Presented at the 50th Annual Southwest Petroleum Short Course, Lubbock, Texas, April 2003

New Dynamometer Technology Allows Quick Setup and Easy Operation

LeMoyne Boyer, Doneil Dorado and Andy Cordova
Lufkin Automation

Abstract

Dynamometers have been used for many years to analyze beam-pumped wells. The evolution from mechanical systems to modern computerized systems have provided the industry with sophisticated dynamometers for the diagnosis of wells. Typical modern systems require significant capital outlay and specialized training for proper operation; this has limited the use of dynamometers for well analysis. This illustrates a need in the industry for a simple, accurate dynamometer data-gathering tool which is easy to setup and use.

This paper describes a new self-contained system which can record surface and pump cards on a well within minutes of arrival at the well. It automatically calculates inferred production based on the pump card. It also allows the operator to record valve checks, counterbalance, and perform pump leakage calculations without an on-site computer. All data can be brought to the office and transferred to a desktop computer for a more detailed analysis if needed.

(LUF617/300/0506)

Background

Dynamometers for beam pump systems have gone through a significant evolution over the last several decades. Early models were bulky mechanical devices that did not allow the user to view the data while the unit was running. A later generation was developed utilizing X-Y plotters where the user could view the surface dynamometer card while the pumping unit was running. Data was compared to manual calculations to determine if the unit was in proper operational tolerances. With the invention of the sucker-rod wave equation the use of the computer was introduced.[1] Actual X-Y co-ordinates were entered into the program from plotted surface dynagraphs so the computer could run the sucker-rod wave equation and calculate downhole pump cards. Several methods were developed to digitize the points using an electronic pen/board and special memory devices attached to the X-Y plotters.

During this evolutionary process operators learned that quality data was necessary to get meaningful results. Common problems involved not picking equal time increments for load and position data. Another common problem was finding load and position transducers, that would provide reasonably accurate readings.

The next generation of dynamometers (for example, see Figure 1) utilized a computer with a signal conditioning device to automatically convert the analog load, position, current and RPM signals directly to a digital signal that could be interpreted by the computer.[2,3] Of course early computers were bulky, required AC power and were not easily adapted for use in the oil field. The development of laptop computers with their self contained batteries and the ability to use 12VDC from a vehicle was quickly accepted for dynamometer work in the oil field. The dynamometer had finally become a tool that could be used at the well site to provide a complete well analysis or even redesign the pumping system, if needed.

Dynamometers today are typically of the computer type and are complicated systems that offer many features, some of which are not often utilized. Many independents have opted to only have their operators shoot fluid levels and simply do not supply dynamometer equipment. With an average cost of $20,000 or more plus required training, it is often considered too expensive. On top of that, many companies are not willing to supply expensive laptop computers to their operators in the field.

In past years many companies had artificial lift technicians that were responsible for shooting fluid levels and running the dynamometer. Working with field supervisors, operators, and engineers these technicians became a valuable part of a team, helping to reduce the lifting costs in a field. Many companies today have eliminated or minimized these positions, combining these responsibilities with those of the operators.

With manpower constraints in today's oilfield, dynamometer analysis has been under pressure due to the lack of available time that operators can spend at a well site gathering and analyzing data. Consequently many wells are not being optimized as they should. This has been partly resolved by the more widespread acceptance and use of automation systems with rod pump controllers, which can gather data and control the well keeping it optimized.

Advances in electronics technology have been successfully applied to automated rod pump controllers resulting in a very reliable, low cost, accurate and very advanced device.[4] Rod pump controllers have practically evolved into permanently mounted dynamometers that are on hand to provide data and optimization of the well 24 hours a day.

To address these issues, rod pump controller technology has been adapted to a portable instrument[5] that utilizes standard transducers required by a typical dynamometer system. The real benefit from the new system is that it is much easier and less complicated to use, thereby allowing for much quicker data collection than any of the current dynamometers on the market. It can provide a quick analysis of the pumping system and, if a more detailed analysis is required, the data can be stored and retrieved at the office using the utility software provided.

Discussion and Results

Equipment and Features

The dynamometer system, shown in Figure 2, includes a self-contained microprocessor with advanced data acquisition circuitry which provide accurate readings of polished rod load and position throughout the stroke. A built-in large LCD and keypad eliminate the need for a dedicated laptop computer while gathering dynamometer data at the site.

