PRACTICAL ROD PUMPING OPTIMIZATION TECHNIQUES USING COMPUTERS

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ABSTRACT

In an environment of low oil prices, rod pumping system optimization is more important than ever before. This is especially true for high water cut wells that account for the vast majority of rod pumped wells in the Permian Basin. To maintain profitability, rod pumping wells must be well designed to start with, and analyzed on a regular basis to detect and correct problems as soon as possible. This requires accurate data and the right tools. One of the most powerful set of tools for this purpose is modern diagnostic analysis and design software.

The purpose of this paper is to present practical optimization techniques that anyone can use to optimize the operation of rod pumping wells. These techniques, although easy to understand and apply, require the use of modern rod pumping software with unique capabilities. The procedures described in this paper have been proven to work, and when applied correctly, will result in measurable improvements in system efficiency, reduced lifting costs, and extended equipment life. The computer programs used to develop these techniques are:

RODSTAR - an expert system predictive computer program,
RODDIAG - a diagnostic analysis wave equation computer program, and
CBALANCE - a tool for obtaining counterbalance information and for aiding in pumping unit balancing.

INTRODUCTION

Rod pumping system optimization must start when the rod pumping system is first designed. When designing a new rod pumping system, you must have as much information as possible about the system. This is vital in order to select the best possible pumping unit, rod string, pump size, motor size, etc. Do you expect production to increase or decrease in the future? Do you expect excessive rod-tubing friction due to paraffin, scale, or dog legs? Do you expect this well to pound fluid or to have gas interference problems? Answers to these questions are important for making the right choices and for specifying the right inputs to the simulation software for predictions that are as accurate as possible.

Another very important aspect of rod pumping optimization is diagnostic analysis of existing wells. This allows you to detect downhole problems such as a leaking traveling valve or plunger, fluid pound or gas interference, excessive rod-tubing friction, and a lot more. Also, it helps you figure out if the gearbox is overloaded or if the unit is out of balance, if the rods are overloaded, etc. After you detect a downhole problem such an overloaded rod string, or a surface equipment problem such as an overloaded gearbox, you can go back to a predictive wave equation program to solve the problem. This requires redesigning the system and evaluation of different alternatives for fixing the problem in the most economical way.

Another Way to Balance Pumping Units

Pumping unit balancing is an important tool for optimizing rod pumping system performance. Traditionally, the term "balanced unit" means a pumping unit whose peak gearbox torque on the upstroke equals the peak gearbox torque on the downstroke. Therefore, balancing a unit this way minimizes gearbox torque. However, it does not necessarily minimize energy consumption. The RODSTAR and RODDIAG computer programs can determine the ideal amount of counterbalance needed to either minimize gearbox torque (the conventional way to balance units), or to minimize energy consumption. In many cases, by balancing the unit to minimize torque, you also minimize energy consumption. However, there are many situations where you can significantly reduce lifting costs by balancing the unit for minimum energy consumption instead of torque. Although this will result is higher gearbox loading, it will give you the highest system efficiency. As long as the gearbox is not overloaded, this would be a better way to balance units.

The reason there is a difference between balancing a unit for minimum torque versus for minimum energy consumption has to do with motor efficiency. When you balance a unit to minimize gearbox torque, the only two points you look at are the peak torque on the upstroke, and the peak torque on the downstroke. However, the points between these two values determine energy consumption since each of these torques corresponds to a different motor efficiency. The closer the instantaneous hp is to the rated motor hp, the higher the efficiency is. When calculating the maximum counterbalance moment required for minimum energy consumption, RODSTAR and RODDIAG use actual motor efficiency curves to calculate the instantaneous efficiency of the motor for each torque point. Using a unique balancing routine, they can determine what value of maximum counterbalance moments results in the lowest overall energy consumption.

The CBALANCE computer program can be used to determine where to move the counterweights to balance the pumping unit in one step for either minimum torque, or minimum energy consumption. Actually, using the CBALANCE program is the only way to balance the unit for minimum energy consumption since the traditional way of balancing units using an amp meter is equivalent to balancing the unit for minimum torque.

DESIGN GUIDELINES FOR NEW ROD PUMPING SYSTEMS

The following design guidelines will help you avoid equipment failures, reduce lifting costs, and maximize the profitability of your rod pumping systems:

- Design steel rod strings with balanced stress loading (equal percent loading at the top of each rod section). The RODSTAR[1], [2] program does this automatically when you ask it to design a steel rod string for you. Figure 1 shows an example printout from RODSTAR for a case where the program designed the steel rod string. As this figure shows, the rod string stress loading is balanced.

- To minimize rod string costs, try using API grade D or C rods first, before looking into high strength non-API rods or Fiberglass rods.

- Keep gearbox torque and rod string stress loading between 75% and 95%. Anything less than 75% would be overkill, while anything over 95% may result in an overloaded gearbox if the unit cannot be kept balanced all the time.

- To maximize system efficiency, use the largest pump plunger and longest stroke length possible (but not if rods or gearbox are overloaded).

- When comparing different system designs, include both capital and operating expenses. For example, although a system with fiberglass rods may be more expensive than a system with steel rods, the fiberglass system may be better if it has substantially lower lifting costs because of better system efficiency. Figure 2 shows an example printout of RODSTAR's rod cost table. The costs are based on $/ft values that user enters once when he first sets up the program.

- Use measured dynamometer cards to "calibrate" your predictive wave equation computer program to the wells you are designing. This will enable you to determine what rod-tubing friction factors to use to better simulate downhole friction. The RODSTAR program makes this easy by allowing you to overlay a measured dynamometer card on the same plot as the predicted dynamometer card.

- Compare pumping units not only based on cost, but also based on system efficiency, maximum production capacity, and rod fall speed (to avoid rod buckling problems). Also, for units that can rotate CW or CCW, you will that one rotation is better than the other. For example, most conventional units have lower gearbox torque when rotating CCW with the well to the right.

