies are effective for producing some idea of polished rod position which, when plotted with load is useful for detecting some degree of incomplete pump fillage. A controller can recognize the change in surface card shape and shut down the prime mover. This method is time tested and proven to be effective. However, as technology moves forward, the industry demands more and more from the Rod Pump Controller. Crude estimates of pump fillage based on surface cards are no longer sufficient; RPC load and position data are being used for well analysis, the transducers themselves need to be more durable and new safety concerns dictate where and how these devices can be installed. Our experience indicates that the best solution to address all of these issues is using Hall-effect sensors installed on the motor shaft and the crank to detect bottom of stroke and RPM.

Anyone who has ever spent much time setting up RPCs to control wells know that some wells are very easy to figure out and some are very difficult. Gas interference and down-hole pressures can create challenging problems for how to best configure the controller to optimize production. In such cases accurate cards can be very helpful in the same sense that a pair of reading glasses can be helpful when trying to read fine print. Clear and precise pump cards can help immensely in distinguishing between such things as gas interference or pumped-off conditions. Each of these situations might indicate different pump-up and down time RPC settings. It stands to reason that the best way to get a clear picture of down-hole conditions is with the down-hole card.

Another familiar application for the RPC is to connect it to a SCADA system and use the RPC data with diagnostic programs for well analysis. In these situations accurate load and position data are critical. The old computer adage "garbage in, garbage out" applies here. There is no substitute for accurately measured data.

Position devices also need to be designed to provide years of reliable service in the harsh oilfield environment. Moving parts on the device itself or the transducer cable tend not to hold up over time.

The industry also continues to demand safer practices when working around pumping units. Many traditional position devices are designed for installation on the walking beams. In most cases this requires someone to climb up on the pumping unit to the walking beam to install the device. Since many oil companies no longer permit climbing on their pumping units for safety concerns, the alternative is to have the installer lifted in a bucket truck up to the beam, Though this is a good solution, it adds significant cost to the job.

TYPES OF POSITION DEVICES

Position devices fall into three categories 1) digital input devices that signal a single point in the stroke, 2) analog input devices that give a continuous signal of polished rod position, and 3) two digital input devices measuring both motor RPM and top or bottom of stroke. This section will give consideration to each type as to how well they meet the forego-ing requirements.

Examples of position transducers that use a single digital input to indicate a certain point in the stroke are typically proximity switches and reed switches. This type of device samples position only once and assumes polished rod motion throughout the rest of the cycle. Accurate polished rod position is only truly known at one point in the stroke. By combining this single input with other data such as saved dynamometer position, this method can increase the probability of accurate position, but it is still only an assumed position and not very reliable for doing analysis work. However, there are many benefits to this technology, it is easy to install while standing on the ground, it uses no moving parts and it can provide years of reliable service without failing.

Analog position transducers such as inclinometers, angle transducers or other potentiometers or "stroke pots" give a more accurate measure of polished rod position than a single digital input. These devices continuously measure the angle of the walking beam and update the controller many times throughout the stroke. This data is much more reliable than simply assuming polished rod position, but these devises also have their downsides. In most cases they must be mounted on or near the walking beam and thus have safety issues or may require a man lift to install.

In the case of angle transducers an arm is attached to a potentiometer and the walking beam and moves up and down keeping a parallel relationship to the beam at all times. Inside the unit the arm is connected to a potentiometer that moves up and down with the motion of the walking beam. Angle transducers have several moving parts and therefore must be maintained and are prone to breakage.

Inclinometers are a better solution because the internal moving parts are not mechanical but fluid which moves back and forth across a disk. Inclinometers are energized with an 8-volt circuit and their internal circuits can fail when they receive a power surge. They also tend to lag true polished rod position rather than moving simultaneously with the walking beam and thus are not completely accurate. This lag can be corrected for within the POC firmware or in the inclinometer itself with a lead circuit. Lufkin Automation's internal testing has shown that the POC programming solution can be more accurate than using the internal lead circuits.

The third, and most recommended method of measuring polished rod position uses two Hall-effect digital input sensors. One sensor is installed on the crank to indicate bottom of stroke. The other is installed on the motor shaft and measures motor speed and revolutions for each stroke of the pumping unit. This "N rev" number can then be divided into 360" of rotation to provide the degree of crank angle change in each revolution of the motor. Since crank angle and polished rod position are directly related this provides a very good method for determining accurate polished rod position at any moment during the stroke.