The user has the option of connecting a standard horseshoe load cell for accurate dynamometer data, or a clamp-on load cell can be used for a quicker analysis. The clamp-on, as is well known, does not require the operator to stand-off the well, but will sacrifice some accuracy in the measured load, and suffers from not knowing the zero offset which changes each time the device is clamped on a polished rod.

Position is measured with a standard string potentiometer transducer. This has been found to be the most accurate method of measuring position for this application and has been used for many years. If a simple calibration procedure is followed, it is not necessary to measure the stroke length of the pumping unit and enter it manually.

This new quick dynamometer system allows an operator to obtain a quick surface dynamometer card in a matter of minutes. Alternatively, a rod design can be pre-entered so that the system will calculate an accurate downhole card within seconds after the surface card is collected. Also included is a calculation of the total fluid production (*inferred production*), giving the operator a quick overview of his well and its production.

Another feature is the valve check and counterbalance program. The user can record load and position while the well is stopped on the upstroke and downstroke, and counterbalance measured. This data can be analyzed on-site to determine the standing and traveling valve loads, determine effective counterbalance, and quantify pump leakage in barrels per day.

A serial and USB interface provide flexibility for transferring stored data to a personal computer, if desired. The utility software installed on a laptop or desktop computer provides a means to archive the data gathered, generate simple reports for printing or e-mailing, and export the data for further analysis, for example using Lufkin Automation's DIAG software suite.

Since the system is intended to be portable, a battery pack is included to provide several days worth of data gathering capacity between charges (assuming the unit is turned off between well sites). The battery is of the sealed pure lead-tin type which have been manufactured for about 30 years. This technology provides a much longer cycle life, high stability voltage source, wider temperature range, and a longer shelf life compared to conventional lead acid batteries.

In addition, power saving features have been incorporated so that the dynamometer will automatically turn off after a period of non-use. The user also has direct control of the backlight (it can be turned off or on at will, or come on with keypad activity and automatically turn back off after a programmed period of inactivity).

These features and data gathered in the field with the instrument are further discussed below. Figure 3 shows the experimental arrangement used for testing the instrument.

Quick Cards

The fastest way to see if the well is operating normally (e.g. full pump, little or no gas interference) is to use the Quick Card option. Surface cards are obtained by installing the end-devices on the well (most likely a clamp-on load cell and string transducer), turning the dynamometer and pumping unit on, and then selecting Quick Card from the menu. The dynamometer automatically observes the position and load range from the end-devices and begins drawing real-time surface cards as soon as these ranges are determined (usually within two strokes). Multiple cards can be stored for later review and transfer to a computer.

Figure 4 shows a screen shot of a stored quick card obtained at a well in the Permian Basin (7700 ft pump depth) using a clamp-on load cell and the string position transducer. As shown, the card is automatically scaled non-dimensionally (0 to 100%), both for position and load. Scaled this way, the card will look the same whether a horseshoe load cell or a clamp-on load cell are used. This type of card can provide immediate visual feedback to the field analyst if there are problems with the well that need to be further investigated. Types of problems that may be found with this method include excessive stuffing box friction, fluid pound, gas interference, pump tag, and excessive pump leakage.

This particular card shows a slightly higher than normal stuffing box friction, as indicated by the flattened ends of the card. If it is desired to further quantify the amount of friction and associated electrical consumption, it would be necessary to go to the Dynamometer Card option to obtain quantitative data.

Rod parts or fouled or inoperative pumps may be difficult to catch with this technique, since this condition would normally look like a flattened horizontal oval on a quantitative dynagraph screen, but here the card would be stretched to fill the screen and would look like a large rounded oval, and could be mistakened as a full pump by an inexperienced operator.

Dynamometer Cards

For quantitative work, the Dyno Card option would be selected. Figure 5 shows a quantitative card captured on the same well, using the horseshoe load cell. As a comparison to the Lufkin Portable Analyst II (PAII) Dynamometer, see Table 1. As presented in the table, peak and minimum loads recorded by the two systems were very similar, within 1.5% of each other.

This dynamometer has the capability built-in for calculating the pump card, if the rod taper and related configuration data are entered. The algorithm is similar to that implemented in the DIAG software, and uses the Fast Fourier Transform method to solve the wave equation. A straight hole is assumed in this model, which is adequate for most wells. If a deviated well is encountered, it may be necessary to export the surface cards to a diagnostic program that can account for rod drag friction more accurately.[6,7]

With the pump card at hand, the analyst can immediately see if the pump is properly filling (as seen in the figure), or if there are operational problems with the well. It is well known that surface card shapes are as unique as fingerprints, but pump card shapes are very limited and definitive in nature.[8,9] Thus it is easy to discern what problems may exist with the well, and recommend corrective action.