- Use a correctly sized prime mover to maximize efficiency.

- When using a fiberglass-steel rod string, make sure that the bottom of the fiberglass section is not in compression. Also, avoid designing systems with excessive overtravel since this reduces system efficiency.

- When using fiberglass rods, make runs for the highest and lowest fluid levels expected during the life or the system to ensure that the pumping unit, rods, and motor are correctly sized. This is because the highest fluid level over the pump mãy result in more gearbox loading and larger required motor size than for fluid level at the pump.

MODERN DIAGNOSTIC ANALYSIS AND SYSTEM RE-DESIGN TECHNIQUES

The purpose of analyzing a rod pumping system is to diagnose surface and downhole equipment problems that are responsible for: low system efficiency, low production, frequent rod parts, pump failures, gearbox failures, etc. The most effective way to analyze a rod pumping system is with a computer program that combines wave equation [3], [4] rod string simulation with pumping unit kinematic[5] modeling. New software such as CBALANCE and RODDIAG have unique features that make accurate system diagnostic analysis easier than in the past. After you analyze a system and diagnose any existing problems the next action is to fix the problems. The recommended procedure for optimizing the performance of an existing system using CBALANCE, RODDIAG, and RODSTAR, is as follows:

Step 1: Run the CBALANCE computer program to obtain the existing maximum counterbalance moment (maximum torque on the low speed shaft due to the cranks and counterweights).

Step 2: Run the RODDIAG computer program to analyze the rod pumping system and to find out if the gearbox is overloaded, if the unit is out of balance, if the rods are overloaded, etc. Also, RODDIAG will help you diagnose pump problems, excessive rod-tubing friction, etc.

Step 3: "History-match" the measured dynamometer card with RODSTAR. You can do this by reading the RODDIAG data file into RODSTAR and superimposing the actual and predicted dynamometer cards on the same plot. Then you can vary input parameters such as rod-tubing friction or fluid level until you can get the best possible match.

Step 4: After you get a good match between the measured and predicted dynamometer cards in RODSTAR, you can use RODSTAR to determine the best way to solve the problems you found.

Step 5: Finally, run CBALANCE to find out where to move the counterweights to balance the unit in one step.

Before you can attempt to optimize an existing rod pumping system, you must first collect field data that consists of a quantitative dynamometer card, pumping speed, pumping unit direction of rotation, etc. Figure 3 shows the data sheet used for the RODDIAG and CBALANCE programs. One of the most important pieces of data needed to analyze gearbox loading and unit balancing is counterbalance information. Up to now, the most common way of obtaining the counterbalance data needed was to measure the counterbalance effect (CBE) in the field. This is done by measuring the polished rod load required to counterbalance the cranks and counterweights. For this measurement you can use the same dynamometer system used to record the dynamometer card. The CBE is a polished rod load measurement that is indirectly related to the maximum counterbalance moment of the cranks and counterweights. The measured CBE is typically expressed as the polished rod load required to keep the cranks and counterweights at a given crank angle (for example, 14250 lbs @ 95 degrees). Ideally, this crank angle must be as close as possible to 90° or 270° to minimize the measurement error. However, in many cases it is difficult to get a good CBE without chaining off the polished rod, or by using a polished rod clamp to remove some of the polished rod load (to the wellhead). This is true because many units are not in good balance and therefore, the cranks will not stop at a horizontal position when you stop the unit. If you measure the CBE with the cranks close to a vertical position, you will introduce a large error into the calculation of the maximum counterbalance moment. The safety hazard of chaining the polished rod and the inaccuracies associated with field CBE measurements can be avoided by using the CBALANCE computer program.

The CBALANCE Computer Program

CBALANCE contains a large database of crank and counterweight information for the majority of the pumping units found in today's oil fields. The information in the program's database includes: a list of counterweights that can fit on the crank type you select, the maximum and minimum distances each counterweight can physically move on the crank, the center of gravity of each master or auxiliary counterweight, etc. The CBALANCE computer program performs two major tasks that are important for rod pumping system optimization:

1) It allows you to get counterbalance data without a field measurement.

2) It calculates the counterweight positions required to balance the unit in one step.

CBALANCE is designed to work along with diagnostic and predictive wave equation computer programs. Using the information in its database CBALANCE can accurately calculate the existing maximum counterbalance moment. This value is then entered into a diagnostic or predictive computer program to calculate the existing gearbox loading and energy consumption. The RODSTAR and RODDIAG computer programs can calculate the maximum counterbalance moment you need to balance the unit either for minimum torque, or for minimum energy consumption. You can enter the balanced maximum counterbalance moment back into CBALANCE to find out where to move the weights to balance the unit in one step. CBALANCE calculates all possible combination of counterweight positions that can balance the unit. For example, if you have four counterweights, you may be able to balance the unit by only moving two of them instead of moving all four.

This is much easier and more accurate than balancing the unit with the old-fashioned trial-and-error amp meter method. This method is based on the fact that the current drawn by the motor is proportional to motor torque. If the peak amps drawn by the motor on the upstroke equals the peak amps drawn on the downstroke, then the unit is considered to be balanced. This common balancing method has the following disadvantages that CBALANCE eliminates:

1) It is time consuming. To balance the unit you may have to move the weights several times. This may take from 30 minutes to three hours depending on the unit. Also, it depends on the experience of the crew doing the work. The time required to balance the unit may be even longer if you find that you need to add or remove counterweights.

2) The trial-and-error approach is inaccurate because in many cases you balance the unit for the wrong fluid level. This occurs because to move the counterweights you must turn the unit off. While the unit is off, the fluid level in the annulus rises.

3) The trial-and-error approach is dangerous. Since you have to move large counterweights several times, you are increasing the risk of injury. This is especially true if you have to remove or add counterweights.

CBALANCE allows you to figure out exactly what you need to do to balance the unit before you do any unnecessary field work.

