APPLICATION OF EXPERT SYSTEM TECHNOLOGY TO THE DESIGN OF ROD PUMPING SYSTEMS

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ABSTRACT

A "smart" predictive computer program called RODSTAR has been developed that combines expert rod pumping knowledge with state-of-the-art wave equation and pumping unit modeling algorithms. With this computer program one can get optimized system designs in minutes by asking the program to calculate the strokes per minute, plunger size, and rod string design for a desired production rate. RODSTAR also helps the user select the pumping unit size and warns him about bad designs, pump or rods that are too big for the tubing, or pumping speed that is too high.

The program's capability to automatically design steel or fiberglass rod strings ensures minimum rod loading and lowest rod string cost. In addition to the expert features of its design algorithms, the program calculates rod stresses at the top and bottom of each rod section to help avoid rod compression, and recommends prime mover size for NEMA D, gas engines, or ultra high slip motors. It also calculates prime mover energy consumption, monthly electricity bill, overall system efficiency, and the effect of prime mover speed variation and unit inertia on net gearbox torque. It can simulate full pump, fluid pound, or gas interference, and any pumping unit geometry including non-beam pumping units.

INTRODUCTION

When designing a rod pumping system one must specify the equipment, strokes per minute, and stroke length required to get the desired production at the lowest possible cost. In an effort to select the best system design for a well, the designer is mostly concerned with the following parameters:

* Production Rate
* Capital costs
* Rod loading
* Gearbox loading
* System efficiency and power costs

Ideally, the designed system will give the highest present value profit after tax, considering capital and operating costs. However, because of the data, expertise, and time required to achieve this goal with conventional rod pump design software, most system designs are far from ideal.

In most cases production rate is of highest priority, followed by rod loading, gearbox loading, and power cost. If electricity cost is high, it can be lowered by using a larger pump and a slower pumping speed. However, a large pump will increase rod loading and gearbox torque. Also, a large pumping unit must be used and this will increase capital cost. On the other hand, a smaller pump demands a faster pumping speed or longer stroke to make the desired production. This increases power consumption but reduces the required pumping unit gearbox size. Usually, a compromise must be reached between efficiency, equipment loading, and equipment size and cost. RODSTAR's fast execution, user friendly interface, and accurate algorithms enable the user to easily and quickly evaluate many system designs. Because of its automatic design capabilities RODSTAR can be effectively used even by inexperienced users.

A very important aspect of system design is pumping rate. It is recommended that the displacement rate of the rod pumping system be 15% to 20% higher than the maximum expected production rate. This ensures enough pump capacity to account for normal pump wear. However, if the pumping rate is substantially higher than what the well is capable of producing, then the well will pump off. Fluid pound is a problem that results from the common practice of over-designing the pumping capacity. Fluid pound is damaging to the pump, rods and pumping unit. With RODSTAR the user can enter a target production and ask the program to calculate the strokes per minute needed. Also, because RODSTAR can simulate fluid pound, the user can see what will happen when the well starts to pound fluid. He can also use RODSTAR to evaluate the benefits of pump off control by comparing full and pumped off designs for the same well.

Another important aspect of rod pump system design is the method used by the designer. The wave equation method first developed by Gibbs[1] is accepted today as the most accurate way of simulating the rod string. RODSTAR uses the one dimensional wave equation to simulate the behavior of the rod string and to predict the stress loading used in its expert rod string design calculations.

RODSTAR DESIGN CALCULATIONS

RODSTAR is a rod pump system simulator that can predict the performance of any pumping system. The program predicts the downhole and surface dynamometer cards, gearbox peak torque and loading, structure loading, sucker rod stress loading, pump stroke, expected surface production, maximum counterbalance moment, prime mover size, overall system efficiency, daily energy consumption, monthly electricity bill, and other useful information. In addition to calculating the maximum and minimum stresses at the top of each rod string, RODSTAR calculates the minimum stress at the bottom of each rod section as well. This is especially important when designing fiberglass rods that cannot take compressive loads.

RODSTAR uses an exact kinematic analysis model[2] that permits simulation of any pumping unit geometry including long stroke units such as the Rotaflex. RODSTAR comes with a large pumping unit data base that contains data for most new and old units. In case a pumping unit is not included in the program's data base, it can still be simulated because the user can easily enter his own pumping unit dimensions. RODSTAR uses actual motor curves to calculate the instantaneous motor efficiency and corresponding power consumption for each calculated torque point. This approach gives very accurate results that are very close to field measurements of power consumption.

The program also allows the user to enter the rod-tubing friction coefficient. If this is unknown, the user can ask RODSTAR to calculate it. The friction coefficient calculated by RODSTAR is an estimate for average friction for a straight wellbore. When simulating a deviated well, or a well with heavy oil production, paraffin, or scale problems, then a higher rod-tubing friction coefficient must be entered to accurately predict system performance.

