QRod™, a Practical Beam Pumping Design Program

by
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Abstract

This paper presents a computer based tool for those wanting to use the wave equation in their beam pumping design activities, but do not require the needs of a more sophisticated, full featured program. This program properly handles the problems faced by a person responsible for designing what could be termed normal rod pumped installations. The output of the program includes pump size, rod string, surface unit size, and motor size for an input depth and production rate. The author has found that accepted design practices are not used much of the time. Whether it is because they are too cumbersome and time consuming or that acceptable knowledge about proper design procedures are not widely understood, I do not know. The objective of this software is to help the designer implement state of the art beam pumping design technology without getting buried with details. The program is a Windows™ program requiring Windows 3.x and a 386 class computer or better. All important input and output information is available on a single window displayed for the user. More detailed information including graphs may be optionally displayed. It uses a rapid solution method to the damped wave equation allowing the user to see immediately the effect of changing a parameter such as tubing anchor, stroke length, stroke rate, and pump diameter. Correlations are used for the motion of conventional, Mark II™ and air balanced units. allowing the program to determine the size of the pumping unit required. Tapered rod strings (API taper) and FiberGlass/Steel combination strings are allowed. A full featured context sensitive help file is available to the user. This means that whenever the main screen is active you can get help by simply pressing F1.The program is suitable for use on a desktop or laptop computer with or without an attached printer. Provisions are made for results to be saved to files for later examination.

What is QRod?

QRod is a beam pumping simulator. After the user supplies the input data appropriate for the problem at hand, the program mathematically simulates the motion of the surface unit. It then solves the partial differential equation describing the motion of the rod string. Next it calculates the gear box torque, determines proper counter balance and displays the results. If the AutoCalc option is selected all of the results are immediately refreshed upon changing any input data. This allows the user to immediately see the effect of changing input data. All commonly changed input data and output information are presented on one window for quick inspection by the user. This output may be enhanced by displaying graphs and tables.

There are three primary design variables for a beam pumping system once a depth and desired pumping rate are known. They are: 1. Stroke Length, 2. Pump Diameter, and 3. Stroke Rate. The user must change these 3 input variables to achieve the desired design objective. The desired design objective may be to minimize power required, or minimize rod loading for example. The user may also change secondary design variables to fit the particular situation. QRod has number of secondary design variables including Unit Type, Rod String Type, Pump Inlet Pressure, Fluid Specific Gravity, Tubing Pressure, and Damping Factor. Additionally, the user may change several mathematical parameters to obtain the desired speed and accuracy of solution.

What Can QRod Do For Me?

QRod was developed to be a useful design tool. If you need to select a pumping unit, rods, and a pump size for a well, it can be very helpful. While it is not designed to be an analysis tool you can use QRod to check an existing pumping system. Also, QRod was not designed to replace a full featured beam pumping simulator when the effects of motor slip, deviated hole, fluid inertia, and partial fillage are important. It is designed to replace API RP11L type calculations with a much more accurate solution that is still easy to use. You will find QRod useful both in the office and on the laptop computer in the field for design and trouble shooting wells having beam pumping system problems.

When Should I Use QRod?

You should always use some kind of design procedure on beam pumping installations to have a more efficient system and to minimize failures. You should use QRod to design and check normal beam pumping installations. QRod will not be as accurate as full featured simulators when your design involves motor slip, deviated hole, fluid inertia, and partial fillage. Fluid inertia is important for shallow (<2500 ft) wells having large (>2 1/2 inch) pumps. You will find that QRod gives more accurate results than the API RP11L method.

How Does QRod Work?

QRod solves the damped wave equation describing the motion of sucker rods in a beam pumped well using a finite difference technique. The solution requires input to the boundary conditions of the problem. These are a description of the motion of the polished rod as a function of time and a description of pump loading as a function of pump position. The surface boundary condition is satisfied by using correlations for the various kinds of pumping units. The pump boundary is satisfied by logic in the program that determines if both valves of the pump are closed or if one of the valves is open. Careful experiments have shown that when QRod is run the results obtained are very close to what actually occurs.