Besides accurate polished rod position the benefits of this method are numerous. Rather than an analog device, two digital inputs are used. With analog devices circuitry can fail in the event of a power surge. Hall-effect sensors use a magnet and a sensor to sense the magnetic pulse with each revolution. Thus there is very little that can fail electrically or mechanically. Both sensors can usually be installed while standing on the ground or the pumping unit base and do not require a climbing harness or a bucket truck. By using Hall-effect sensors for position measurements and polished rod load cells for load measurements, RPCs can have dynamometer quality data to use in its calculations.

OTHER BENEFITS OF KNOWING MOTOR SPEED

By having motor speed data in the POC this data can be used in many ways to add useful features to an RPC and protect the Rod Pumping system.

Motor speed can be used to calculate motor power that can be used as a backup method of pump-off control.' Pump-off can be detected by monitoring a drop in motor power. RPCs that normally use load and position to determine pump-off can also record the motor power number at each pump-off event. This can be useful if the controller ever loses its load signal. The RPC can automatically fall back to motor power control and continue operation without a load signal until it is restored. See example 15 to view the relationship between the surface card area and PRHP.

Motor speed is also useful for detecting NO RPM or LOW RPM conditions. The POC can record an alarm condition or shut down the pumping unit if one phase of the voltage drops out, a pump sticks or a low voltage condition occurs. This is another way the POC can protect a rod pumping system.

Stroke Pot, Proximity Switch, Reed Switch, Inclinometer, Hall Effects and string position transducer are all options. While the string transducer may give very accurate position its longevity in day to day operations is short term and we therefore concentrate on the Hall Effects.

PUMP FILLAGE OF THE DOWNHOLE CARD VS. PUMP-OFF SEPTOINT OF THE SURFACE CARD

Pump fillage is an automatic setting. By that I mean the operator simply inputs a certain amount of pump fillage that is acceptable to him. For instance 80% pump fillage. When the pump card reaches 80% pump fillage the well shuts down for the predetermined amount of downtime. This would occur when the net stroke is 80% of the gross stroke. Gross stroke is the actual downhole plunger movement, and net stroke is the actual plunger downstroke in which the TV is open. Consequently, the operator doesn't have to view a pumped off card to set the pump-off set point associated with surface cards.

In some cases with special geometry units the surface stroke may appear pumped off when pump fillage is still full or adequate. See example I, surface card indicates about 50% incomplete fillage. The downhole pump card in this example indicates greater fillage and possible premature pump-off and shutdown if relying on the surface card only. This could result in loss of production. This same pump card further indicates delayed closing of the traveling valve on the upstroke.

In other circumstances with fiberglass rods the pump-off may actually appear on the left side of the surface card instead of the right side. When controlling off the downhole pump card pump-off is always indicated in the same manner. Thus, less interpretation is required on the part of the operator. (Example *2* Surface card and Pump card with complete fillage. Example **3** is the same application with incomplete pump fillage.)

Gas interference can cause significant change to the surface card as well. Gas interference can be seen in the surface card. However, when viewing the downhole pump card it is easy to determine the amount of incomplete fillage due to gas. The operator, knowing his incomplete pump fillage due to gas, can then set his pump fillage parameter more accurately.

INFERRED PRODUCTION

Inferred Production can be calculated from a surface stroke. However, accuracy demands that it be derived from the downhole pump card. Normally, steel rods are going to have less plunger movement down hole than the actual surface stroke. A Well Manager/ Controller using the patented downhole algorithm will accurately calculate inferred production based on a per stroke basis using the downhole net plunger movement, strokes per minute, plunger constant, and daily per cent run time.

In Fiberglass rod installations there may be a significant increase in downhole plunger stroke resulting in greater production potential. Example 4 is an application with a 144 inch surface stroke. Anticipated production rates based on the surface stroke would be significantly lower at 144 inches than the 226 inches occurring at the pump. The downhole stroke is presented in example 5.

However, poorly designed systems, possibly due to having too large a pump may result in abnormal rod stretch and loss of production due to a shortened downhole plunger stroke. This can be verified and accurately scaled through well management using downhole pump card technology.

In answering the first question above about which application produces the most fluid, the obvious answer is the 1 ¾" pump would provide more fluid.