A unique RODSTAR feature is the ability to simulate the behavior of shallow, high rate wells that are affected by fluid inertia effects. Fluid inertia effects are present in wells that pump relatively incompressible fluids with pump plungers of 2.25" or larger, from depths of less than 3500 feet. Fluid inertia effects can significantly increase polished rod load and polished rod horsepower[3]. RODSTAR gives accurate results for these types of wells and successfully predicts the shapes and loads for surface and downhole dynamometer cards.

To minimize the data the user has to collect to run the program, RODSTAR contains data of all common rod, pump, and tubing sizes, rod material by manufacturer, and the recommended stress loading calculation methods for fiberglass and non-API steel rods. After the user selects the rod material or manufacturer from easy to use menus, the program automatically gets the data it needs from its data base.

EXPERT SYSTEM DESIGN FEATURES

In rod pumping so far, "expert systems" have only been applied for diagnostic analysis[4], [5]. RODSTAR represents the first implementation of expert system techniques to the design of rod pumping systems. RODSTAR's expert logic is designed to minimize the time and expertise required for rod pump system design. Unlike the conventional trial and error approach to rod pump system design, RODSTAR allows the user to quickly get a working design with minimum effort. Although the expert system features of RODSTAR are extremely helpful, they can be easily bypassed by experienced users who prefer to enter their own system designs.

The main expert design features of RODSTAR include the capability to calculate the spm needed for a user specified target production, automatic plunger size selection, automatic rod string design, and pumping unit size recommendation. These options can be selected one at a time, or in any other combination including selecting all of them simultaneously.

Calculation of Strokes per Minute

The user can either enter a strokes per minute or a target production rate. If a target production rate is entered, RODSTAR calculates the spm needed. If the user enters a target production that is too high, RODSTAR informs the user that his target production is too high and recommends a more realistic maximum production rate. At this point the user can change his target production or ask RODSTAR to continue. The program attempts to calculate the spm as long as the minimum rod load does not become negative. If the target production cannot be achieved, RODSTAR calculates the maximum production possible with the present system.

Expert Rod String Design

One of the most powerful "expert" features of RODSTAR is the ability to automatically design steel or fiberglass rod strings. The user has the option to enter his own design, enter an API rod number, or ask for a RODSTAR recommendation. If he selects the API rod number option the program shows him all available API rod numbers and he can select the one he wants from a menu. The program automatically fills in and displays the data for the length, weight per foot, and modulus of elasticity for each rod section.

If the user selects to enter his own design then he must enter all data for the rod string such as rod diameter, length, rod grade or material, and service factor. RODSTAR can simulate steel or fiberglass rods, for any rod grade.

If the "RODSTAR recommendation" option is selected, the user must choose either a 100% steel rod string or a combination of fiberglass and steel. If the user requests a RODSTAR design for a steel rod string then he must specify the maximum and minimum rod diameters he is willing to consider. For example, he may enter 1" for the maximum rod size and 3/4" for the minimum. RODSTAR will attempt to design a rod string within these limits. If rod loading is low, RODSTAR may recommend a straight 3/4" rod string or a two way taper with 7/8" on top and 3/4" on bottom. If rod loading is high, then RODSTAR may recommend a three way taper. After RODSTAR decides how many rod tapers are needed, it automatically adjusts the length of each rod section to equalize the stress loading. This minimizes rod loading. RODSTAR performs these calculations at a fraction of the time compared to manually adjusting the length of each rod section and re-running the program. RODSTAR performs the appropriate stress loading calculations for API or non-API rods such as the Electra, Norris 97, LTV HS, or UPCO 50K rods. Figures 1-3 show a RODSTAR output for a case where the user asked the program to recommend a rod string design. In this case, the maximum rod to consider was 1" and the minimum was 3/4". As the output shows, because Electra rods were used, RODSTAR recommended a straight 3/4" rod string since rod loading is only 81%.

If the user requests RODSTAR to design a fiberglass rod string with steel rods or sinker bars on the bottom, he only needs to specify the diameter and grade of the steel section. Based on this information, RODSTAR will attempt to design a rod string that is not overloaded, is not in compression, and has a large downhole stroke. RODSTAR automatically adjusts the length of the steel section to ensure the fiberglass rods are not in compression and to avoid excessive rod stretch. To avoid overloading the fiberglass rod section the program selects the appropriate rod size based on available diameters. Also, RODSTAR ensures that the recommended rods fit in the tubing. For example, if a 2-7/8" tubing is used, the 1.5" fiberglass rod size will not be considered because it cannot be used in 2-7/8" tubing. Figures 4-6 show an example RODSTAR output for a case where RODSTAR automatically designed a fiberglass rod string and calculated the strokes per minute for a target production of 500 BFPD. As this output shows, RODSTAR calculated a strokes per minute of 12.5 and recommended a rod string of 60% fiberglass and 40% steel. The calculated rod string is not overloaded, is not in compression, and results in pump overtravel. This system design was accomplished with a single RODSTAR run. However, with conventional design programs several runs and considerable experience may be needed to achieve the same results.

