22

Review of Downhole Dynamometer Testing

Roberto L. Soza
Exxon Company, USA

Abstract

Electronic Downhole Load Cells (DHLC) have been used to quantify rod loadings calculated by predictive and diagnostic wave equation programs. Test results to date show that software calculations agree closely with DHLC measurements. However, there is a difference in how software programs account for buoyant forces which results in discrepancies in reported loads and placement of the zero load line. The overall impact of this difference in the tests run to date. has not been large and may only be critical in the most demanding rod pumping conditions.

Introduction

Predictive and diagnostic software is widely used to design rod pumping systems and diagnose rod pumping performance. These programs are based on wave equations that model rod string dynamics and calculate rod loading throughout the rod string length. Recent interest has been focused on the accuracy of the rod loading predictions made by modeling programs and more specifically the amount of compressive force that is calculated versus the actual compressive force experienced by the rod especially at the bottom of the rod string. This area of the rod string is of especial interest because of the large number of tubing and rod failures that occur in the lower sections of rod pumped wells which are generally attributed to rod buckling.

In order to attempt to verify the predictions made by predictive and diagnostic wave equation programs, an electronic downhole load cell was run in several rod pumped wells. To date a total of 25 tests have been run by industry. This paper will review the procedures involved in the testing, review results of four of these tests and compare test results to predictions made by predictive and diagnostic wave equation programs. Additional DHLC testing and rod buckling has also been addressed in References 1,2, and 3.

Testing Methodology

The DHLC used in these tests was developed by Glen Albert Engineering and has been described in several articles which are referenced at the end of this paper. Figure 1 shows a schematic of the load cell used for these tests. For these tests the bottomhole assemblies were run with one load cell immediately above the pump and a second load cell at a rod taper change. Table 1 shows the rod string configurations for each of these four tests.

The tests were run using the same basic test methodology. The rods were pulled to install the DHLC's in the rod string. The wells were then allowed to stabilize and a quantitative surface dynagraph was run simultaneously with the DHLC recording data at the same time. The DHLC was programmed to record data as per the time schedule shown in Figure 2. After the load cells are retrieved, data is retrieved from the load cell memory and downhole load data is plotted in conventional dynagraph pump card output minus the standing valve load. In addition to load and position data, pressure and temperature are also recorded.

Analysis Technique for comparing Measured to Calculated Cards

A conventional analysis of the dynagraph pump cards was used [4,5,6,7]. Figure 3 shows a schematic of a pump card. Conventional analysis of downhole pump cards requires some degree of interpretation in that fluid load lines are drawn at the point where the traveling and standing valves seat. Typically these lines are drawn where the vertical lines start turning. On some cards, exactly where this occurs is dependent on the expertise of the person analyzing the card. The distance between the two lines represents the fluid load. The loads below the lower fluid load line represent friction effects during the downstroke. The loads above the upper fluid load line are loads that are primarily due to fluid inertia and friction during the upstroke. Friction effects showing up above or below the fluid load lines are due to higher than anticipated friction loads (i.e. loads that are calculated by the wave equation to be in excess of the friction coefficient input into the program). Fluid inertia loads showing up outside the fluid load lines are loads that the wave equation programs calculate to be in excess of normal fluid inertia effects. Basically, the loads above and below the fluid load lines are loads the wave equation programs calculate but cannot readily distribute along the rodsting.

One other important load that needs to be considered on a pump card is where the zero load line is calculated to be by the diagnostic programs. This line is drawn on the pump card at a point where the rods are not experiencing any tensile or compressive load.

The buoyancy force (Fb) is designated as the load between the lower fluid load line and the zero load line. The magnitude of Fb impacts rod loading calculations. This discussion will be expanded in the following section.

Comparison of DHLC vs. Predictive and Diagnostic Loads

Figure 4 compares a dynagraph card from the DHLC versus calculated downhole pump cards from diagnostic programs. In general, the card character agrees closely and is representative of other tests. The conclusion being that the diagnostic programs are doing a good job of modeling rodstring dynamics.

Tables 2-5 compare quantitative values measured by the DHLC to calculated values reported by predictive and diagnostic programs. Pump stroke and fluid load for the most part match with the exception of one instance. However, a comparison of loads show there is a definite variance between the DHLC loads and the loads reported by the diagnostic programs. The loads calculated by various predictive software packages matched closely.