Designing a Beam Pumping System with QRod

In order to help you learn how to use QRod is would be helpful for you to go through an example problem. Let us design a pumping system to pump 400 BPD of .95 Specific gravity fluid from a depth of 5000 ft in this example. The following sequence of steps is helpful, but you do not have to do all things in the order shown. The text will give the mouse actions required, but you can use keystrokes if you like.

Select Depth, Target Rate, Stroke Length, and Pump Diameter

Enter the depth (5000) and target rate (400). You may enter these values by typing the appropriate numbers in the active boxes and using the TAB or ENTER to get to the next box. You may also select the values from the pull down list. Notice that none of the other boxes on the screen are enabled (they are grayed) until you fill out depth and target rate. Any item that is visible, but grayed, may not be selected. After starting the program and entering these initial values, the main screen will appear as shown in Figure 1.

Next enter a stroke length. A reasonable value for this situation is 144 inches, although others could be used. The pull down list contains only the standard API strokes when the pin of the unit is in the maximum stroke available. You may enter any value from 24 to 300 inches by typing as before. Next select the pump plunger diameter. You may want to examine the Help for pump diameter where information about the maximum sizes of pump that can be run it various sizes of tubing. Let us assume that we will use 2 1/2 inch tubing on this well, so the maximum size rod pump we could run without and on/off tool is 2 inch. Select a 2 inch diameter pump. When this selection is made, you will see the remainder of the window become enabled. Notice that anchored tubing is the default for that option. At this point the main screen appears as shown in FIgure 2.

Check the Settings Window

Next, check the Settings window. This is where little used parameters may be changed. Bring up the Settings window by clicking on

Settings in the File Menu. When the window comes up you will see the first item is Report Header Text. Any text you put in this box will appear on the first line of any report. You will see 10 other boxes with numbers in them. The numbers are the default values for the various parameters. Also you will see OK, Cancel, and Reset buttons.

The OK button will close the window, saving all the values as they appear in the boxes at the time the window is closed. The Cancel button will cause the window to be closed with no action taken. The Reset button causes all the values to be reset to the factory defaults. The 3 values inside the "Effective Upon Restart" box will not take effect until the next time you run the program unless you select Restart from the File Menu after the Settings window is closed.

For the example problem the only parameter we need to change is Fluid Specific Gravity. Click on the appropriate box (or TAB it) and edit the value by typing .95 in the box. You may use delete or backspace as required in the edit operation. To erase the old value you can highlight it by dragging over the number and then pressing DELETE. At this point the Settings window will look like Figure 3. Click on OK to close the window. At the same time current settings will be save to a file named QROD.CFG in the QROD subdirectory. That file is read each time you restart the program. Notice that a reminder about the Restart appears. Click OK and get back to the main screen

Select Rod String Option

For this example let us try both steel rods and fiberglass/steel combination strings. First we will try steel rods. The steel rod option is already checked.

Pick Rod Sizes

86 rods have been selected by default. That is probably a good place to start for this problem. 86 rods are a 3 taper rod string composed of 1 inch, 7/8 inch and 3/4 inch rods. The percentage of each size is determined by the API method and depends of the pump diameter. This method will result in approximately equal stresses at the top of each rod section or what is referred to as a balanced design.

Pick Rod Grade

Select a rod grade start with, say grade "C.

Select Unit Type

The default unit type is CWConv which is a clockwise rotating conventional unit. We will use that to start with in this example.

Select Stroke Rate

The stroke rate is set when the program knows what unit type and stroke length you have selected. The value is set to about 65% of the value which will result in a downward velocity faster than the rods will fall in fluid. You may select the stroke rate by one of 2 methods. You may slide the Stroke Rate slide button with the mouse or you may click on the SPM for Tar Rate check box.