Other information is provided by this simple analysis. Peak and minimum surface and pump loads are shown, as well as the pumping unit period and strokes per minute. The instantaneous inferred production is calculated, and can be correlated to recent test data and percent run times to see if there is a discrepancy due to a worn pump, tubing leakage, leaking casing check valve etc. Gross and net pump stroke are calculated, as well as pump fillage. Again, multiple dynamometer cards can be stored for later review.

All this data can be used in an initial diagnosis of a well. However, it must be kept in mind that this analysis is simplified, and does not determine equipment loading (e.g. motor, gearbox, structure, rod loading). It also does not perform in-depth analyses of the entire system taking into account such things as motor current, inertia effects (e.g. for wells with significant speed variation), effects of rod drag in deviated wells, or tubing movement. These features are best handled by the more sophisticated computer-based dynamometer systems, and the personnel trained to use them.

Clamp-On Load/Offset Adjustment

Clamp-on load cells have always been questionable as to their accuracy. There are many reasons for this. A clamp-on load cell generally measures a strain in the polished rod, and correlates this to rod stress, and finally to rod load. A generic formula for relating rod load to measured longitudinal strain would look like:

$$PRL = E \cdot \varepsilon \cdot A \qquad (1)$$

where PRL is the polished rod load (in lbs), E is Young's Modulus (typically around $30(10)^6$ psi for steel), ε is the measured strain (typically using a strain gage), and A is the area of the polished rod (in^2). Part of the problem is that the polished rod was not designed to be the spring element of a precision load transducer. Thus there are uncertainties as to the Modulus, cross section area and so forth. Also, the surface of the polished rod is typically very rough, abused by polished rod clamps, liners, weathering etc. A very simplified uncertainty analysis can be performed. If each of the above terms in the formula have a 4% uncertainty, then the measured load would have a root-mean-square uncertainty of 7% (but the actual error could be higher). These effects cannot be corrected for in a clamp-on design due to the uncertainty of the material being measured.

Another uncertainty with the clamp-on is the zero offset. The transducer is usually placed on the polished rod which already has an unknown load on it, and the act of clamping the device may place additional strain on the gaged element. These effects produce a measured 'load' which needs to be adjusted to a 'known' load. A generally accepted practice in the industry is to stop the well on the downstroke and correlate the indicated load with that of the buoyant weight of the rod string.

A handy feature of this dynamometer allows the zero offset of the clamp-on to be automatically adjusted using the pump card and the calculated buoyancy load at the end of the rod string. This adjustment is feasible for wells with relatively low rod friction. In this manner, the clamp-on can be made 'almost' quantitative, and is probably adequate for a brief analysis. Figure 6 presents dynamometer cards using a clamp-on load cell and the zero-offset adjustment on a gas-engine driven well that would have been difficult to stand-off for a true quantitative analysis.

This adjustment technique was used with a clamp-on load cell on the well shown in Figure 5 for comparison purposes. As presented in Figure 7, the shape of the dynamometer cards compare very well with those in Figure 5, but the adjusted clamp-on loads are about ~1300 lbs high. Table 1 shows that the maximum polished-rod load error is 7%, while the minimum polished-rod load error is about 12.5%.

In spite of this, the indicated range of the clamp-on is within 2% of the horseshoe load cell, a better than expected result, considering the prior discussion on uncertainty. It should also be noted that this type of range accuracy can only be expected with a clamp-on load cell that is trim calibrated at the factory to have a consistent mV/V output. There is no doubt that these results cannot be expected in the general case, and there will be variability due to the care with which the operator places the clamp-on load cell on the rod, and the quality of the rod being clamped.

Well Configuration

Being a simplified dynamometer, only limited information is needed to obtain surface and pump cards. If only surface cards are desired, the user simply enters the well name and stroke length. If pump cards and inferred production are desired, the user enters the rod string data (type, lengths, diameters) and pump diameter. An example screen is shown in Figure 8. If a standard rod diameter is entered, the dynamometer populates the rod weights and modulus so these entries don't have to be entered manually. The damping factor, stuffing box friction, tubing head pressure, and tubing gradient have defaults that can be edited if desired for more accurate results (they have a secondary affect on the shape of many pump cards).

Valve Checks, Counterbalance and Pump Leakage

The quick dynamometer system allows the operator to record valve checks and counterbalance measurements, and then analyze this information. Figure 9 shows an example of a well where the valve checks are being analyzed to mark the standing valve load. The standing and traveling valve loads, residual friction (if performed), counterbalance, and pump leakage can all be analyzed in the dynamometer.