There are two reasons for the discrepancy in the loads reported by the diagnostic programs. First is the issue of interpretation. Software programs report loads including buoyancy forces which tend to communicate that large negative compressive loads are being exerted on the rodstring. The programs report the loads in this manner because there is a buoyancy force being exerted on the bottom of the rodstring. However, this force is a triaxial force and it is generally agreed that this force does not cause rod buckling. In order to clarify the actual amount of buckling force, buoyancy forces need to be backed out of the reported minimum stress values on software program output.

The second issue is why the diagnostic loads do not agree with the measured loads even after buoyancy effects have been backed out. The diagnostic output includes friction and fluid inertia loads that the program was unable to distribute along the rodstring based on the friction coefficient input into the program and normal fluid inertia effects. These loads are reported at the bottom of the rodstring making the minimum rod stress at the bottom more negative than actual. Once friction and fluid inertia effects are backed out of the pump card calculated by the diagnostic program the measured and calculated loads tend to agree more closely.

As noted from the measured pump cards, the buckling forces that are being experienced by the rodstrings in these cases are in the 100's of pounds range instead of the much larger minimum forces reported. Whether this type of loading is causing undue compression related failures is yet to be thoroughly quantified. Reference 8 describes a series of surface tests based on Euler's testing methodology that will potentially quantify negative effects of compressive forces of this magnitude.

Buoyancy Forces and Zero Load Line

During the course of analysis it was discovered that the diagnostic programs varied in the placement of the zero load line on the pump card. Figure 5 shows two sets of pump cards drawn by diagnostic programs. The first set of pump cards is for a well that has a conventional 86 rod string with 250' of 7/8" rods on bottom. The second well has an 87 rod string with 60' of 1.5" sinker bars on bottom. Comparing the first set of cards shows that the cards have similar characteristics with a slight difference in the placement of the zero load line. Comparing the second set of pump cards yields the same conclusion except that the difference in the placement of the zero load line is more significant. This discrepancy is due to how buoyancy is calculated by different diagnostic programs and appears to be an area for improvement in some diagnostic programs.

Future testing

DHLC testing was initiated to quantify the amount of compressive forces exerted in the rod string and to verify the values predicted or calculated by predictive and diagnostic programs. To date twenty-five tests have been run on mostly conventional wells with steel rod strings. One test has been run on a well with fiberglass rods and on one directional well with a Rotaflex pumping unit and COROD. The testing methodology for all of these tests has been essentially the same as discussed. As shown on this report, DHLC and software results have agreed closely and compressive forces in these tests have been measured in the 100's of pounds.

What next? Confirmation of software predictions and calculations still need to be addressed for fiberglass rod and ribbon rod installations. In addition, shallow, high volume wells with high fluid inertia effects need to be tested as these type wells present problems for diagnostic programs. Other areas of interest are wells that are pounding fluid. Ultimately operators and software developers need to coordinate efforts to be able to maximize the benefits of these tests so results may be used to improve predictive and diagnostic programs.

Conclusions

1. DHLC measurements on conventional wells with steel rod strings agree closely with predictive and diagnostic software calculations.
2. Diagnostic software programs account for buoyancy effects differently resulting in discrepancies in placement of the zero load line. The net effect is the rod stress calculations on the rod string are impacted. On the analysis done to date, this effect is more pronounced with wells with larger diameter rods on bottom.
3. Much confusion has been generated by the large negative stress loads reported in the software output. DHLC measurements confirm that compressive forces experienced by the rod string are much smaller and further analysis will quantify the negative effect of forces of this magnitude.
4. Efforts need to be expanded between operators and software developers to enhance predictive and diagnostic software through the use of DHLC measurements.
5. Consensus needs to be reached in how to handle buoyancy in calculations.

References

1. Albert, Glenn D.: (Downhole Dynamometer Update), paper presented at the Southwestern Petroleum Short Course 42nd Annual Meeting, Lubbock, Texas, April 19-20, 1995.
2. Ott, R.E. and Mendenhall, G.L.: (Making the Most of Rod Design - A Comparison of Measured and Modeled Rod String Stresses Emphasizing Fiberglass Rods), SPE paper presented at the Permian Oil and Gas Recovery Conference, Midland, Texas, March 1994.
3. Mendenhall, G.L. and Ott, R.E.: (Solving Rod Buckling), paper presented at the Southwestern Petroleum Short Course 42nd Annual Meeting, Lubbock, Texas, April 19-20, 1995.
4. Gibbs, S.G. and Nolen, K.B.: *Principles of Well Weighing*, NABLA Corporation, Midland, Texas, 1993.
5. Gibbs, S.G. and Nolen, K.B.: *Principles of Rod Pumping*, NABLA Corporation, Midland, Texas, 1993.
6. Svinos, J.G.: *Rod Pumping Optimization*, Theta Enterprises, Fullerton, California, 1992.
7. Takacs, G.: *Modern Sucker Rod Pumping*, Penwell Publishing Company, Tulsa, Oklahoma, 1993.
8. Long, S.W. and Bennett, D.W.: (Euler Loads and Measured Sucker Rod Buckling), paper presented at the Southwestern Petroleum Short Course 42nd Annual Meeting, Lubbock, Texas, April 19-20, 1995.