Manual Setting of Stroke Rate

For this problem, the program has set the stroke rate to 13.1 SPM. Click on ReCalc to calculate the problem with the data you have entered. (If you check the AutoCalc check box the program will automatically recalculate for you every time you change an item.) Notice that this combination gives us a production of 700 BPD as shown in Figure 4. The combination of stroke length, stroke rate and pump size is too large for the problem at hand. Next we will look at the automatic determination of stroke rate.

Automatic Calculation of Stroke Rate

If you click this button an "X" is put in the check box. We say that the box is "checked". The program will then determine what stroke rate is required to get the target rate. Upon doing this you will find that the result is 8.4 SPM that gives a producing rate of 404 BPD. The calculation stops when the answer is within 1% of the target as shown in Figure 5.

We need to improve on our design for this example, but first let us look at the 2 remaining buttons on the left side of the main screen.

Choosing AutoCalc

If this box is checked, the program automatically calculates any time it has a new value, except when you change values in the Settings window. There are times when you will want to operate in this automatic mode. There are also times when you will want to operate in the manual mode when the calculations are not made until you press the ReCalc button. It is really an individual preference almost as to whether you use AutoCalc or not as the program does not take too much time to make one cycle.

Using the ReCalc Button

When this button is pressed, the program recalculates the problem. Each time this is done 4 pumping cycles are simulated and the torque calculations are made. After that is done all output showing is refreshed.

Looking at the Output

All of the important output from the program is on the right hand side of the screen. More detailed output is available in secondary windows where graphical information and more detailed text is available.

Output Side of the Main Window

The calculated rate, rod taper, rod loading, polished rod loads, peak torque, unit size and motor size are shown on this side of the screen. These are the most important results for a steel string design. For the example problem we see that for 8.4 SPM we get a rate of 404 BPD. This is for an 86 rod string composed of 33.4% of 1 inch, 32.8% of 7/8 inch, and 33.8% of 3/4 inch rods. The loading on the top rod is 107.8% of the allowable for grade "C" rods meaning that the rods are over loaded. The loading is calculated using the modified Goodman diagram method.

The PPRL (peak polish rod load) is 21,800 lb. and the MPRL is 5,800 lb. This means that the beam rating of the unit should be at least 21,800 lb. The calculated peak torque for a balanced unit is 710,000 in-lb. This value determines the minimum gear box rating for the unit. The program displays the minimum unit size that satisfies all of the design requirements. Notice that there may not be a unit made with the calculated combination of gear box, beam rating and stroke. The values displayed are simply the minimum required.

The last number displayed on the output side is motor size. This is the motor size determined from polish rod horsepower, the calculated cyclic load factor, and the mechanical efficiency of the surface unit. As with the unit, thjs number is a minimum value. The actual motor used should be the next largest standard size. Before continuing with the design, let's look at the graphs and other output.

Graphs

From the Window Menu, which became enabled when you calculated the first time, select "Show Cards". Notice that this item appears checked after you select this item. The next time you click it, it will be unchecked. As long as this item is checked, a small graph will appear on top of the main screen showing the surface and pump dynamometer cards each time the program recalculates. You can move the graph around by dragging it by the title bar. There is space for 2 graphs to be displayed over the ICON block on the main screen if you position them carefully.

Next, select "Show Torque Curve" from the Window Menu. When you do this a new graph will appear, but the Cards graph will disappear. Both graphs are there, the Cards graph is just behind the main screen. To bring it to the front, click on ReCalc and you will be able to see both graphs and all of the output on the main screen if you position the graphs carefully. Figure 6 shows the main screen with both of these graphs displayed in the upper right hand portion of the main screen.

Text

If you want to look at more detailed information of all available output, select "Show Output Text" from the Window Menu. This causes the scrollable text window to appear containing this information as shown in Figure 7. If you position the main screen to the far left of your screen, place the 2 graphs over the ICON block and the output text window on the far right you will be able to see almost all of everything on all 4 screens at the same time. When the output screen came up it covered up part of the main screen. Press ReCalc which will bring the main screen to the top again. You will see that you can jump between each of the screens simply by clicking on them with the mouse.