Pump Capacity calculations based on surface stroke would indicate:

1 ¼" x 9.5 SPM x 120" Surface SL = 207 BPD with 85% efficiency = 176 BPD
1 ¾" x 9.5 SPM x 120" Surface SL = 407 BPD with 85% efficiency = 346 BPD

Example **6** reflects the surface card utilizing the 1 ¼" pump. Example 7 pertains to the application utilizing the 1 ¾" pump. This example would indicate a loss of stroke downhole due to its slant upward and to the right.

In the application of the fiberglass rod design provided by the operator the following would be more representative of the actual production, based on net pump stroke:

Net downhole stroke length of 134" x 1 'A" x 9.5 SPM = 232 BPD
Net downhole stroke length of 54" x 1 ¾" x 9.5 SPM = 183 BPD

Examples 8 and 9 portray the actual downhole stroke for the 1 ¼" and 1 ¾" pumps.
Thus, the 1 ¼" pump with the fiberglass rod string actually produces more fluid!

Review and comparison of the following cards illustrate the benefit and enhanced ability of the pump card to both trouble shoot well performance and provide reliable control as well.

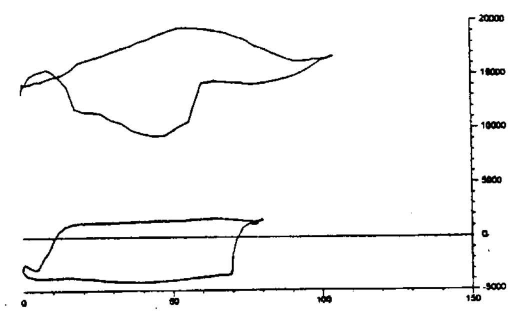
The answer to the second question posed at the beginning of the paper relates to a surface card that has a problem. The downhole pump card answers the question.
Example 10 is an application where the surface card throws a big question mark to the operator. Normally an analysis would be performed on the well to determine what is occurring at the pump. Utilizing the downhole technology of pump cards available now in rod pump controllers/well managers the answer will be displayed for the operator at the well site. Note example 11.

Examples 12 and 13 reflect both the surface card and downhole pump card on a well that has complete pump fillage. Pump Card shows 100% pump fillage. Example 14 is the same well with 57% pump fillage. The example indicates downhole plunger movement increased 6". This increased plunger travel creates a tag that influences the shape of both cards.

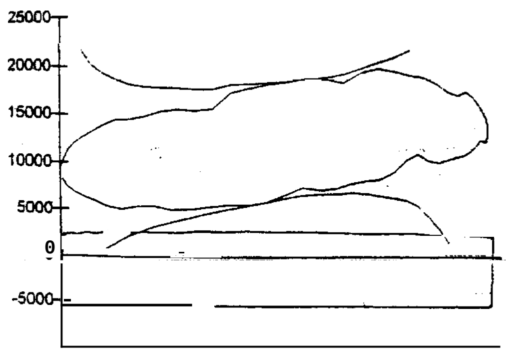
CONCLUSION

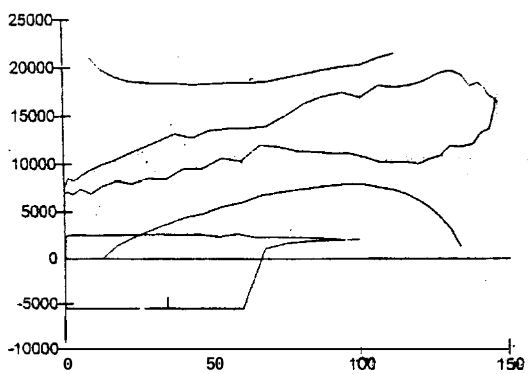
Using **DIAG** analysis software imbedded in the controller a downhole dynamometer card can be calculated from a surface card on each and every stroke, viewed on the display at the control, and employed for diagnosing problems while controlling the well. Instead, of taking a snapshot of 1 card over a 24 hour period we can now look at each and every card 24 hours a day, 7 days a week, 365 days a year to determine optimum pumping time and off time. Thus, providing the operator greater system protection, more accurate production data, gas flow if wanted, and simplified analysis interpretation.

[1] Utility of Motor Speed Measurements in Pumping Well Analysis and Control", S.G. Gibbs SPE Production Engineering (August 1987).