RODSTAR Optimized Steel Rod Design

API RP 11L[6] recommended rod tapers are based on a method developed by Neely[7]. Neely's method is based on estimates of the dynamics forces in the rod sting obtained by curve fitting wave equation calculated numbers. This technique uses the Modified Goodman Diagram along with estimates of the dynamic forces in the rod string to calculate rod tapers that are supposed to have equal stress loading. However, although for many cases this method gives reasonable results, there are many cases for which the resulting stress loading is far from balanced. This is especially true when designing systems with non-conventional pumping units such as the Mark II or enhanced Class I geometry units. To avoid the limitations of this older method, the RODSTAR program contains an algorithm that automatically determines the proper length of each rod section in order to minimize and "balance" the stress loading of the rod string. Since RODSTAR uses the wave equation to calculate the percent rod loading at the top of each rod segment, it gives very accurate results.

Figures 7-12 are two sets of RODSTAR outputs that show the difference between a rod string design based on an 86 API rod taper, and one calculated by RODSTAR's rod string design algorithm. As Figure 7 shows, the API RP 11L assumption of equal stress loading is incorrect in this case since rod loading varies from 81% for the top rod to 90% for the bottom one. However, using the more accurate wave equation based method coupled with expert logic, RODSTAR came up with a rod sting that has a stress loading of 84% for all three tapers. As Figure 10 shows, the required rod lengths are quite different from the API recommended ones.

Recommended Pumping Unit Size

If the user enters a target production rate, RODSTAR will display a recommended API pumping unit size to help the user decide what unit to use. This recommendation is displayed at the input screen where the user selects the pumping unit. This recommendation is only for the API unit size and does not contain a unit type or manufacturer. The user has to select the manufacturer and type of pumping unit he wants to use. This recommendation is intended for design of new systems since when RODSTAR is used to evaluate changes to an existing system the pumping unit is already known.

ON-LINE EXPERT ADVICE

To help avoid mistakes, RODSTAR has on-line expert help and advice to ensure that the user becomes aware of equipment limitations or special equipment needs. For example, if the user enters a pump size that is too large for the selected tubing size, or if a thin wall pump must be used, RODSTAR makes the user aware of this fact by popping up a warning window. It also contains knowledge of the maximum rod sizes for any tubing size, when slimhole couplings are needed, what size sinker bars can fit in the tubing, maximum recommended pumping speed, etc. For example, if 1" rods are selected for a 2 7/8" tubing, the program reminds the user that slimhole couplings must be used.

RODSTAR performs several checks and "expert" data evaluations that are invisible to the user unless a potential problem is detected. For example, RODSTAR can predict bad system designs such as severe undertravel, even before the program performs any predictive calculations. It then warns the user and advises him on how to solve the problem. This eliminates unnecessary runs and provides the user with effective solutions to problems that he may not know how to solve.

CONCLUSIONS

As this work shows, combining expert system technology with traditional design algorithms can result in very powerful design tools. With this type of computer programs, expertise that once could only be applied by human experts or was only available in the literature, can now be effectively used by every user.

The combination of modern rod pump system simulation algorithms and expert design logic makes RODSTAR the first practical rod pump expert design tool for personal computers. With RODSTAR good system designs can be obtained in minutes instead of hours. RODSTAR's algorithms allow the program to be used for any system design regardless of depth, pumping unit type, rod type, or well deviation.

RODSTAR helps the user get the most economic pumping system designs because it calculates the system energy consumption and uses the smallest diameter rod string for the job. Also, because the program can accurately simulate the behavior of any pumping unit geometry, it allows easy and accurate pumping unit, or overall system performance comparisons.

References

1. Gibbs, S. G.: "Predicting the Behavior of Sucker Rod Pumping Systems, "J. Pet. Tech. (July, 1963) 769-778.

2. Svinos, J. G.: "Exact Kinematic Analysis of Pumping Units," SPE 12201 presented at the 58th Annual Technical Conference and Exhibition of the SPE, San Francisco, CA, October 1983.

3. Svinos, J. G.: "Use of Downhole Pulsation Dampener to Eliminate the Effect of Fluid Inertia on a Rod Pump System," SPE 18779 presented at the SPE California Regional Meeting, Bakersfield, CA, April 5-7, 1989.