If you look at the text window you will see that the Counter Balance Effect required to balance the unit is 10,400 lb. Also you will see that the polished rod horsepower is 22 hp and the motor horsepower is 40.

Tweaking the Example Steel Rod Design

The design that we have at this point is not good enough. For one thing the rods are overloaded. You would think that one way to reduce the loading is to use a smaller pump. We have more capacity that we need anyway. We should be able to run at a higher stroke rate. So lets reduce the pump size to 1 1/2 inch. That is the largest rod pump that can be run in 2 3/8 inch tubing. After making that change and pressing ReCalc, we see that we now only have 247 BPD at 8.4 SPM. The rod taper will changed slightly also.

Click on the SPM for Tar Rate box to cause the program to determine the SPM for 400 BPD. Several interesting things appear. First of all, the rod loading is higher than before. Second, the Cards graph shows a slight bit of overtravel, that is the pump stroke is more than the surface stroke. On the output text screen you can see that the pump stroke is 149 inches. The most interesting thing is that the motor power has increased more than 50% to 63 hp. This is because of the increased friction in the downhole system. Remember that the friction there is proportional to rod velocity that was increased when we increased the stroke rate.

Next try clicking on CCWConv from the Unit Type Menu. This runs the same problem, just rotating the unit in the counter clockwise direction. After pressing ReCalc (if you do not have the AutoCalc option set) you will see that we get the same production. However, the rod loading is down. Notice that the rod loading decreases, and motor power goes down to 54 hp, a decrease of almost 15%. Also the torque is down to the point that a smaller unit can be used. A click on Mark II from the unit menu will show that even a smaller unit can be used if it is a Mark II.

Going back to the CCWConv unit selecting grade "D" rods we have an acceptable design. There is no correct design because the design objectives will differ from case to case. Any acceptable design should not exceed the allowable loading for any component in the system.

This result is shown in Figure 8. The design shows that a 912 unit is required although only 640,000 in-lbs torque is displayed. The actual value of torque is slightly over 640,000 but rounds to 640,000. This is yet another example that someone has to think when using a program that is almost automatic.

Running the Same Problem with FiberGlass Rods

Click on the F/Gl option button in the Rods frame. This will select the FiberGlass/Steel combination rod string design. We now need to fill in the 3 blank boxes that have appeared. Select 1.2 inch for the FiberGlass size, 75% FiberGlass and 1.25 for the Steel rod size to start with. Click on SPM for Tar Rate to automatically determine the stroke rate. Voila! Interesting results, Hmmmmmmm. We get the same production with a lower stroke rate than with the steel rods because we get more overtravel with the FiberGlass.

Intersection Information

Lets replace the Torque curve with more important information pertaining to FiberGlass rods, namely the intersection loading. From the Window first uncheck "Show Torque Curve" then check "Show Intersection Info". Press ReCalc and position the Information screen where the Torque curve screen was. We can see that the loading on the FiberGlass rods and the glass/steel intersection is 61%. However, we only have 700 lb. load on the FiberGlass for a minimum load. Since FiberGlass needs to be loaded in tension at all times, this may not be a very safe design. Also you will notice that the loading on the FiberGlass at the surface is low.

Tweaking the FiberGlass Design

Lets put a little more steel at the bottom, thereby reducing the chances of getting compression loading in the FiberGlass and at the same time save some money. Steel is cheaper than FiberGlass. Notice that we have pretty good overtravel, the pump stroke is 161 inches. We can increase the overtravel by increase the stroke rate, but that will decrease the minimum loads that will occur.

Highlight the 75 in the Percent box and type in 70 and press ENTER. After pressing ReCalc you will see that we have a fairly good design. Notice that the production has gone up as a result of the additional overtravel so click on the SPM for Tar Rate box to get our design rate back.These results, along with the cards and intersection information are shown in Figure 9.