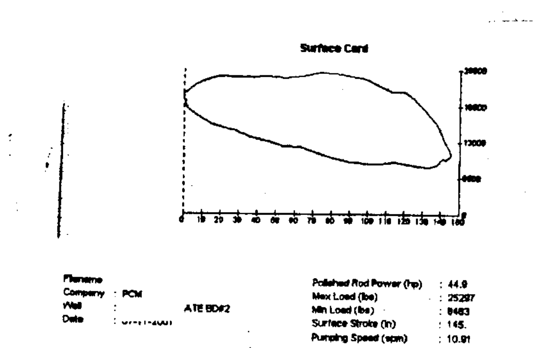


EXAMPLE 1

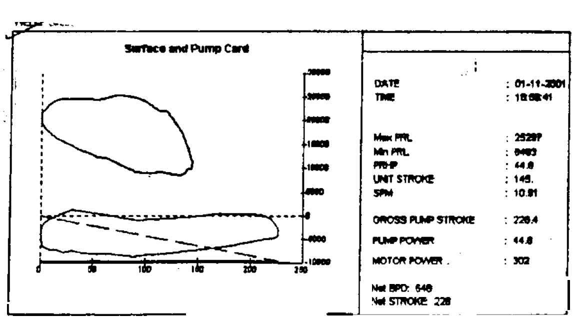




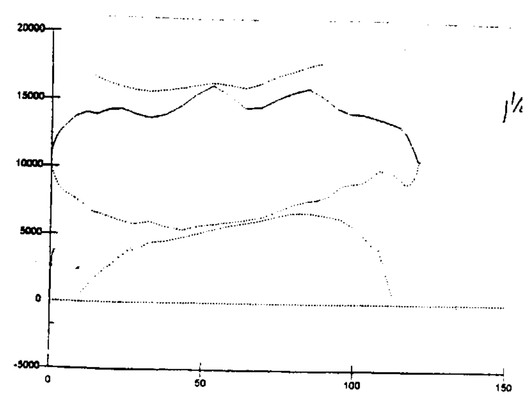
EXAMPLE 3



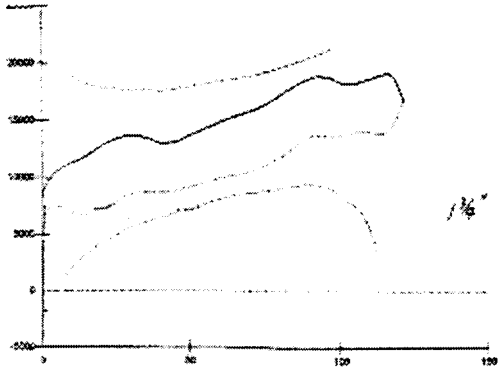
EXAMPLE 4



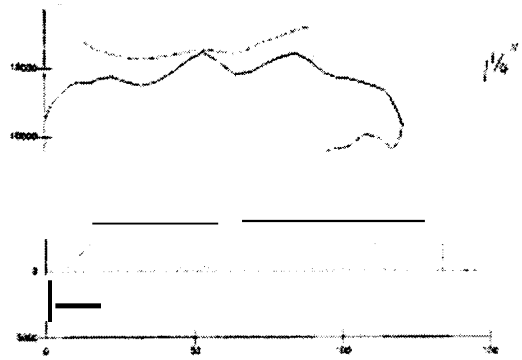
EXAMPLE 5



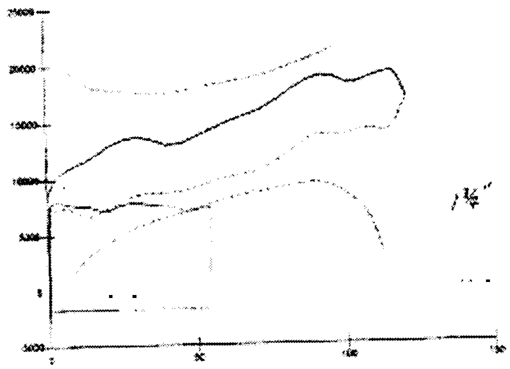
EXAMPLE 6



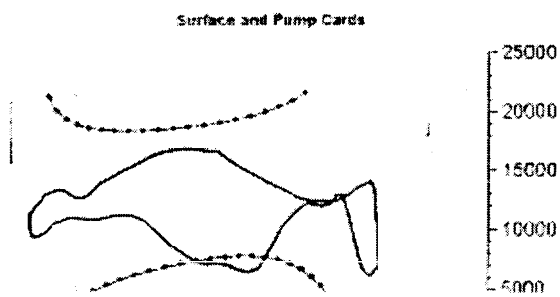