Pump leakage is calculated in barrels per day using the initial load-loss rate technique described in.[10] As shown, this well has a pump leakage of about 32 BPD; this well is on a pump-off controller, and operating at about 75% of the time, therefore no production is being lost, even though the pump efficiency has likely decreased somewhat from its new condition.

Laptop Utility Software

The utility software provides a simple interface to retrieve all data from the dynamometer instrument. Example screen shots are shown in Figure 10. Well configurations can be transferred to and from the dynamometer, as well as quick cards, dynamometer cards, and valve checks. Features are provided to manage groups of wells, and synchronize the dynamometer stored data to the computer's database.

Conclusion

The need for a dynamometer tool that is cost effective, reliable, oil-field proven, and easy to use has been met. Companies that have traditionally relied exclusively on a fluid level machine will be able to justify the cost of this dynamometer system since it is about the same price as a fluid level machine. The advantage is that it will provide more useful information for an operating company to better optimize their wells, improve their production, and minimize equipment failures.

References

1. Gibbs SG, Neely AB, "Computer Diagnosis of Down-Hole Conditions in Sucker Rod Pumping Wells," Journal of Petroleum Technology, January 1966, pp. 91–98.
2. Gibbs SG, Nolen KB, "Wellsite Diagnosis of Pumping Problems Using Minicomputers," Journal of Petroleum Technology, November 1973, pp. 1319–1323.
3. Hudgins TA, "Sucker Rod Pumping System Analysis Utilizing Portable Data Units and Remote Analysis Using Microprocessor Controller Units," Southwestern Petroleum Short Course, Lubbock, TX, April 1984, pp. 384–390.

4. Dugan L, Howard L, "Beyond Pump-Off Control with Downhole Card Well Management," Southwestern Petroleum Short Course, Lubbock, TX, April 2002, pp. 55–61.
5. Schaible B, "New Technologies Boost Bottom Line: Dynamometer System," The American Oil & Gas Reporter, Jan 2003, p. 140.
6. Gibbs SG, "Design and Diagnosis of Deviated Rod-Pumped Wells," Journal of Petroleum Technology, July 1992, pp. 774–781.
7. Xu J, Nolen KB, Boyer L, Gibbs SG, "Diagnostic Analysis of Deviated Rod-Pumped Wells," Southwestern Petroleum Short Course, Lubbock, TX, April 2001, pp. 133–140.
8. *Principles of Well Weighing*, "Dynamometer Analysis for Sucker Rod Pumping Wells," Nabla Corporation, 1995.
9. *Principles of Rod Pumping*, Section 4, Diagnosis of Existing Beam Systems, Lufkin Automation, 2002.
10. Nolen, KB, Gibbs SG, "Quantitative Determination of Rod-Pump Leakage With Dynamometer Techniques," SPE Production Engineering, August 1990, pp. 225–230.

Table 1. Comparison of the SAM Quick Dynamometer and the Portable Analyst II (PAII) Dynamometer systems.

Description	PAII Load (lbs)	SAM Quick Dyno Load (lbs)	Error (lbs)	Error (%)
Peak Polished Rod Load	18562	18701	139	0.7%
Minimum Polished Rod Load	9106	9236	130	1.4%

Table 2. Comparison of clamp-on and horseshow load cells with the SAM Quick Dynamometer system.

Description	Horseshow Load *(see Figure 5)* (lbs)	Adjusted Clamp-on Load *(see Figure 7)* (lbs)	Error (lbs)	Error (%)
Peak PR Load	18701	20008	1307	7.0%
Minimum PR Load	9236	10393	1157	12.5%
Peak—Minimum Load	9465	9615	150	1.6%

Figure 1. Early NABLA Corporation 'portable,' computerized dynamometer system (~1971).

Figure 2. SAM Quick Dynamometer system.