If you click on the Steel option button in the Rods from and then on SPM for Tar Rate you will get the steel rod design back. So it is possible to easily go back and forth between FiberGlass and Steel to compare the 2 designs.

The possibilities are almost endless. This looks like a good design, but the original case we did only required 40 hp so there is plenty to think about when designing an optimal beam pumping system. I will leave it to you to optimize this problem.

Saving Text

From time to time, especially when you are in the field on a laptop and do not have an attached printer you may want to save the results of a case that you have run. Just click on "Save Text" from the File Menu and all of the text that appears in the output text screen will be appended to a file named QROD.TXT in the QROD subdirectory. Each time you click on "Save Text" the current values will be appended to the file. At a later time you may examine and/or print the file or portions of it. You will need to erase the file periodically to keep it from becoming too large. QRod will create the file if it does not exist.

Printing

You may select the printing of either graphs or text if you have a printer attached. Any printer supported by Windows should work fine, although better and faster graphics will result with a laser or ink jet printer.

Graphs

To print the graphs associated with the project, select "Print Graphs" from the File Menu. When you do this a text screen will pop up. This screen allows you to put any annotation you desire at the top of the printed report. You can put up to 4 lines of about 40 characters as you see fit. The information you type in will be available throughout the current session with QRod, although you may edit it as you see fit. Press CTRL+Z to cause the report to be printed.

Text

To print the text associated with the project, select "Print Text" from the File Menu. You will get the same request to enter report header information as with the graphs. Again press CTRL+Z to cause the report to be printed.

Exit QRod

To exit QRod, select "Exit" from the File Menu. This will close the program down along with all associated windows and files. Additionally the positions of the windows you have moved will be save for the next time you run the program.

Summary

QRod is a program that obtains a solution to the damped wave equation describing the motion of sucker rod pump strings. It uses an approximation for the motion of the surface unit as the surface boundary condition. The results obtained include loads, stresses, torques, power, and pump displacement. I have attempted to put in all the features needed to do the job accurately without adding bells and whistles which tend to add very little to the accuracy but much to the complexity for many problems. QRod is best used in conjunction with a full featured sucker rod simulator such as RodMaster™ by S. A. Holditch and Associates when more detailed studies are required. QRod was developed in Visual Basic 3.0™ under MSDOS 6.2™ and Windows 3.11™. I hope you will try using the program and as I am sure that it will help you do your job more efficiently.