4. Foley, W. L. and Svinos, J. G.: "Expert Adviser Program for Rod Pumping," J. Pet. Tech. (April 1989) pp. 394-400.

5. Svinos, J. G.: "Successful Application of Microcomputers to

Analyze Sucker Rod Pumps," SPE 17789 presented at the 1988 Symposium on Petroleum Industry Applications of Microcomputers, San Jose, CA, June 27-29, 1988.

6. API RP 11L, Recommended Practice for Design Calculations for Sucker Rod Pumping Systems (Conventional Units), Fourth Edition, June 1, 1988.

7. Neely, A. B.: "Sucker Rod String Design," Petroleum Engineer (March 1976) pp. 58-66.

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                         * * *  RODSTAR  * * *
                                                   (C) Theta Enterprises
                                                   Tel: (714) 879-8951
Company: Major Oil
Well: Test R#1 (Electra rods)                    Disk file: TESTR#1B.RST
User: John G. Svinos                             Date: 9/14/89

------------------------------------------------------------------------
Production rate (BFPD): 418              |  SPM: 12
Pump condition: Full pump                |  Surface stroke (in): 100
Fluid specific gravity: 1                |  N/No': .221
System efficiency (Motor->Pump): 48%     |  Fo/SKr: .231
Electricity cost: $ .066/bbl             |  Min. required motor HP: 28
Fl. level from surface (ft): 4000        |  Feet over pump: 500

Peak polished rod load (lbs): 16028      |  Unit structure loading: 63%
Min. polished rod load (lbs): 1276       |  Gearbox loading: 79%
Polished rod horsepower: 19.8            |  Maximum rod loading: 81%
Weight of rods in fluid (lbs): 6484      |  Fluid load on pump (lbs): 5755
Tubing pressure (psi): 100               |  Casing pressure (psi): 0
========================================================================

TUBING                                      PUMP
------------------------------------------------------------------------
Tubing O.D. (in): 3.5                    |  Pump depth (ft): 4500
Tubing I.D. (in): 2.992                  |  Pump type: Insert
Tubing anchor depth (ft): 4350           |  Plunger size (in): 2
Tubing stretch (in): .1                  |  Gross pump stroke (in): 88
Rod-tubing friction: .8                  |  Pump volum. efficiency: 85%
========================================================================

ROD STRING STRESS ANALYSIS (rod tapers calculated)   Service factor: .9
------------------------------------------------------------------------
  Diam.   Length     Rod    Stress   Top Max.    Top Min.    Bottom Min.
  (in)     (ft)     Grade   Load %  Stress(psi) Stress (psi) Stress(psi)
 ------  ---------  -------  ------  ----------- ------------ -----------
   .75     4500      EL       81      36281        2890          N/A
========================================================================

PUMPING UNIT: Lufkin Mark II
------------------------------------------------------------------------
API size: M-320-256-100                  |  Unit ID: ML55
Calculated stroke length (in): 100       |  Crank hole # 1 (out of 3)
Structural unbalance (lbs):-3470         |  Crank offset angle (deg): 24
Rotation with well to right: CCW         |
Rot. inertia (lb-ft^2): 440000           |  Art. inertia (lb-ft^2): 1498700
========================================================================
```

Figure 1 - First page of RODSTAR output for first example

```
* * *  RODSTAR  * * *
                                                   (C) Theta Enterprises
                                                   Tel: (714) 879-8951
Company: Major Oil
Well: Test R#1 (Electra rods)                   Disk file: TESTR#1B.RST
User: John G. Svinos                            Date: 9/14/89

---------------------------------------------------------------------------
TORQUE ANALYSIS (pumping unit inertia effects included)
                                              BALANCED
                                              --------

Peak gearbox torque (M In-lbs):                  251
Gearbox loading:                                  79%
Cyclic load factor:                             1.27
Maximum counterbalance moment (M in-lbs):        576
Counterbalance effect (lbs):                    8104
===========================================================================

RECOMMENDED PRIME MOVER SIZE (for balanced unit with fluid level at pump)
---------------------------------------------------------------------------
NEMA D motor:  40 HP
Single or double cylinder engine:  40 HP
Multicylinder engine:  30 HP
Ultra high slip motor: SIZE 4, 405 T FRAME, 100 AMP. FUSE
Prime mover speed variation (%): 9
===========================================================================