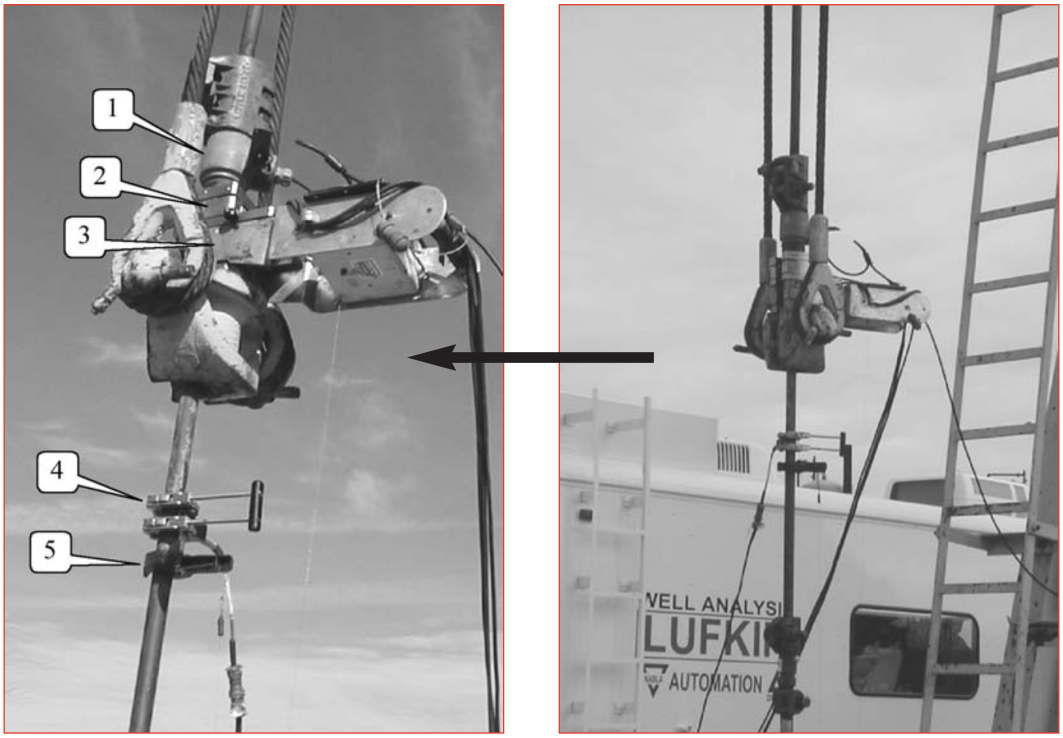
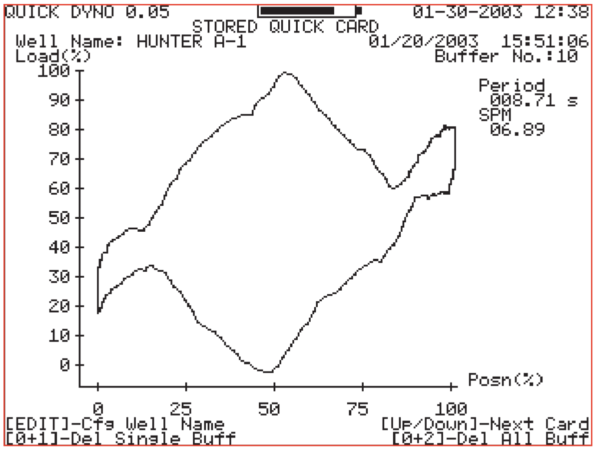
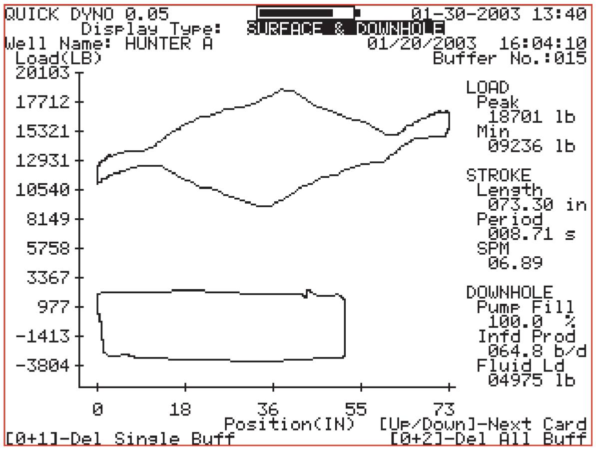


Figure 3. Experimental arrangement showing, 1) POC polished rod load cell, 2) horseshoe load cell for the SAM Quick Dynamometer, 3) horseshoe load cell and string position transducer basket for comparison with the PAII Dynamometer, 4) clamp-on load transducer for the SAM Quick Dynamometer, and 5) string transducer clamp for the SAM Quick Dynamometer.