The RODDIAG Computer Program

RODDIAG is a modern diagnostic analysis computer program that combines a diagnostic wave equation rod string model with exact pumping unit kinematic algorithms. RODDIAG is a diagnostic tool that basically allows you to find out how a rod pumping system operates and if there are any problems you must fix. RODDIAG requires measured dynamometer data along with data about the rod string, plunger size, existing counterbalance data, etc. In addition to calculating the downhole pump card shape, RODDIAG has several unique capabilities such as: two possible balancing recommendations (balancing for minimum torque or minimum energy consumption), calculation of energy costs per barrel of oil and per barrel of fluid, calculation of stresses at the top and bottom of each rod section, recommended prime mover size, and interactive calculation of pump intake pressure, fluid level, and fluid flow through the pump. However, RODDIAG is strictly a diagnostic tool and cannot be used for system design. To evaluate the effect of changing spm, plunger size, rod string design, etc., you must use a predictive wave equation computer program such as RODSTAR.

AN EXAMPLE OF ROD PUMP SYSTEM OPTIMIZATION

Following is an example that shows how the above five optimization steps work on an actual rod pumping system:

Well N109 has had frequent pump failures and above average rod string parts. Find out the cause of these problems and recommend changes to minimize or eliminate them. There is severe H_2S corrosion in this well and production is not expected to increase.

Solution:

To perform a diagnostic analysis, a dynamometer card-was measured and a data sheet was completed as shown on Figure .

Step 1: Run CBALANCE

To find out the existing maximum counterbalance moment, run CBALANCE using the data at the bottom of the data sheet. The output of the CBALANCE program for this case is shown in Figure 4. The value of the required balanced maximum counterbalance moment is unknown at this point.

Step 2: Run RODDIAG

Using the data sheet and the measured dynamometer card file for this well, run the RODDIAG computer program. RODDIAG's output for this well is shown in Figure 5. This single page report shows useful information about all parts of the system. The downhole pump card shape shows fluid pound. This explains the frequent pump failures. Also, the rods are overloaded, which explains the higher-than-average rod parts. Because of the severe H_2S corrosion, a service factor of 0.8 was used. This means that we use only 80% of the maximum allowable stress calculated by the API Modified Goodman Diagram[6].

Also, the RODDIAG output shows that the gearbox is overloaded and the unit is out of balance. You can reduce gearbox loading to 93% by balancing the unit. However, this is not recommended since the system design must be changed to reduce rod loading and minimize fluid pound. However, before deciding what system design changes to make, you must first "history-match" the existing system with RODSTAR.

Step 3: History-match existing system with RODSTAR

This is a very important step that allows you to find out the following:

1) Was the dynamometer used to measure the dynamometer card properly calibrated? (or was it reading too low or too high?)
2) Was the fluid level measured correctly?
3) What rod-tubing friction factors give the best match between the measured and predicted dynamometer card shapes?
4) Is any other well data wrong?

For this step, you must save the RODDIAG input file for this well, exit RODDIAG, and run RODSTAR. The RODSTAR program provides the option to load a RODDIAG file and superimpose the measured and predicted cards on the same plot. However, since RODSTAR does not know the actual pump condition, you must select to simulate fluid pound with the same pump fillage as the one determined by RODDIAG (69% in this case). To get a good match between the measured and predicted dynamometer card shapes, five runs were made with the RODSTAR program. For a better match, the rod-tubing friction coefficients had to be adjusted from the average values calculated by RODSTAR. Figure 6 shows the final RODSTAR run made for this case. As this figure shows, there is a good match between the measured and predicted dynamometer cards.

Step 4: Redesign the System with RODSTAR

After the history-matching step, you can proceed with system redesign. In this case, to avoid damaging the pump and rods, you must eliminate or minimize fluid pound without losing production. You can do this with a percentage timer or a pump off controller. However, because production is not expected to increase, it is better to redesign the system to eliminate fluid pound. To do this, we have three options or a combination:

- Slow down the unit.
- Use a smaller plunger.
- Use a shorter stroke length.

RODSTAR can help you decide which option (or combination of options) is best. Since changing the pump size is more expensive, you must evaluate the other two alternatives first. In this case, after making four runs, I determined that the best solution was to reduce the pumping speed and to use the middle crank hole. As Figure 7 shows, I ran RODSTAR with a target production of 100 bfpd. The program calculated a pumping speed of 6.9 spm. Because I used the second crank hole (73.1 inch stroke) gearbox loading was reduced to 90%. Gearbox loading can be reduced to 69% by balancing the unit for minimum gearbox torque. I would not recommend rebalancing the unit since leaving the counterweights where they are minimizes energy consumption without overloading the gearbox. However, if one wanted to balance the unit for minimum torque, the new counterweight positions could be easily calculated by running CBALANCE with a balanced maximum counterbalance moment of 374.4 M In-lbs as calculated by RODSTAR. This is shown in Figure 8. In this case the only way to balance the unit is by moving all counterweights to position 9.25.

OPTIMIZATION RESULTS FOR EXAMPLE CASE

As a comparison of Figures 4 (before) and 7 (after) shows, the proposed pumping system changes improve the operation of the system significantly. Following is a summary of the major improvements made to this system:

System Parameter	Before	After
Polished Rod HP	6.3	4.8
System Efficiency	23%	36%
Gearbox Loading	124%	90%
Max. sucker rod loading	108%	96%
Lifting cost per barrel of oil	$0.159	$0.100

CONCLUSIONS

With the right tools, system optimization can be easy and very profitable. Lifting costs can be reduced by designing rod pumping systems better from the start. Modern diagnostic analysis, system redesign and computer aided balancing can make a big difference in reducing rod and pump failures and lifting costs.

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2. Svinos, J. G.: "RODSTAR - An Expert Rod Pumping System Predictive Simulator," CIM/SPE paper 90-31 presented at the International Technical Meeting, Calgary AB, June 10-13, 1990.