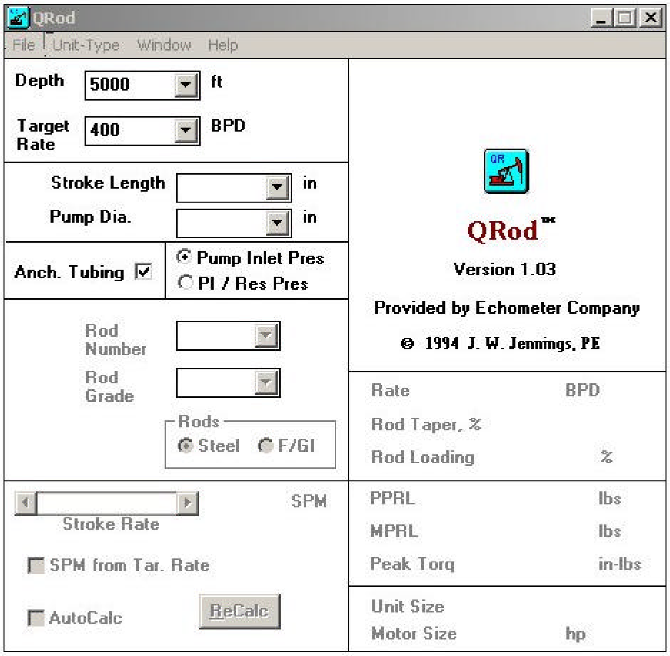

Figure 1

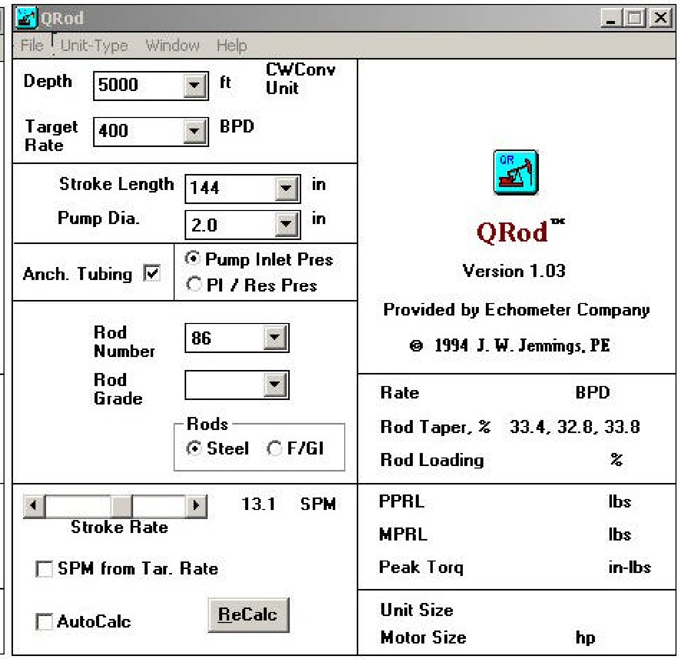

Figure 2

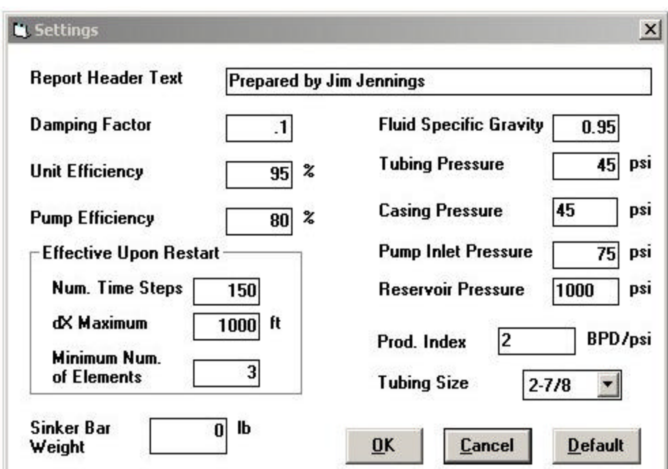

Figure 3

