TAM – Electrical Motor Power Features

A Note about Electrical Safety

In those wells where the pumping system is powered by electrical motors, current (Amps) and power (kW) measurements have been used routinely for many years as a tool to achieve balanced torque conditions at the gearbox of pumping units. These measurements require connecting instruments to live electrical circuits, which always involves the associated risk of electrical shock. It is important that all safety procedures be followed and instrument instruction and operation manuals be read and understood prior to performing these measurements. To increase the safety of working conditions, all shocks and defective equipment should be reported. A shock means that something is wrong. The slightest shock when operating an electrical device might, under other circumstances, result in instant death if part of the body makes only slightly better contact with the ground or a grounded metallic object.

The level of current passing through a human body is the key factor in any electrical shock accident. Most of the more than 1,000 electric shock fatalities that occur in the U.S. every year are due to voltages less than 440 volts; the most common oil field voltage is 480 volts. It is imperative that respect be given to all electrical equipment and circuits and that adequate precaution be taken regardless of voltage. Table 1 shows that even a very small amount of electrical current passing through the body can be hazardous.

Current in milliamperes (mA)	Physical effect
2 mA alternating current (AC) or 10 mA direct current (DC)	Threshold of a sensation (a strong tingling)
10 mA AC or 60 mA DC	“Let go” current, above which one freezes due to muscular contraction
100 mA AC or 500 mA DC	Death due to heart fibrillation and paralysis of breathing

Table 1 - Effects of electric shock

When dealing with electrically powered equipment—such as motors, switch boxes, control boxes, etc.—the integrity and grounding of which is unknown by the operator, prudent practice should result in the following precaution: if the operator has to touch electrically powered devices and is not wearing protective insulating gloves, the first contact should always be made using the back of the hand. As seen in the table above, even a small current of 10 mA AC will cause a strong muscular contraction. Touching the device with the back of the hand will result in a contraction away from the electrified device rather than possibly “locking” the hand to a main switch handle.

Introduction to Power Measurement in Rod Pumped Wells

Acquisition of motor current and power data simultaneously with dynamometer records provides the necessary information to perform a very complete analysis of the beam pumping system that includes the balancing analysis, motor performance, operating cost, and overall pumping system efficiency.

Since the majority of beam pump motors are operated with 3-phase alternating power, quantitative measurement of instantaneous power requires using sensors that consist of two current probes and three voltage leads, which are connected to the three phase leads inside the pumping units switch box

TAM Power Measurement Sensor Options

The TAM software is designed to allow power measurements using wireless sensors and wired sensors connected to an Echometer Well Analyzer that has been licensed to acquire dynamometer and fluid level data with the TAM application. The TAM program will process power data acquired with TWM and subsequently imported into TAM.

Power Sensors Setup

The reader is referred to the TAM help file “Using a Power Sensor in a Dyn Test” to view and print a quick guide showing the essential steps for installation of the power sensors. That guide is also presented in the following three figures.