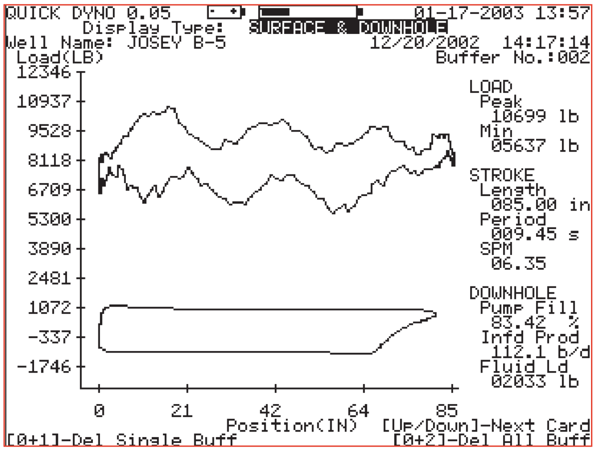
```
QUICK DYNO 0.05                          01-30-2003 12:38
              STORED QUICK CARD
 Well Name: HUNTER A-1              01/20/2003   15:51:06
 Load(%)                                  Buffer No.:10
                                         Period
                                          008.71 s
                                         SPM
                                          06.89
[EDIT]-Cfg Well Name            [Up/Down]-Next Card
[0+1]-Del Single Buff            [0+2]-Del All Buff
```

Figure 4. Stored Quick Card using a clamp-on load cell. Card shows some stuffing box friction.



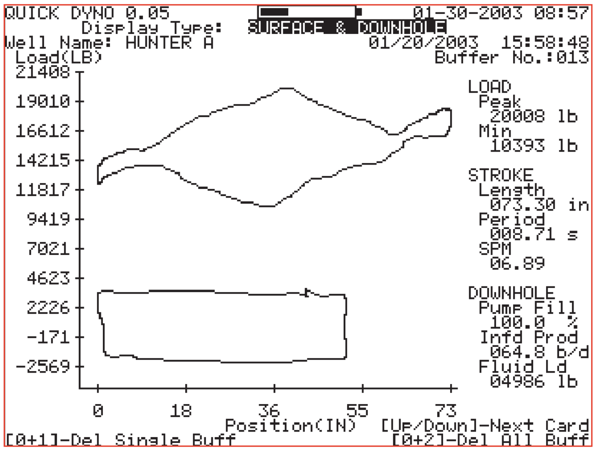
```
QUICK DYNO 0.05                          01-30-2003 13:40
    Display Type:  SURFACE & DOWNHOLE
Well Name: HUNTER A                 01/20/2003   16:04:10
 Load(LB)                                Buffer No.:015
                                         LOAD
                                          Peak
                                           18701 lb
                                          Min
                                           09236 lb
                                         STROKE
                                          Length
                                           073.30 in
                                          Period
                                           008.71 s
                                          SPM
                                           06.89
                                         DOWNHOLE
                                          Pump Fill
                                           100.0  %
                                          Infd Prod
                                           064.8 b/d
                                          Fluid Ld
                                           04975 lb
                 Position(IN)   [Up/Down]-Next Card
[0+1]-Del Single Buff            [0+2]-Del All Buff
```

Figure 5. Stored quantitative dynamometer card, using horseshoe load cell.



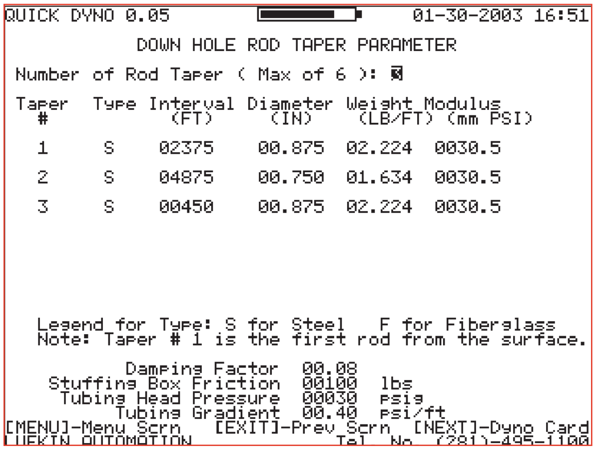
```
QUICK DYNO 0.05                          01-17-2003 13:57
    Display Type:  SURFACE & DOWNHOLE
Well Name: JOSEY B-5                12/20/2002   14:17:14
 Load(LB)                                Buffer No.:002
                                         LOAD
                                          Peak
                                           10699 lb
                                          Min
                                           05637 lb
                                         STROKE
                                          Length
                                           085.00 in
                                          Period
                                           009.45 s
                                          SPM
                                           06.35
                                         DOWNHOLE
                                          Pump Fill
                                           83.42  %
                                          Infd Prod
                                           112.1 b/d
                                          Fluid Ld
                                           02033 lb
                 Position(IN)   [Up/Down]-Next Card
[0+1]-Del Single Buff            [0+2]-Del All Buff
```

Figure 6. Dynamometer cards from a gas-engine driven well, using a clamp-on load cell, with the automatic zero-adjustment.