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5. 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.

6. API RP 11BR: "Care and Handling of Sucker Rods," American Petroleum Institute, March 1969.

* * * RODSTAR 2.1 for Windows * * *

Company: First Oil Co.
Well: SWPSC#1
User: John G. Svinos

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Tel: (714) 879-8951

Disk file: SWPSC#1.RST
Date: January 3, 1994

INPUT DATA

Target prod. (BFPD):	325
Run time (hrs/day):	24.0
Tubing pres. (psi):	60.0
Casing pres. (psi):	60.0

Fluid level

(ft from surface):	4750
(ft over pump):	0
Stuf.box fr. (lbs):	100

Fluid properties

Water cut:	76%
Water sp. gravity:	1.02
Oil API gravity:	30.0
Fluid sp. gravity:	0.985

Motor & power meter

Power meter: Detent
Electr. cost: $.06/KWH
Type: NEMA D

Unit: Lufkin Conventional - New (C-640D-305-144)

API size: C-640-305-144 (unit ID: CL18)
Crank hole #1 (out of 4)

Calculated stroke length (in):	145.9
Rotation with well to right:	CCW
Max. CB moment (M in-lbs):	Unknown
Structural unbalance (lbs):	-520
Crank offset angle (deg):	0.0
Rot. inertia (lb-ft²):	1070000
Art. inertia (lb-ft²):	688315

Tubing and pump information

Tubing O.D. (in):	2.875	Rod-tub. frict.:	0.84(up)
Tubing I.D. (in):	2.441		0.84(dn)
Pump depth (ft):	4750.0	Tub.anch.depth (ft):	4600
Pump condition:	Full	Pump load adj. (lbs):	0
Pump type:	Insert	Pump vol. efficiency:	85%
Plunger size (in):	1.75		

Rod string design (rod tapers calculated)

Diameter (inches)	Rod Grade	Length (ft)	Tensile Strength (psi)
+ 1.0	D (API)	1875	115000
0.875	D (API)	1875	115000
0.75	D (API)	525	115000
@ 1.625	C (API)	475	90000

CALCULATED RESULTS

Peak pol. rod load (lbs):	22946
Min. pol. rod load (lbs):	8123
System eff. (Motor->Pump):	34%
Fluid load on pump (lbs):	4875
Buoyant rod weight (lbs):	12337
Production rate (BFPD):	332

Balanced minimum required motor HP:	42.4
Polished rod HP:	22.7
Unit struct. loading:	75%
N/No': 0.165, Fo/SKr: 0.091	
Strokes per minute	7.92

Required prime mover size (calc. speed variation: 10)	BALANCED (Min Ener)	BALANCED (Min Torq)
NEMA D motor:	50 HP	50 HP
Single/double cyl. engine:	50 HP	50 HP
Multicylinder engine:	50 HP	50 HP

Torque analysis and electricity consumption	BALANCED (Min Ener)	BALANCED (Min Torq)
Peak g'box torq. (M in-lbs):	631	555
Gearbox loading:	99%	87%
Cyclic load factor:	1.63	1.68
Max. CB moment (M in-lbs):	1103.65	1207.83
Counterbalance effect (lbs):	15603	17125
Daily electr. use (KWH/day):	589	602
Monthly electric bill:	$1078	$1101
Electr. cost per bbl. fluid:	$0.107	$0.109
Electr. cost per bbl. oil:	$0.444	$0.454

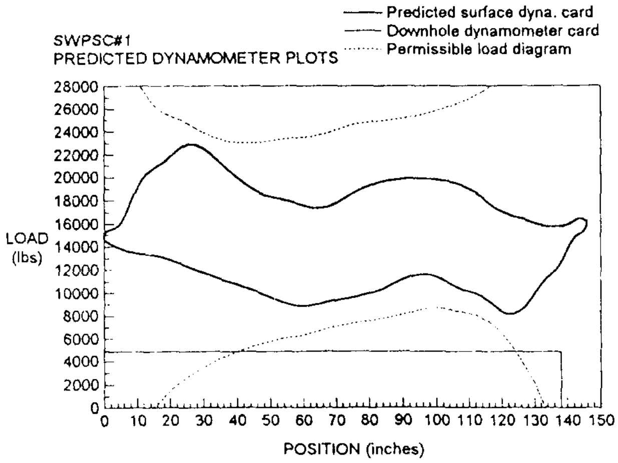
Tubing, pump and plunger calculations

Tubing stretch (in):	0.2
Prod. loss due to tubing stretch (BFPD):	0
Gross pump stroke (in):	138
Pump spacing (in. from bottom):	14.3
Minimum pump length (ft):	19.0
Recommended plunger length (ft):	3.0

Rod string stress analysis (service factor: 0.9)

Stress Load %	Top Maximum Stress (psi)	Top Minimum Stress (psi)	Bot. Minimum Stress (psi)
90%	29088	10469	5043
90%	26982	6587	1691
90%	24526	2302	731
59%	12232	411	-2239

\+ Requires slimhole couplings.
@ Stress loading, top maximum stress and top minimum stress calculated based on elevator neck diameter of 1".