EXAMPLE 7



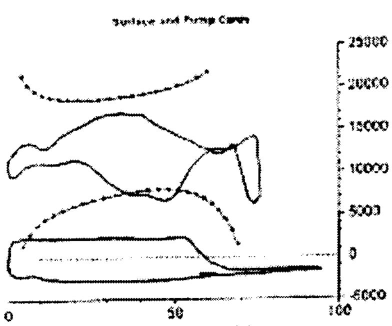
EXAMPLE 8



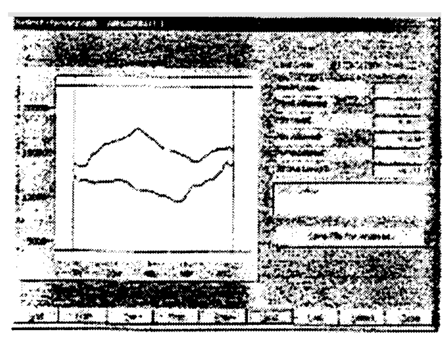
EXAMPLE 9



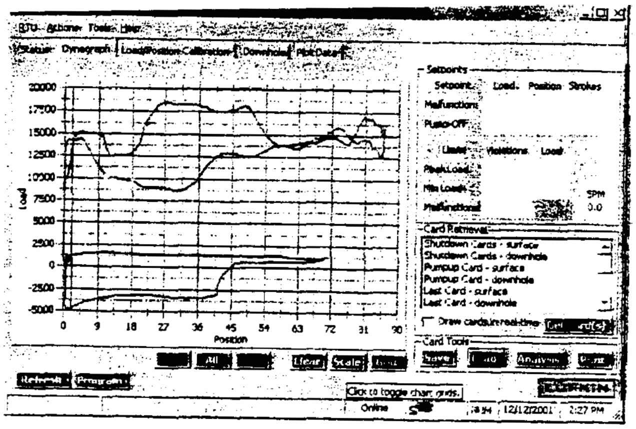
EXAMPLE 10



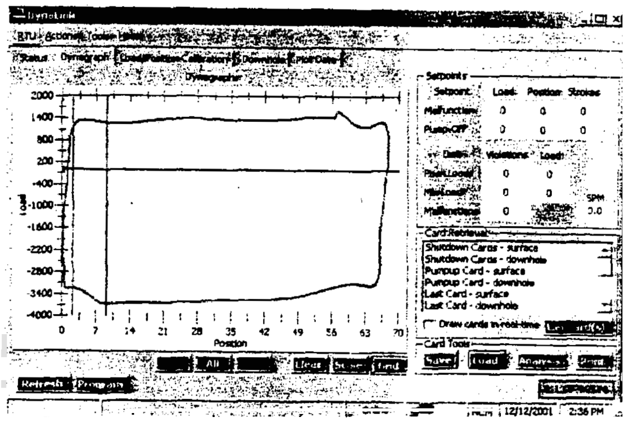
EXAMPLE 11



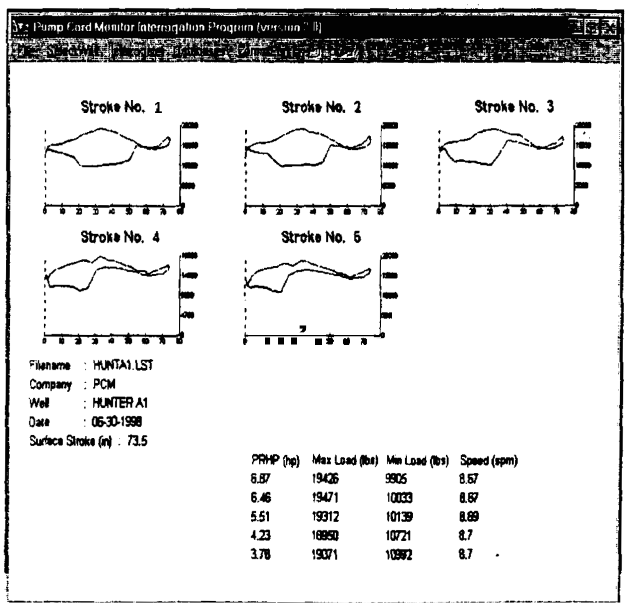
EXAMPLE 12



EXAMPLE 14



EXAMPLE 13



EXAMPLE 15