ENERGY CONSUMPTION (for balanced unit)
---------------------------------------------------------------------------
Power meter type: Non-detent (credit for generated power)
Electricity cost: $ .06/KWH
Daily electricity consumption (NEMA D only): 459 KWH/day
Monthly electric bill: $ 839/month
Electricity cost per barrel of fluid: $ .066/bbl
===========================================================================
```

Figure 2 - Second page of RODSTAR output for first example

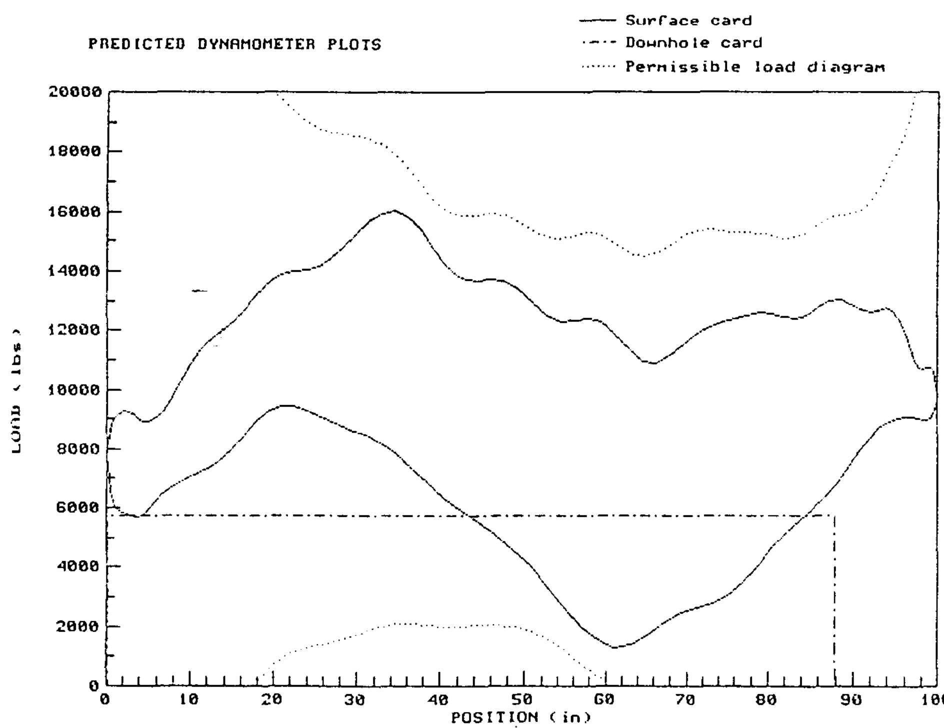

Figure 3 - Third page of RODSTAR output for first example

* * * RODSTAR * * *

(C) Theta Enterprises
Tel: (714) 879-8951

Company: Major Oil
Well: FGEX # 2
User: J.G. Svinos

Disk file: FGEX#2.RST
Date: September 13, 1989

Production rate (BFPD): 517	SPM: 12.5 (calc.)
Pump condition: Full pump	Surface stroke (in): 126
Fluid specific gravity: 1.05	N/No': .632
System efficiency (Motor->Pump): 52%	Fo/SKr: .615
Electricity cost: $ .124/bbl	Min. required motor HP: 67
Fl. level from surface (ft): 7800	Feet over pump: 300
Peak polished rod load (lbs): 25813	Unit structure loading: 85%
Min. polished rod load (lbs): 5924	Gearbox loading: 81%
Polished rod horsepower: 48.3	Maximum rod loading: 90%
Weight of rods in fluid (lbs): 11604	Fluid load on pump (lbs): 8529
Tubing pressure (psi): 50	Casing pressure (psi): 50

TUBING	PUMP
Tubing O.D. (in): 2.875	Pump depth (ft): 8100
Tubing I.D. (in): 2.441	Pump type: Insert
Tubing anchor depth (ft): 8091	Plunger size (in): 1.75
Tubing stretch (in): 0	Gross pump stroke (in): 136
Rod-tubing friction: .5 (calc.)	Pump volum. efficiency: 85%

ROD STRING STRESS ANALYSIS Service factor: .9

Diam. (in)	Length (ft)	Rod Grade	Stress Load %	Top Max. Stress(psi)	Top Min. Stress (psi)	Bottom Min. Stress(psi)
+ 1.175	4860	Fiberflex	90	23806	5464	839
+ 1	3240	D	89	24222	2024	N/A

+Requires slimhole couplings

PUMPING UNIT: Lufkin conventional

API size: C-640-304-144	Unit ID: CL15
Calculated stroke length (in): 126.1	Crank hole # 2 (out of 4)
Structural unbalance (lbs):-520	Crank offset angle (deg): 0
Rotation with well to right: CCW	