Acknowledgments

The author wishes to thank Exxon Company, U.S.A. for the support in presenting this paper. Additional thanks go to Mobil U.S.A. for contributing test data, Sam Gibbs and Ken Nolen of NABLA Corporation and John Svinos of Theta Enterprises for their technical assistance.

Table 1
Rod String Configurations

Case well 1 & 2	Pump, DHLC, 7/8" rods, DHLC, 3/4, 7/8, 1" Rods
Case well 3	Pump, DHLC, 1-1/2" sinker bars, 7/8" rods, DHLC, 1" rods
Case well 4	Pump, DHLC, 1-1/2" sinker bars, 3/4" rods, DHLC, 7/8" rods, 1" rods

Table 2
DHLC Loads Compared to Predictive Programs Loads

Well 1	Fluid Load	Pump Stroke	Bottom Min. Reported Load w/o Buoyancy w/ Friction	Bottom Minimum Loads w/o Buoyancy and w/o Friction
DHLC	5300	157	-300	-300
Predictive 1				
Predictive 2	5676	159	-194	
Predictive 3	5659	154	-228	
Predictive 4				
Diagnostic 1	3363	161	-1049	-134
Diagnostic 2	4412	163	-692	+308
Diagnostic 3	4672	163	-630	+170
Diagnostic 4				

Table 3
DHLC Loads Compared to Predictive Programs Loads

Well 2	Fluid Load	Pump Stroke	Bottom Min. Reported Load w/o Buoyancy w/ Friction	Bottom Minimum Loads w/o Buoyancy and w/o Friction
DHLC	4350	133	-150	-150
Predictive 1	4851	132	-18	
Predictive 2	4900	134	-163	
Predictive 3	4613	131	-197	
Predictive 4				
Diagnostic 1	2750	138	-993	-93
Diagnostic 2	4072	138	-903	-350
Diagnostic 3	4312	138	-618	+282
Diagnostic 4				

Table 4
DHLC Loads Compared to Predictive Programs Loads

Well 3	Fluid Load	Pump Stroke	Bottom Min. Reported Load w/o Buoyancy w/ Friction	Bottom Minimum Loads w/o Buoyancy and w/o Friction
DHLC	6500	92	-200	-200
Predictive 1	6710	100	+2	
Predictive 2	6221	101	-302	
Predictive 3	6798	98	-25	
Predictive 4	7557	96	-532	
Diagnostic 1	6077	94.5	-998	+6
Diagnostic 2	6226	97	+1605	+2605
Diagnostic 3	6862	97	-340	+660
Diagnostic 4	6959	95	-1060	+117

Table 5
DHLC Loads Compared to Predictive Programs Loads

Well 4	Fluid Load	Pump Stroke	Bottom Min. Reported Load w/o Buoyancy w/ Friction	Bottom Minimum Loads w/o Buoyancy and w/o Friction
DHLC	5200	148	-900	-900
Predictive 1	6142	154	0	
Predictive 2	6095	160	-252	
Predictive 3	6090	156	-15	
Predictive 4				
Diagnostic 1				
Diagnostic 2	6101	155	+620	+1120
Diagnostic 3	6097	156	-675	-475
Diagnostic 4				