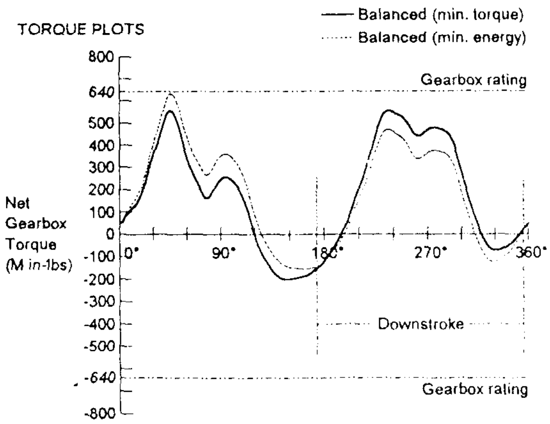


Figure 1 - Example RODSTAR printout showing optimized rod string design

* * * RODSTAR 2.1 for Windows * * *

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Company: First Oil Co.
Well: SWPSC#1 Disk file: SWPSC#1.RST
User: John G. Svinos Date: January 3, 1994

ROD STRING COST ANALYSIS (rod tapers calculated)

Diameter (in)	Rod Grade	Length (ft)	Cost ($/ft)	Total Cost
1.0	D (API)	1875	1.94	3633.75
0.875	D (API)	1875	1.32	2475.94
0.75	D (API)	525	1.04	545.21
1.625	C (API)	475	5.59	2655.25

Pony rods and rod guides: $ 545.00

TOTAL: $ 9855.15

Figure 2 - Example of rod cost report printed by RODSTAR

RODDIAG DATA

Well: N109 Company: MAJOR OIL CO.
Date: 5-1-93 Dyna. file: N109 .DYN, RODDIAG file: N109 .RDG
SPM: 8.3 Runtime (hr/day): 24 Pump depth (ft): 4438
Was fluid level measured ?: Y N , If Yes → Fluid level from surface (ft): 4438
Gross production (BFPD): 93 Water cut: 27 % BOPD: 68 GOR: NA

Tubing size: 2 3/8" Tubing anchored ?: Y N , If Yes → Anchor depth (ft): 4438
Pump type: insert - tubing - large bore , Pump plunger size (in): 1 1/2"
Tubing wellhead pressure (psi): 50 Casing pressure (psi): 50 Rod-tubing friction:
Water SG: 1.0 Oil API gr.: 36 Fluid SG: 0.9 Traveling valve leak ?: Y N
Standing valve leak?: Y N

Rod String Data: Service Factor: 0.8

Section #	Diameter (in)	Length (ft)	Grade/Material	Comments / Notes:
1 (top)	7/8"	1525	C	
2	3/4"	2675	C	
3	1 1/4"	238	C	
4				
5				

Pumping unit manufacturer: American Model: Conventional
API designation: C-228-213-86 Unit ID : CA811
Cranks: K-76-320 Crank rotation with the well to the right: cw ccw
Crank Hole #: 1 2 3 4 5 Stroke length (in): 86

Pumping unit dimensions (required if unit is not in the RODDIAG manual):
R:____ A:____ C:____ I:____ K:____ P:____
Structural unbalance (lbs):____ Crank offset angle (deg):____
For Air Balanced units only: S(psig):____ M(in^2):____ V_o(in^3):____
Maximum counterbalance moment (M In-lbs):____ or CBALANCE file: N109 .CBL
Or → Counterbalance Effect:____lbs @____ Degrees of crank angle
Or → → Counterbalance Effect was recorded on: upstroke - downstroke
For Air Balanced only → Air tank pressure at bottom of stroke (psig):____
For Rotaflex only → Counterbalance weight (1000 x lbs):____

Prime mover type and size: Marathon 30 HP NEMA D Mode:____
$/KWH: 0.05 Power meter type: detent (no credit for gener. power) - non-detent (credit)

Counterweight (with well to right)	Master CWTs	Auxiliary	Position
Front lead	H	None	2.5
Front lag	H	None	2.5
Back lead	H	None	3.25
Back lag	H	None	2.75

Figure 3 - Data sheet for the RODDIAG and CBALANCE computer programs

* * * CBALANCE 1.3 for Windows * * *

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Company: Major Oil Co.
Well: N109
User: JGS

Disk file: N109.CBL
Date: March 3, 1992

Pumping unit: American conventional
Crank type: K-76-320
Crank rotation: Counterclockwise

Maximum CB moment
(M in-lbs)

Existing: 289.5
Balanced: Unknown

EXISTING COUNTERWEIGHT POSITIONS (range is 0 - 10):

	Master weight	Auxiliary weights	Existing position
Front lead	: H		2.50
Front lag	: H		2.50
Back lead	: H		3.25
Back lag	: H		2.75

Because the required balanced moment is unknown, the balanced counterweight positions cannot be calculated.

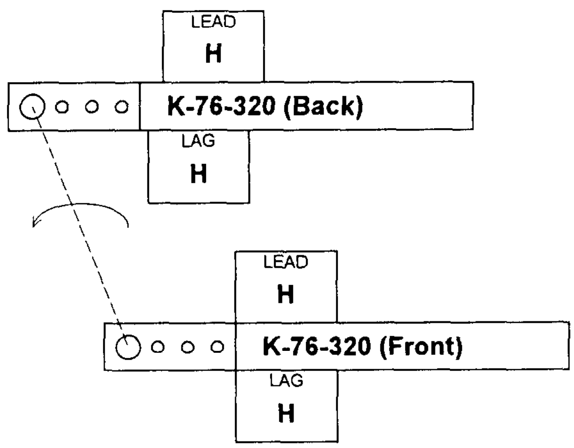

Figure 4 - First CBALANCE output for pumping unit of example well.