Rot. inertia (lb-ft^2): 1500000	Art. inertia (lb-ft^2): 688315

Figure 4

* * * RODSTAR * * *

(C) Theta Enterprises
Tel: (714) 879-8951

Company: Major Oil
Well: FGEX # 2
User: J.G. Svinos

Disk file: FGEX#2.RST
Date: September 13, 1989

TORQUE ANALYSIS (pumping unit inertia effects included)

	BALANCED	EXISTING
Peak gearbox torque (M In-lbs):	520	680
Gearbox loading:	81%	106%
Cyclic load factor:	1.25	1.34
Maximum counterbalance moment (M in-lbs):	1036	1200
Counterbalance effect (lbs):	15828	18417

RECOMMENDED PRIME MOVER SIZE (for balanced unit with fluid level at pump)

NEMA D motor: 70 HP
Single or double cylinder engine: 70 HP
Multicylinder engine: 70 HP
Ultra high slip motor: SIZE 5, 445 T FRAME, 125 AMP. FUSE
Prime mover speed variation (%): 8

ENERGY CONSUMPTION (for balanced unit)

Power meter type: Detent (no credit for generated power)
Electricity cost: $ .06/KWH
Daily electricity consumption (NEMA D only): 1070 KWH/day
Monthly electric bill: $ 1959/month
Electricity cost per barrel of fluid: $ .124/bbl

Figure 5

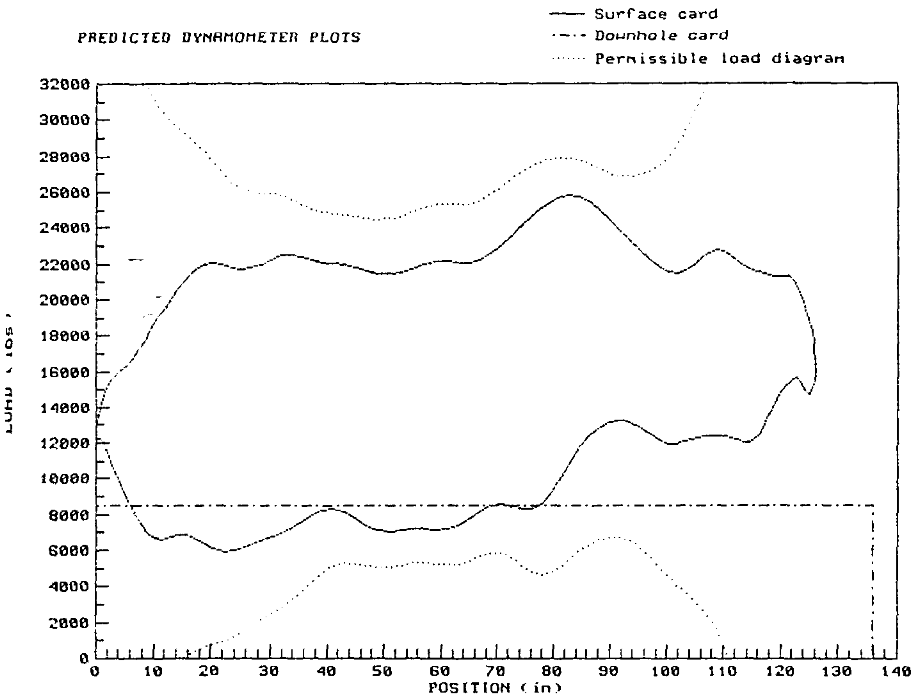

Figure 6

* * * RODSTAR * * *

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Tel: (714) 879-8951

Company: Major B
Well: SWPSC#3 — Disk file: SWPSC#3.RST
User: JGS — Date: Jan 18, 1989

Production rate (BFPD): 309	SPM: 9
Pump condition: Full pump	Surface stroke (in): 128
Fluid specific gravity: 1	N/No': .189
System efficiency (Motor->Pump): 46%	Fo/SKr: .144
Electricity cost: $ .086/bbl	Min. required motor HP: 26
Fl. level from surface (ft): 5000	Feet over pump: 0
Peak polished rod load (lbs): 18803	Unit structure loading: 74%
Min. polished rod load (lbs): 3821	Gearbox loading: 94%
Polished rod horsepower: 19.2	Maximum rod loading: 90%
Weight of rods in fluid (lbs): 9631	Fluid load on pump (lbs): 5207
Tubing pressure (psi): 50	Casing pressure (psi): 50

TUBING	PUMP
Tubing O.D. (in): 2.875	Pump depth (ft): 5000
Tubing I.D. (in): 2.441	Pump type: Insert
Tubing anchor depth (ft): 4750	Plunger size (in): 1.75
Tubing stretch (in): .3	Gross pump stroke (in): 113