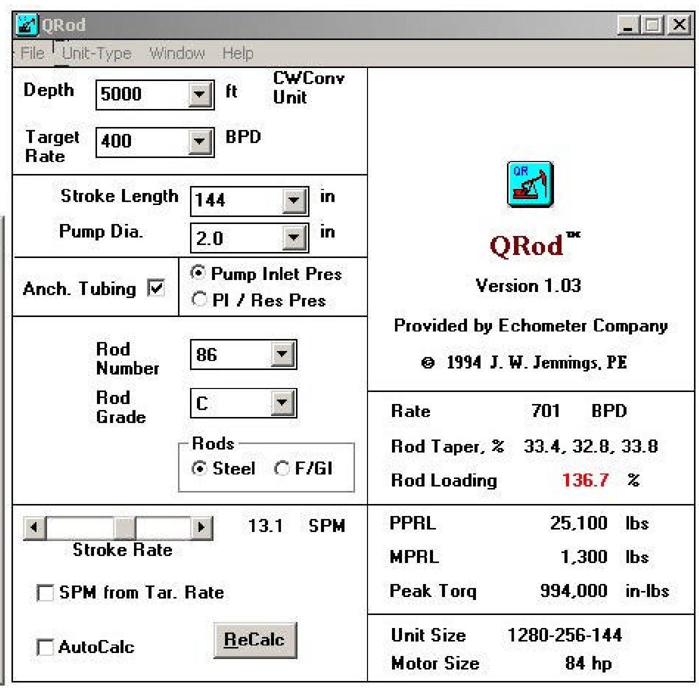

Figure 4

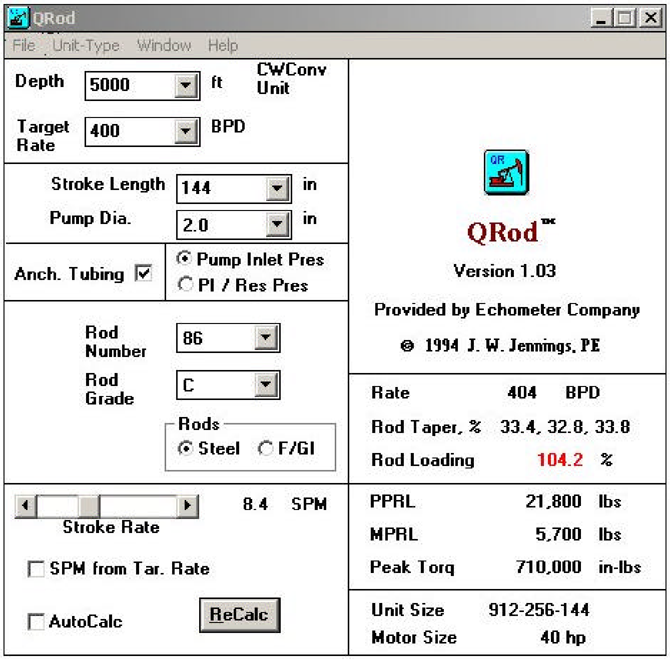

Figure 5

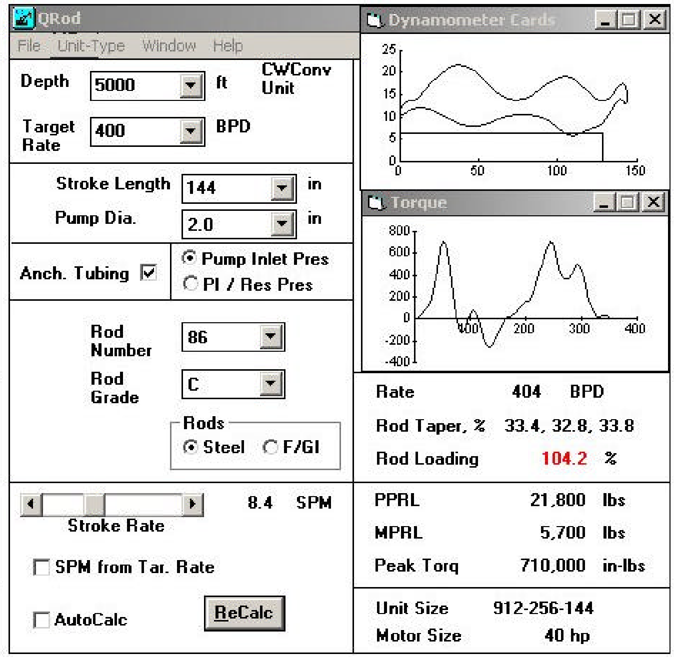

Figure 6