* * * RODDIAG 1.7 for Windows * * *

Company: Major Oil Co.
Well: N109
User: JGS

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Tel: (714) 879-8951

Disk file: N109.RDG
Date: May 1, 1993

INPUT DATA

Run time (hrs/day):	24.0	Tubing pres. (psi):	50.0
Strokes per minute:	8.3	Casing pres. (psi):	35.0
Surf. stroke (in):	86.3	Gross prod. (BFPD):	93

Fluid level (ft from surface): 4438
Fluid level (ft over pump): 0

Fluid properties		Motor & power meter
Water cut:	27%	Power meter: Detent
Water sp. gravity:	1.0	Electr. cost: $.05/KWH
Oil API gravity:	36.0	Type: NEMA D
Fluid sp. gravity:	0.9	Size: 30 hp

Unit: American conventional; TH K-76 OR KL-76 CRA*

API size: C-228-213-86 (unit ID: CAB11)	
Crank hole #1 (out of 3)	
Calc. stroke length (in):	86.3
Rotation with well to right:	CCW
Max. CB moment (M in-lbs):	290
Structural unbalance (lbs):	160
Crank offset angle (deg):	0.0

CBALANCE file: "N109.CBL"
Dyna. data source: "N109.DYN"

Tubing and pump information

Tubing O.D. (in):	2.375	Rod-tub. frict.:	0.50
Tubing I.D. (in):	1.995	Pump type:	Insert
Plunger size (in):	1.5	Pump depth (ft):	4438.0
		Tubing anchor depth (ft):	4438.0

Rod string (service factor: 0.8)

Diameter (inches)	Rod Grade	Length (ft)	Tensile Strength (psi)
+ 0.875	C (API)	1525	90000
0.75	C (API)	2675	90000
# 1.25	C (API)	238	90000

CALCULATED RESULTS

Peak pol. rod load (lbs):	13352	Min. req. motor HP:	18
Min. pol. rod load (lbs):	4443	Polished rod HP:	6.3
System eff. (Motor->Pump):	23%	Unit struct. loading:	63%
Buoyant rod weight (lbs):	8035	*Gearbox loading:	124%
		*Max. rod loading:	108%

Required prime mover size for existing conditions	BALANCED	EXISTING
NEMA D motor:	20 HP	25 HP
Single/double cyl. engine:	15 HP	20 HP
Multicylinder engine:	20 HP	25 HP

Torque analysis and electricity consumption	BALANCED	EXISTING
Peak g'box torq. (M in-lbs):	213	282
Gearbox loading:	93%	124%
Cyclic load factor:	2.02	2.56
Max. CB moment (M in-lbs):	393.12	289.51
Counterbalance effect (lbs):	9947	7368
Daily electr. use (KWH/day):	196	215
Monthly electric bill:	$298	$328
Electr. cost per bbl. fluid:	$0.105	$0.116
Electr. cost per bbl. oil:	$0.144	$0.159

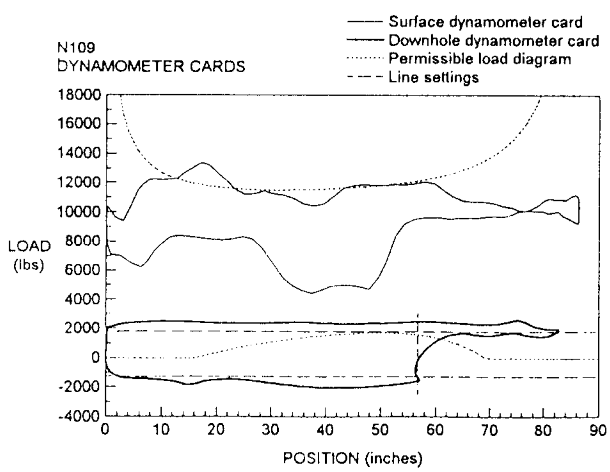
Tubing, pump and plunger calculations

Tubing stretch (in):	0.0	Fl.lev. (ft from surf.):	4438
Gross pump stroke (in):	83	Fl.lev. (ft over pump):	0
Net pump stroke (in):	57	Pump int. pres. (psi):	35
Net str. displ. (BFPD):	124	Pump vol. efficiency:	51.6%
Fl. load on pump (lbs):	3083	Pump fillage:	69%

Rod string stress analysis

Stress Load %	Top Maximum Stress (psi)	Top Minimum Stress (psi)	Bot. Minimum Stress (psi)
105%	22038	7556	2496
108%	20774	3397	-2841
54%	7825	-2560	-1652

\+ Requires slimhole couplings.
\# Stress loading, top maximum stress and top minimum stress calculated based on pin undercut diameter of 0.79".



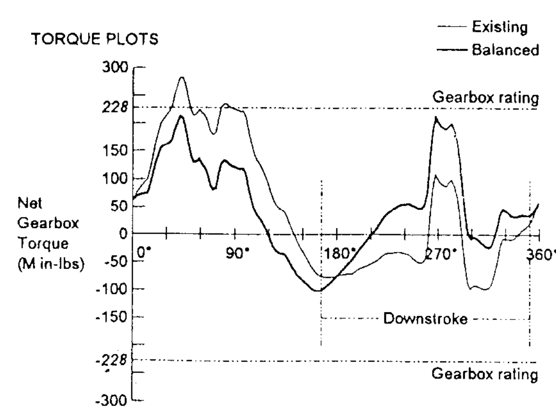


Figure 5 - RODDIAG output for example case.

* * * RODSTAR 2.1 for Windows * * *

Company: Major Oil Co.
Well: N109
User: JGS

© Theta Enterprises
Tel: (714) 879-8951

Disk file: N109.RST
Date: May 1, 1993

INPUT DATA

Strokes per minute:	8.3	Fluid level	
Run time (hrs/day):	24.0	(ft from surface):	4438
Tubing pres. (psi):	50.0	(ft over pump):	0
Casing pres. (psi):	35.0	Stuf.box fr. (lbs):	100

Fluid properties		Motor & power meter
Water cut:	27%	Power meter: Detent
Water sp. gravity:	1.0	Electr. cost: $.05/KWH
Oil API gravity:	36.0	Type: NEMA D
Fluid sp. gravity:	0.9	Size: 30 hp

Unit: American conventional; TH K-76 OR KL-76 CRA*

API size: C-228-213-86 (unit ID: CAB11)	
Crank hole #1 (out of 3)	
Calculated stroke length (in):	86.3
Rotation with well to right:	CCW
Max. CB moment (M in-lbs):	290
Structural unbalance (lbs):	160
Crank offset angle (deg):	0.0
Rot. inertia (lb-ft²):	360000
Art. inertia (lb-ft²):	96200
CBALANCE file: "N109.CBL"	