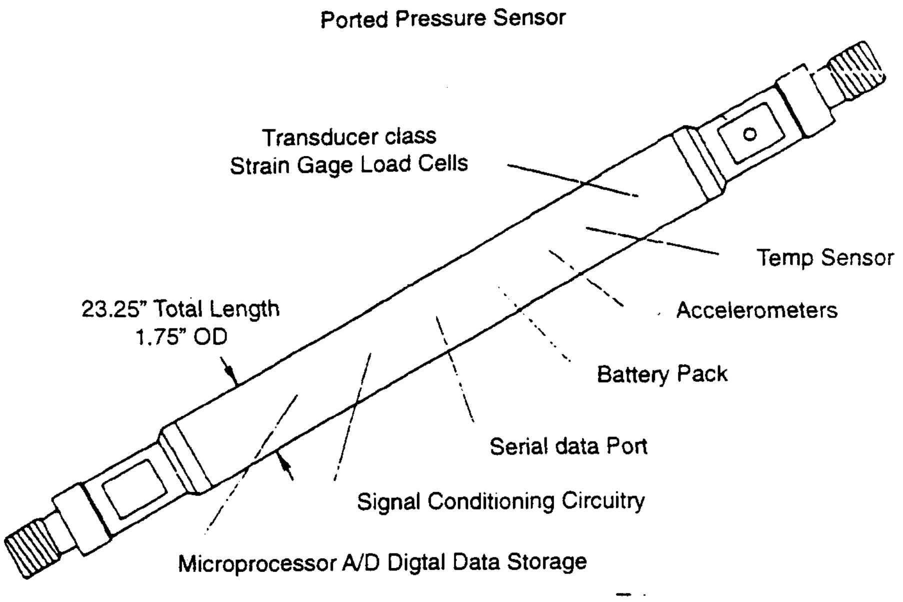


Figure 1 - Downhole Dynamometer

Monday Aug 29 Tools Shipped	Tuesday Aug 30 Pickup tools and RIH/w downhole dyno tools	Wednesday Aug 31 Rig up surf dyno equip. and run first survey at 2:00 p.m.	Thursday Sept 1 Rigup surf dyno equip and run second survey at 9:00 a.m. POOH w/tools and ship back to Glen Albert		Receive load vs data 5-6 days after test is run

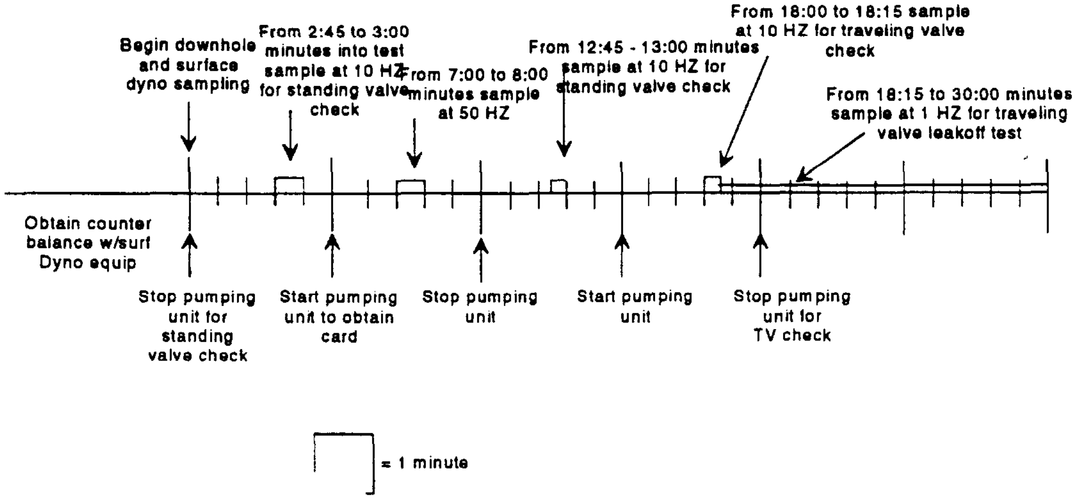


Figure 2 - Downhole Dynamometer Survey
Timeline - Detail

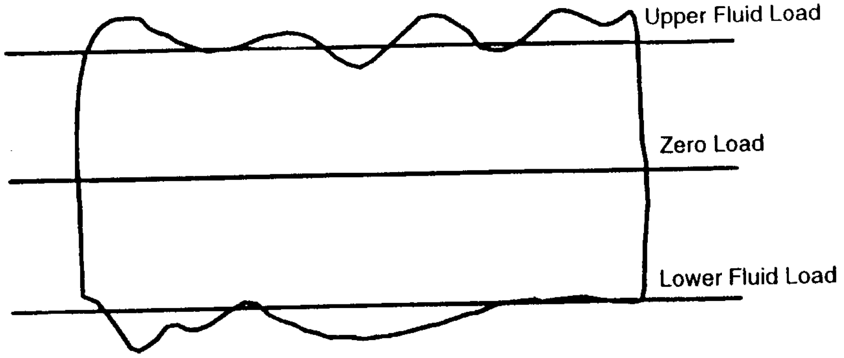
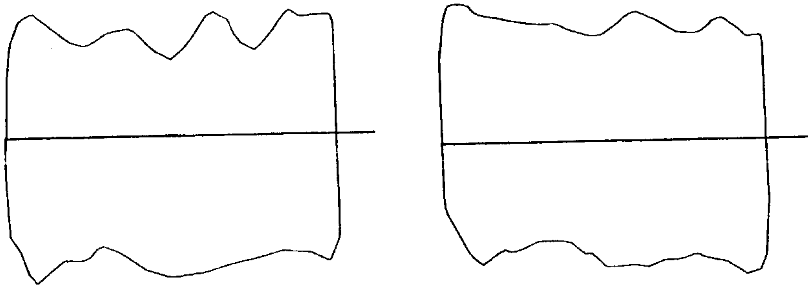
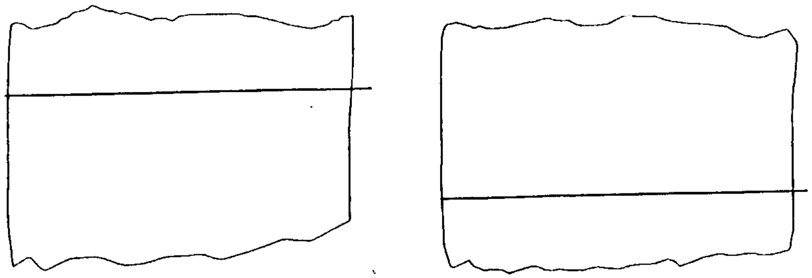