Rod-tubing friction: .8 (calc.)	Pump volum. efficiency: 85%

ROD STRING STRESS ANALYSIS — Service factor: .9

Diam. (in)	Length (ft)	Rod Grade	Stress Load %	Top Max. Stress(psi)	Top Min. Stress (psi)	Bottom Min. Stress(psi)
+ 1	1469	D	81	23942	4866	1397
.875	1500	D	85	23084	2040	-655
.75	2031	D	90	23145	-404	N/A

+Requires slimhole couplings

PUMPING UNIT: Lufkin Mark II

API size: M-320-253-144	Unit ID: ML38
Calculated stroke length (in): 127.9	Crank hole # 2 (out of 3)
Structural unbalance (lbs):-4010	Crank offset angle (deg): 23
Rotation with well to right: CCW	
Rot. inertia (lb-ft^2): 1020000	Art. inertia (lb-ft^2): 1800952

Figure 7

* * * RODSTAR * * *

(C) Theta Enterprises
Tel: (714) 879-8951

Company: Major B
Well: SWPSC#3
User: JGS

Disk file: SWPSC#3.RST
Date: Jan 18, 1989

TORQUE ANALYSIS (pumping unit inertia effects included)

	BALANCED
Peak gearbox torque (M In-lbs):	302
Gearbox loading:	94%
Cyclic load factor:	1.24
Maximum counterbalance moment (M in-lbs):	1010
Counterbalance effect (lbs):	12364

RECOMMENDED PRIME MOVER SIZE (for balanced unit with fluid level at pump)

NEMA D motor: 30 HP
Single or double cylinder engine: 30 HP
Multicylinder engine: 30 HP
Ultra high slip motor: SIZE 3, 326 T FRAME, 60 AMP. FUSE
Prime mover speed variation (%): 8

ENERGY CONSUMPTION (for balanced unit)

Power meter type: Detent (no credit for generated power)
Electricity cost: $ .06/KWH
Daily electricity consumption (NEMA D only): 442 KWH/day
Monthly electric bill: $ 808/month
Electricity cost per barrel of fluid: $ .086/bbl

Figure 8

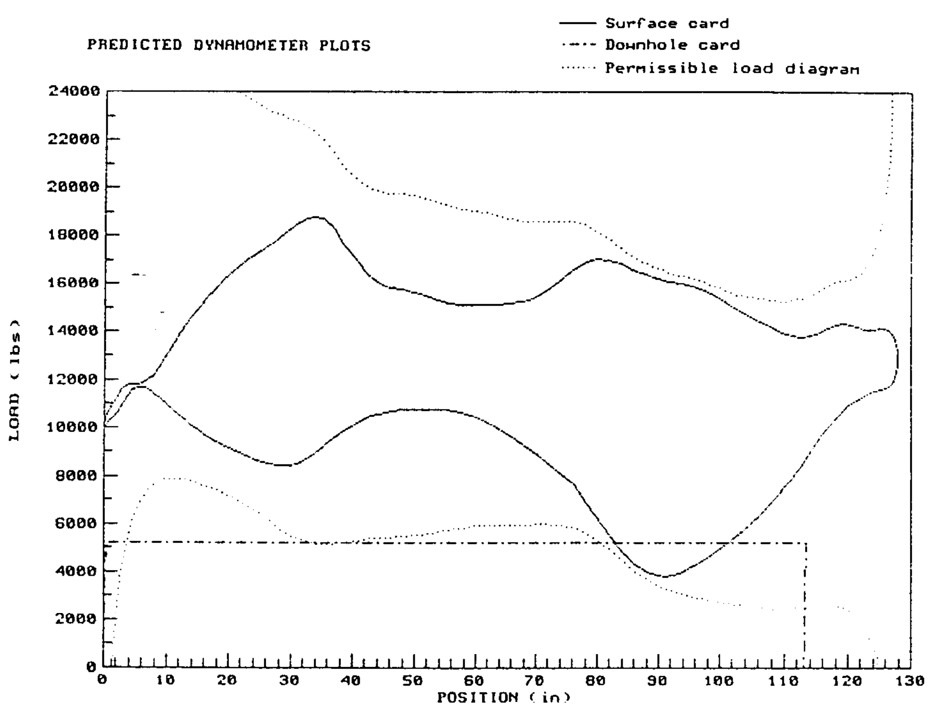

Figure 9

* * * RODSTAR * * *

(C) Theta Enterprises
Tel: (714) 879-8951

Company: Major B
Well: SWPSC#3
User: JGS

Disk file: SWPSC#3B.RST
Date: Jan 18, 1989

Production rate (BFPD): 311	SPM: 9
Pump condition: Full pump	Surface stroke (in): 128
Fluid specific gravity: 1	N/No': .189
System efficiency (Motor->Pump): 45%	Fo/SKr: .137
Electricity cost: $ .087/bbl	Min. required motor HP: 27
Fl. level from surface (ft): 5000	Feet over pump: 0
Peak polished rod load (lbs): 19297	Unit structure loading: 76%