Tubing and pump information

Tubing O.D. (in):	2.375	Rod-tub. frict.:	0.35(up)
Tubing I.D. (in):	1.995		1.60(dn)
Pump depth (ft):	4438.0	Tub.anch.depth (ft):	4438
Pump condition:	Fl pound	Pump load adj. (lbs):	0
Pump type:	Insert	Pump vol. efficiency:	69%
Plunger size (in):	1.5		

Rod string design

Diameter (inches)	Rod Grade	Length (ft)	Tensile Strength (psi)
+ 0.875	C (API)	1525	90000
0.75	C (API)	2675	90000
# 1.25	C (API)	238	90000

CALCULATED RESULTS

Peak pol. rod load (lbs):	13781	Existing minimum required motor HP:	19.2
Min. pol. rod load (lbs):	4595	Polished rod HP:	6.2
System eff. (Motor->Pump):	30%	Unit struct. loading:	65%
Fluid load on pump (lbs):	3083	N/No':0.135, Fo/SKr:0.123	
Buoyant rod weight (lbs):	8035		
Production rate (BFPD):	122		

Prime mover speed variation

Calculated speed variation: 5.2%

Torque analysis and electricity consumption	BALANCED	EXISTING
Peak g'box torq. (M in-lbs):	218	297
Gearbox loading:	96%	130%
Cyclic load factor:	2.18	2.77
Max. CB moment (M in-lbs):	403.59	289.51
Counterbalance effect (lbs):	10208	7368
Daily electr. use (KWH/day):	194	211
Monthly electric bill:	$296	$322
Electr. cost per bbl. fluid:	$0.080	$0.087
Electr. cost per bbl. oil:	$0.109	$0.119

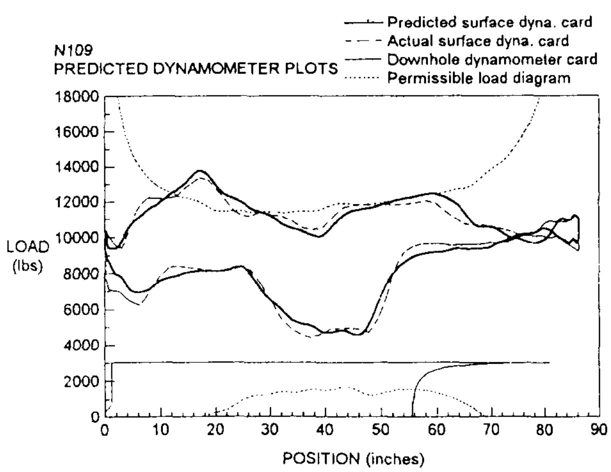
Tubing, pump and plunger calculations

Tubing stretch (in):	0.0
Prod. loss due to tubing stretch (BFPD):	0
Gross pump stroke (in):	81
Pump spacing (in. from bottom):	13.3
Minimum pump length (ft):	14.0
Recommended plunger length (ft):	3.0

Rod string stress analysis (service factor: 0.8)

Stress Load %	Top Maximum Stress (psi)	Top Minimum Stress (psi)	Bot. Minimum Stress (psi)
109%	22751	7808	2908
110%	21397	3958	-2262
53%	8097	-2039	-1909

+ Requires slimhole couplings.
# Stress loading, top maximum stress and top minimum stress calculated based on pin undercut diameter of 0.79".



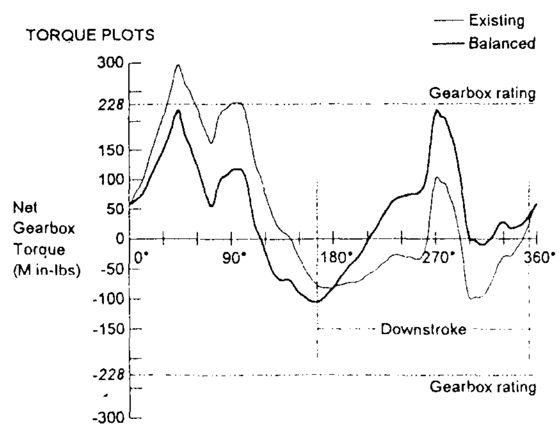


Figure 6 - RODSTAR "history matching" run for example case.

* * * RODSTAR 2.1 for Windows * * *

Company: Major Oil Co.
Well: N109 - Proposed Design
User: JGS

© Theta Enterprises
Tel: (714) 879-8951

Disk file: N109PRP.RST
Date: May 1, 1993

INPUT DATA

Target prod. (BFPD): 100
Run time (hrs/day): 24.0
Tubing pres. (psi): 50.0
Casing pres. (psi): 35.0

Fluid level
(ft from surface): 4438
(ft over pump): 0
Stuf.box fr. (lbs): 100

Fluid properties

Water cut: 27%
Water sp. gravity: 1.0
Oil API gravity: 36.0
Fluid sp. gravity: 0.9

Motor & power meter

Power meter: Detent
Electr. cost: $.05/KWH
Type: NEMA D
Size: 30 hp

Unit: American conventional; TH K-76 OR KL-76 CRA*

API size: C-228-213-86 (unit ID: CAB11)
Crank hole #2 (out of 3)
Calculated stroke length (in): 73.1
Rotation with well to right: CCW
Max. CB moment (M in-lbs): 290
Structural unbalance (lbs): 160
Crank offset angle (deg): 0.0
Rot. inertia (lb-ft²): 360000
Art. inertia (lb-ft²): 96200
CBALANCE file: "N109.CBL"

Tubing and pump information

Tubing O.D. (in): 2.375
Tubing I.D. (in): 1.995
Rod-tub. frict.: 0.35(up) 1.60(dn)

Pump depth (ft): 4438.0
Pump condition: Full
Pump type: Insert
Plunger size (in): 1.5
Tub.anch.depth (ft): 4438
Pump load adj. (lbs): 0
Pump vol. efficiency: 85%