Figure 3 - Schematic of a Pump Card



Well without sinker bars



Well with sinker bars

Figure 5 - Zero Load Line Placement- Diagnostic Programs

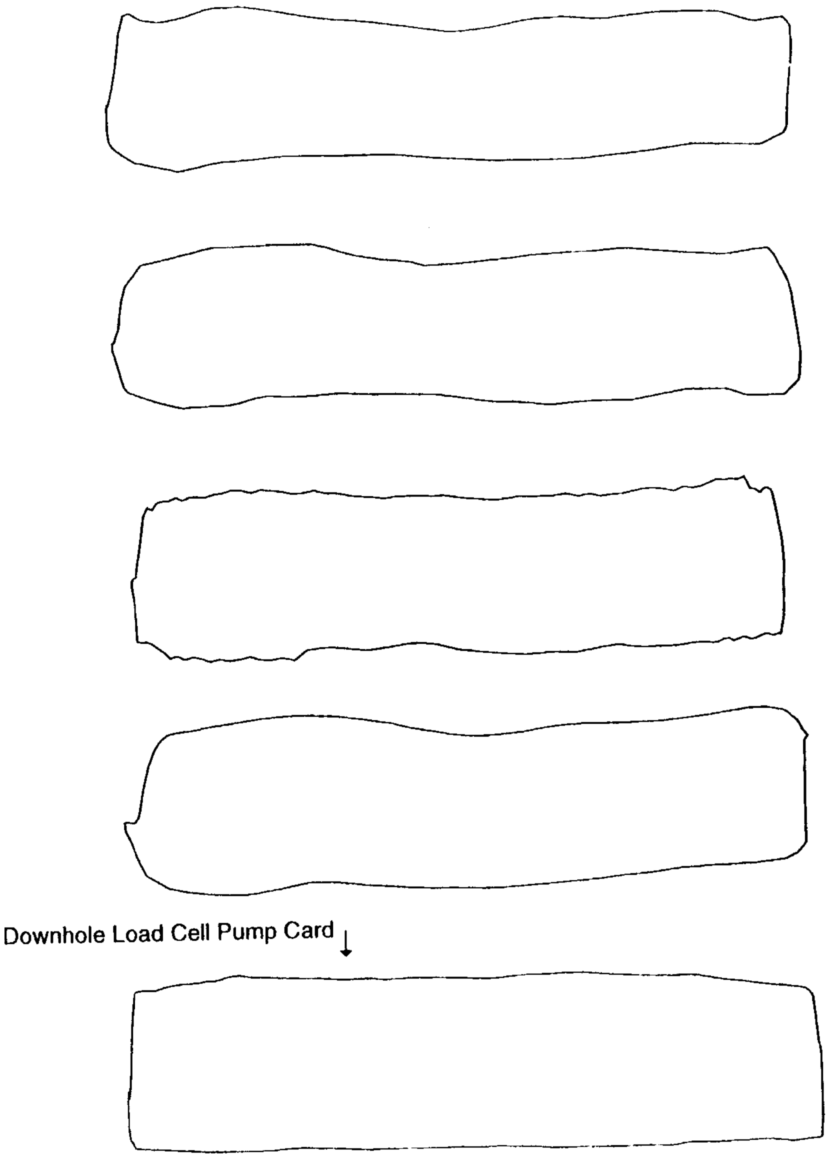


Figure 4 - Comparison of DHLC Dynagraph Card vs Calculated Downhole Pump Cards