Min. polished rod load (lbs): 3937	Gearbox loading: 97%
Polished rod horsepower: 19.6	Maximum rod loading: 84%
Weight of rods in fluid (lbs): 10026	Fluid load on pump (lbs): 5207
Tubing pressure (psi): 50	Casing pressure (psi): 50

TUBING	PUMP
Tubing O.D. (in): 2.875	Pump depth (ft): 5000
Tubing I.D. (in): 2.441	Pump type: Insert
Tubing anchor depth (ft): 4750	Plunger size (in): 1.75
Tubing stretch (in): .3	Gross pump stroke (in): 114
Rod-tubing friction: .8 (calc.)	Pump volum. efficiency: 85%

ROD STRING STRESS ANALYSIS (rod tapers calculated) Service factor: .9

Diam. (in)	Length (ft)	Rod Grade	Stress Load %	Top Max. Stress(psi)	Top Min. Stress (psi)	Bottom Min. Stress(psi)
+ 1	1712	D	84	24570	5014	1111
.875	1737	D	84	22740	1698	-1134
.75	1551	D	84	21118	-982	N/A

+Requires slimhole couplings

PUMPING UNIT: Lufkin Mark II

API size: M-320-253-144	Unit ID: ML38
Calculated stroke length (in): 127.9	Crank hole # 2 (out of 3)
Structural unbalance (lbs):-4010	Crank offset angle (deg): 23
Rotation with well to right: CCW	
Rot. inertia (lb-ft^2): 1020000	Art. inertia (lb-ft^2): 1800952

Figure 10

* * * RODSTAR * * *

(C) Theta Enterprises
Tel: (714) 879-8951

Company: Major B
Well: SWPSC#3
User: JGS

Disk file: SWPSC#3B.RST
Date: Jan 18, 1989

TORQUE ANALYSIS (pumping unit inertia effects included)

	BALANCED
Peak gearbox torque (M In-lbs):	311
Gearbox loading:	97%
Cyclic load factor:	1.24
Maximum counterbalance moment (M in-lbs):	1031
Counterbalance effect (lbs):	12705

RECOMMENDED PRIME MOVER SIZE (for balanced unit with fluid level at pump)

NEMA D motor: 30 HP
Single or double cylinder engine: 30 HP
Multicylinder engine: 30 HP
Ultra high slip motor: SIZE 3, 326 T FRAME, 60 AMP. FUSE
Prime mover speed variation (%): 8

ENERGY CONSUMPTION (for balanced unit)

Power meter type: Detent (no credit for generated power)
Electricity cost: $ .06/KWH
Daily electricity consumption (NEMA D only): 454 KWH/day
Monthly electric bill: $ 830/month
Electricity cost per barrel of fluid: $ .087/bbl

Figure 11

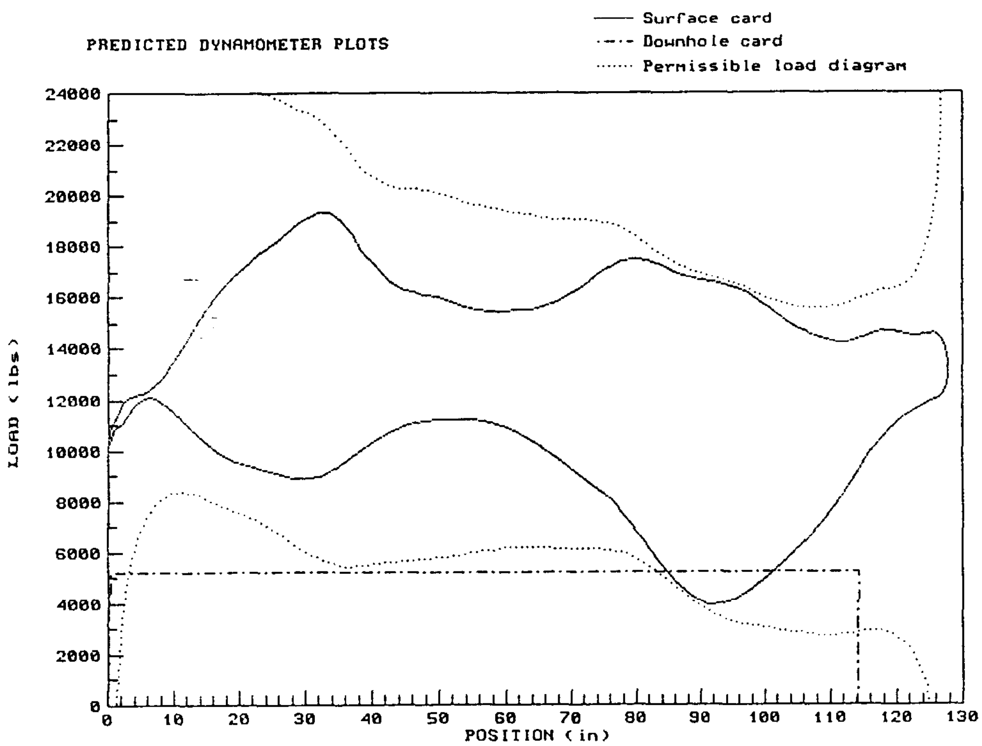

Figure 12