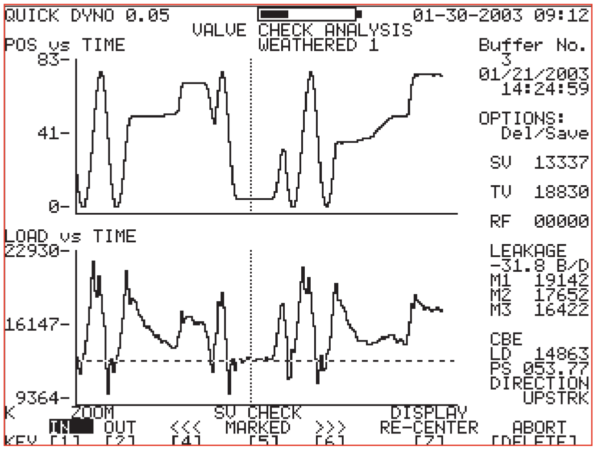
```
QUICK DYNO 0.05                          01-30-2003 08:57
    Display Type:  SURFACE & DOWNHOLE
Well Name: HUNTER A                 01/20/2003   15:58:48
 Load(LB)                                Buffer No.:013
                                         LOAD
                                          Peak
                                           20008 lb
                                          Min
                                           10393 lb
                                         STROKE
                                          Length
                                           073.30 in
                                          Period
                                           008.71 s
                                          SPM
                                           06.89
                                         DOWNHOLE
                                          Pump Fill
                                           100.0  %
                                          Infd Prod
                                           064.8 b/d
                                          Fluid Ld
                                           04986 lb
                 Position(IN)   [Up/Down]-Next Card
[0+1]-Del Single Buff            [0+2]-Del All Buff
```

Figure 7. Clamp-on load cell with automatic zero-adjustment; compare to Fig. 5 and Table 1.



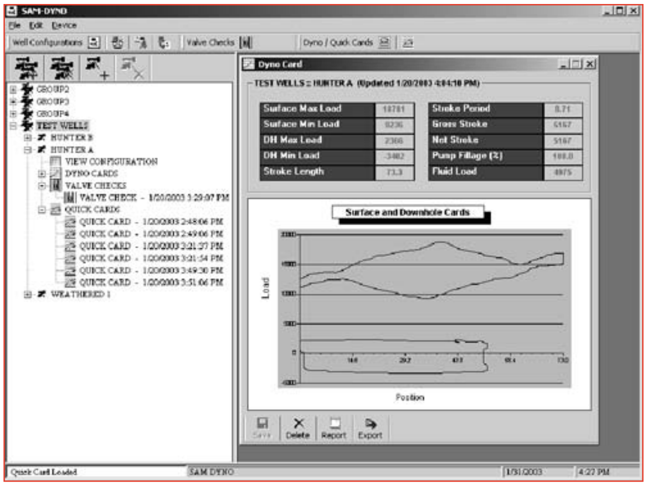
```
QUICK DYNO 0.05                          01-30-2003 16:51
            DOWN HOLE ROD TAPER PARAMETER

 Number of Rod Taper ( Max of 6 ): 3

 Taper  Type Interval Diameter Weight Modulus
   #           (FT)     (IN)    (LB/FT) (mm PSI)

   1     S    02375    00.875  02.224  0030.5

   2     S    04875    00.750  01.634  0030.5

   3     S    00450    00.875  02.224  0030.5




   Legend for Type: S for Steel    F for Fiberglass
   Note: Taper # 1 is the first rod from the surface.

           Damping Factor   00.08
    Stuffing Box Friction   00100   lbs
     Tubing Head Pressure   00030   psig
          Tubing Gradient   00.40   psi/ft
[MENU]-Menu Scrn   [EXIT]-Prev Scrn  [NEXT]-Dyno Card
LUFKIN AUTOMATION         Tel  No  (281)-495-1100
```

Figure 8. Example data entry screen needed to calculate pump cards.