Rod string design

Diameter (inches)	Rod Grade	Length (ft)	Tensile Strength (psi)
+ 0.875	C (API)	1525	90000
0.75	C (API)	2675	90000
# 1.25	C (API)	238	90000

CALCULATED RESULTS

Peak pol. rod load (lbs): 13239
Min. pol. rod load (lbs): 6295
System eff. (Motor->Pump): 36%
Fluid load on pump (lbs): 3083
Buoyant rod weight (lbs): 8028
Production rate (BFPD): 102

Existing minimum required motor HP: 10.1
Polished rod HP: 4.8
Unit struct. loading: 62%
N/No':0.113, Fo/SKr:0.146
Strokes per minute 6.9

Prime mover speed variation

Calculated speed variation: 3.7%

Torque analysis and electricity consumption	BALANCED (Min Ener)	BALANCED (Min Torq)	EXISTING
Peak g'box torq. (M in-lbs):	204	144	204
Gearbox loading:	90%	63%	90%
Cyclic load factor:	1.89	1.9	1.89
Max. CB moment (M in-lbs):	289.51	374.40	289.51
Counterbalance effect (lbs):	8475	10913	8475
Daily electr. use (KWH/day):	148	157	148
Monthly electric bill:	$226	$240	$226
Electr. cost per bbl. fluid:	$0.073	$0.077	$0.073
Electr. cost per bbl. oil:	$0.100	$0.106	$0.100

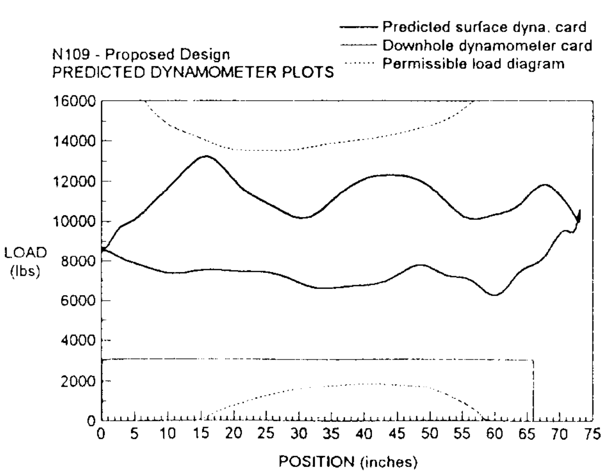
Tubing, pump and plunger calculations

Tubing stretch (in): 0.0
Prod. loss due to tubing stretch (BFPD): 0
Gross pump stroke (in): 66
Pump spacing (in. from bottom): 13.3
Minimum pump length (ft): 13.0
Recommended plunger length (ft): 3.0

Rod string stress analysis (service factor: 0.8)

Stress Load %	Top Maximum Stress (psi)	Top Minimum Stress (psi)	Bot. Minimum Stress (psi)
92%	21850	10635	5920
96%	21072	8058	-794
48%	8055	-715	-1909

\+ Requires slimhole couplings.
\# Stress loading, top maximum stress and top minimum stress calculated based on pin undercut diameter of 0.79".



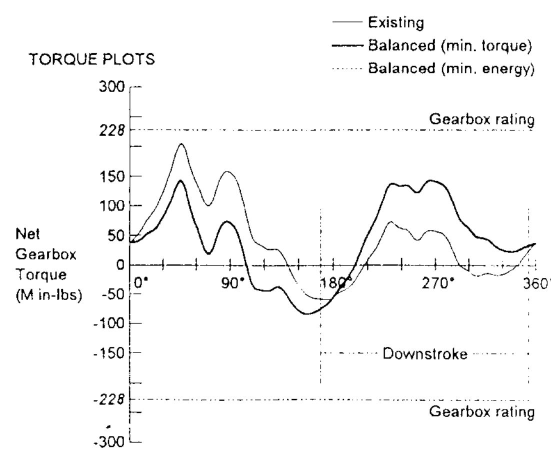


Figure 7 - RODSTAR run with proposed design changes for example case.

*** CBALANCE 1.3 for Windows ***

© Theta Enterprises
Tel: (714) 879-8951

Company: Major Oil Co.
Well: N109
User: JGS

Disk file: N109.CBL
Date: March 3, 1992

Pumping unit: American conventional
Crank type: K-76-320
Crank rotation: Counterclockwise

Maximum CB moment (M in-lbs)	
Existing:	289.5
Balanced:	374.4

EXISTING COUNTERWEIGHT POSITIONS (range is 0 - 10):

	Master weight	Auxiliary weights	Existing position
Front lead	: H		2.50
Front lag	: H		2.50
Back lead	: H		3.25
Back lag	: H		2.75

BALANCED COUNTERWEIGHT POSITIONS (range is 0 - 10):

Front lead (H):	9.25*
Front lag (H):	9.25*
Back lead (H):	9.25*
Back lag (H):	9.25*

*: shows new counterweight position

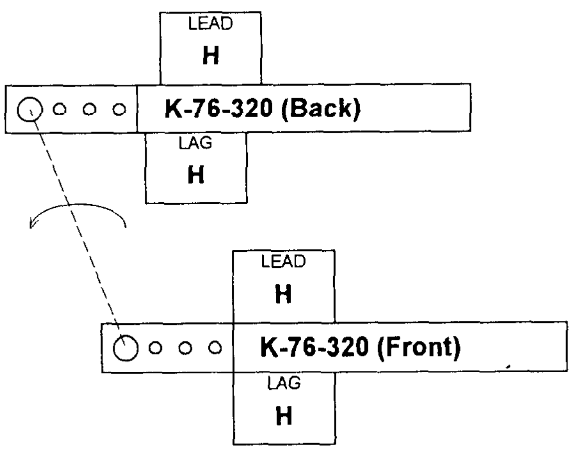


Figure 8 - CBALANCE output with balancing recommendation for example case.