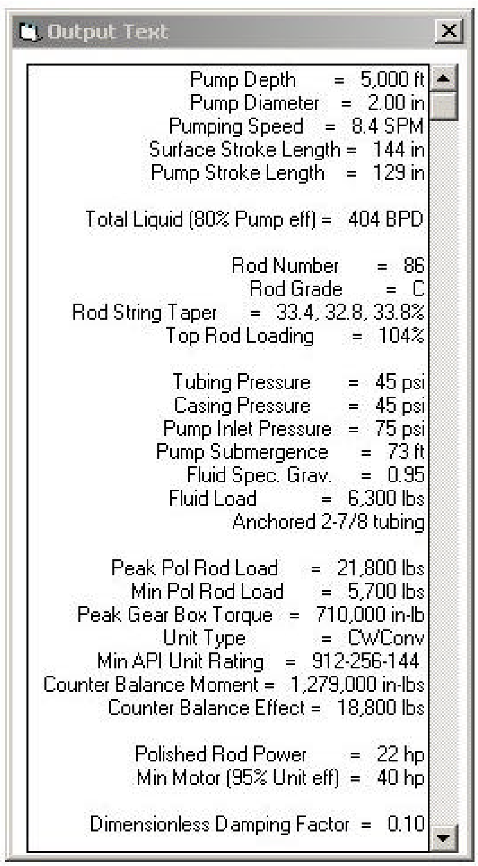

Figure 7

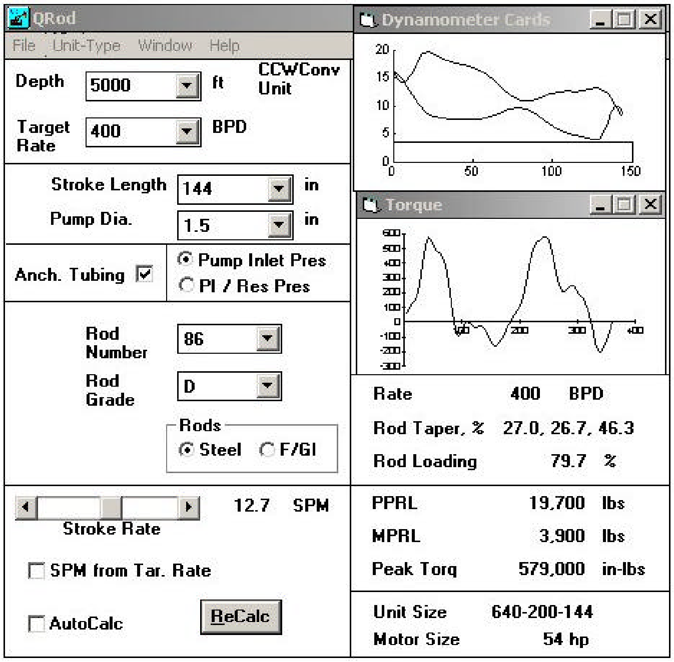

Figure 8

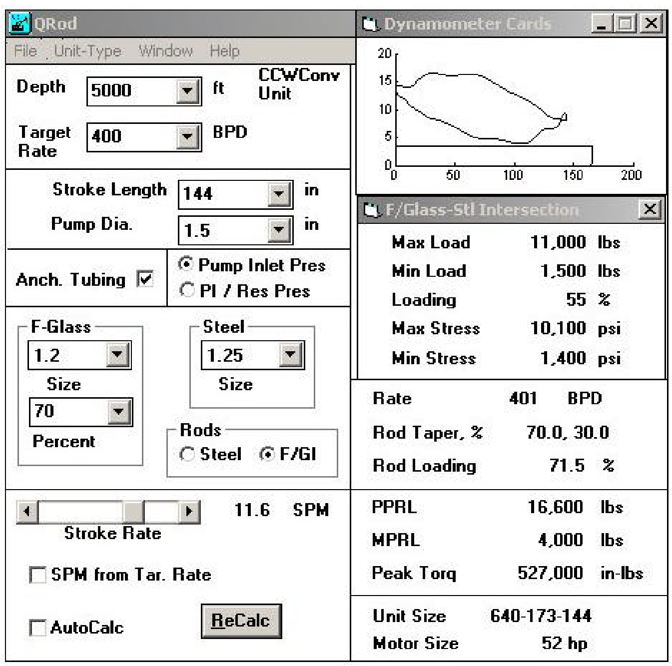

Figure 9