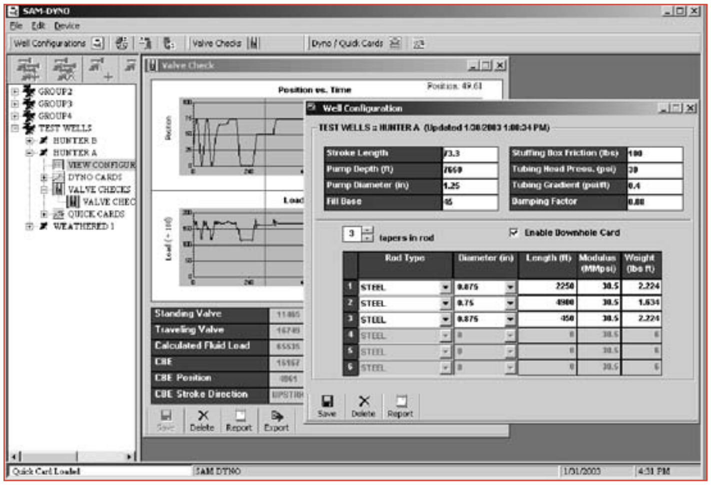
```
QUICK DYNO 0.05                          01-30-2003 09:12
                 VALVE CHECK ANALYSIS
POS vs TIME           WEATHERED 1          Buffer No.
                                             3
                                           01/21/2003
                                             14:24:59
                                           OPTIONS:
                                             Del/Save
                                             SV   13337
                                             TV   18830
                                             RF   00000
LOAD vs TIME
                                             LEAKAGE
                                             -31.8 B/D
                                             M1   19142
                                             M2   17652
                                             M3   16422
                                             CBE
                                             LD   14863
                                             PS 053.77
                                             DIRECTION
                                                UPSTRK
K    ZOOM         SV CHECK          DISPLAY
    IN   OUT   <<<   MARKED   >>>   RE-CENTER    ABORT
KEY [1]  [2]   [4]    [5]     [6]     [7]      [DELETE]
```

Figure 9. Example valve check analysis.



TEST WELLS :: HUNTER A (Updated 1/20/2003 4:04:10 PM)

Surface Max Load	18781	Stroke Period	8.71
Surface Min Load	8236	Gross Stroke	5167
DH Max Load	2366	Net Stroke	5167
DH Min Load	-3482	Pump Fillage (%)	100.0
Stroke Length	73.3	Fluid Load	4975



Standing Valve	11485
Traveling Valve	16749
Calculated Fluid Load	65535
CBE	15167
CBE Position	4861
CBE Stroke Direction	UPSTRO

TEST WELLS :: HUNTER A (Updated 1/30/2003 1:08:34 PM)

Stroke Length	73.3	Stuffing Box Friction (lbs)	100
Pump Depth (ft)	7650	Tubing Head Press. (psi)	30
Pump Diameter (in)	1.25	Tubing Gradient (psi/ft)	0.4
Fill Base	45	Damping Factor	0.80

3 tapers in rod

☑ Enable Downhole Card

	Rod Type	Diameter (in)	Length (ft)	Modulus (MMpsi)	Weight (lbs ft)
1	STEEL	0.875	2250	30.5	2.224
2	STEEL	0.75	4900	30.5	1.634
3	STEEL	0.875	450	30.5	2.224
4	STEEL	0	0	30.5	6
5	STEEL	0	0	30.5	6
6	STEEL	0	0	30.5	6

Figure 10. Screen shots of utility program to archive dynamometer data and export for further analysis.

Sales and Service Centers

Bakersfield

5301 Office Park Drive, Suite 305
Bakersfield, CA 93309
Tel: 661-325-3099
Fax: 661-325-3105

Calgary

Suite 1050
808-4th Avenue S.W.
Calgary, AB, Canada T2P 3E8
Tel: 403-234-7692
Fax: 403-265-6913

Midland

2064 Market Street
Midland, TX 79703
Tel: 432-697-2228
Fax: 432-697-0192

Oklahoma City

2300 S. Prospect
Oklahoma City, OK 73129
Tel: 405-677-0567
Fax: 405-677-7045

Houston (Headquarters)

11375 W. Sam Houston Parkway South Suite 800
Houston, TX 77031
Tel: 281-495-1100
Fax: 281-495-6333

Sales and Service Representatives

Argentina, Belarus, Brazil, Canada, Colombia, Egypt, France, India, Italy, Mexico, Oman, Russia, Trinidad, Venezuela, U.S.A. (Wyoming, North Dakota, Louisiana, Utah, Michigan), United Kingdom