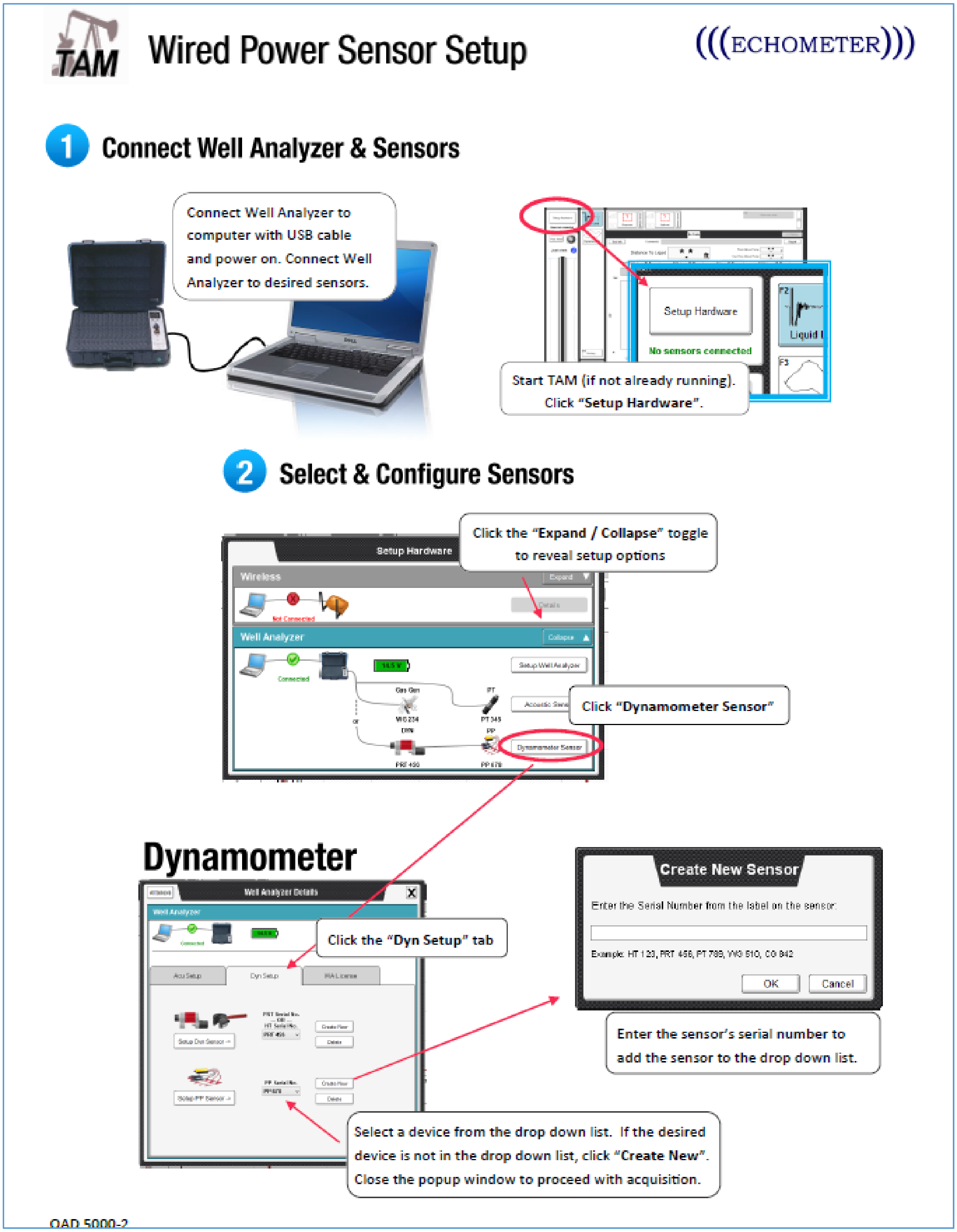


Figure 1 – Quick Guide for Setup of Wired Power Probes

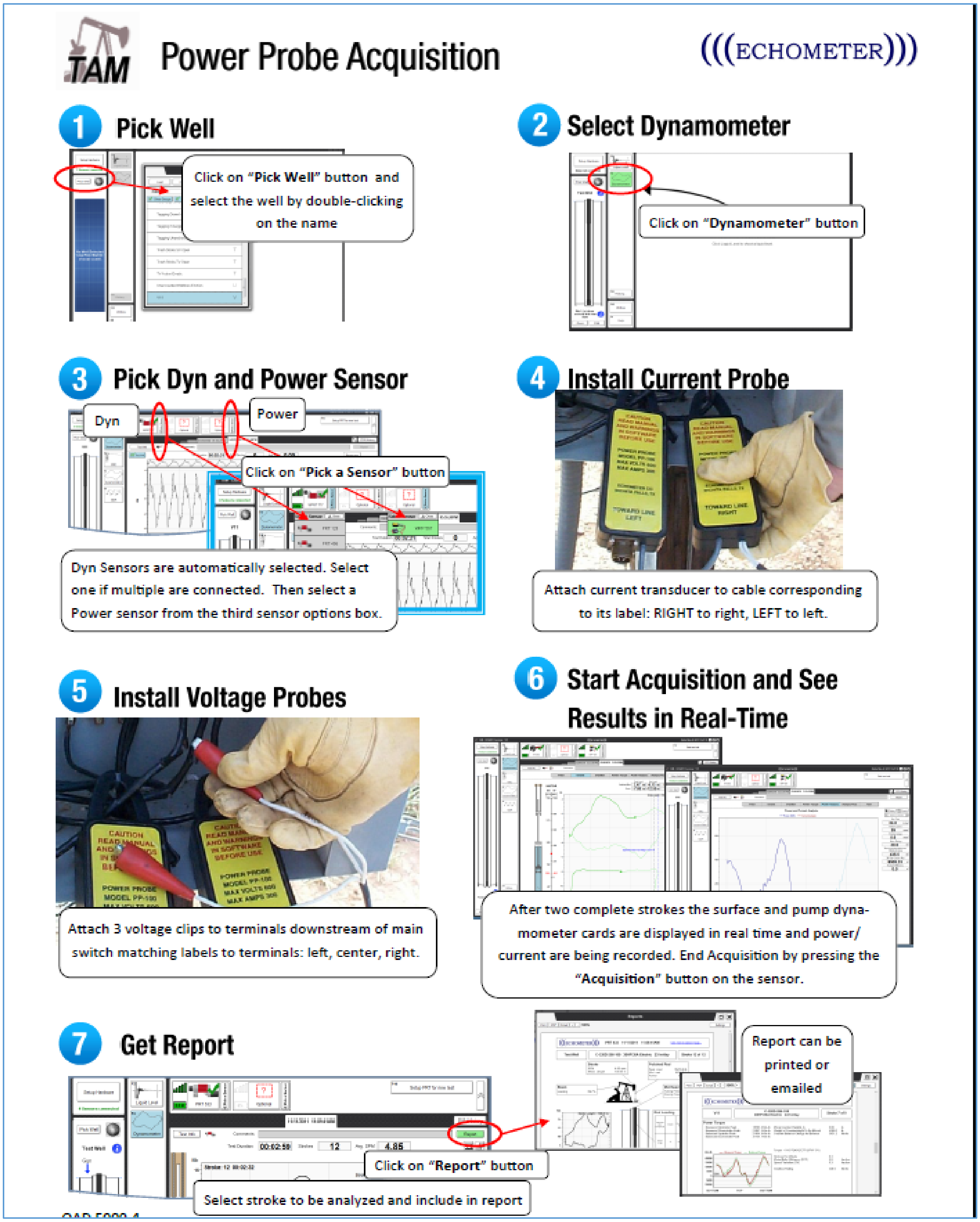


Figure 2 – Quick Guide for Acquisition of Power with Wired Probes

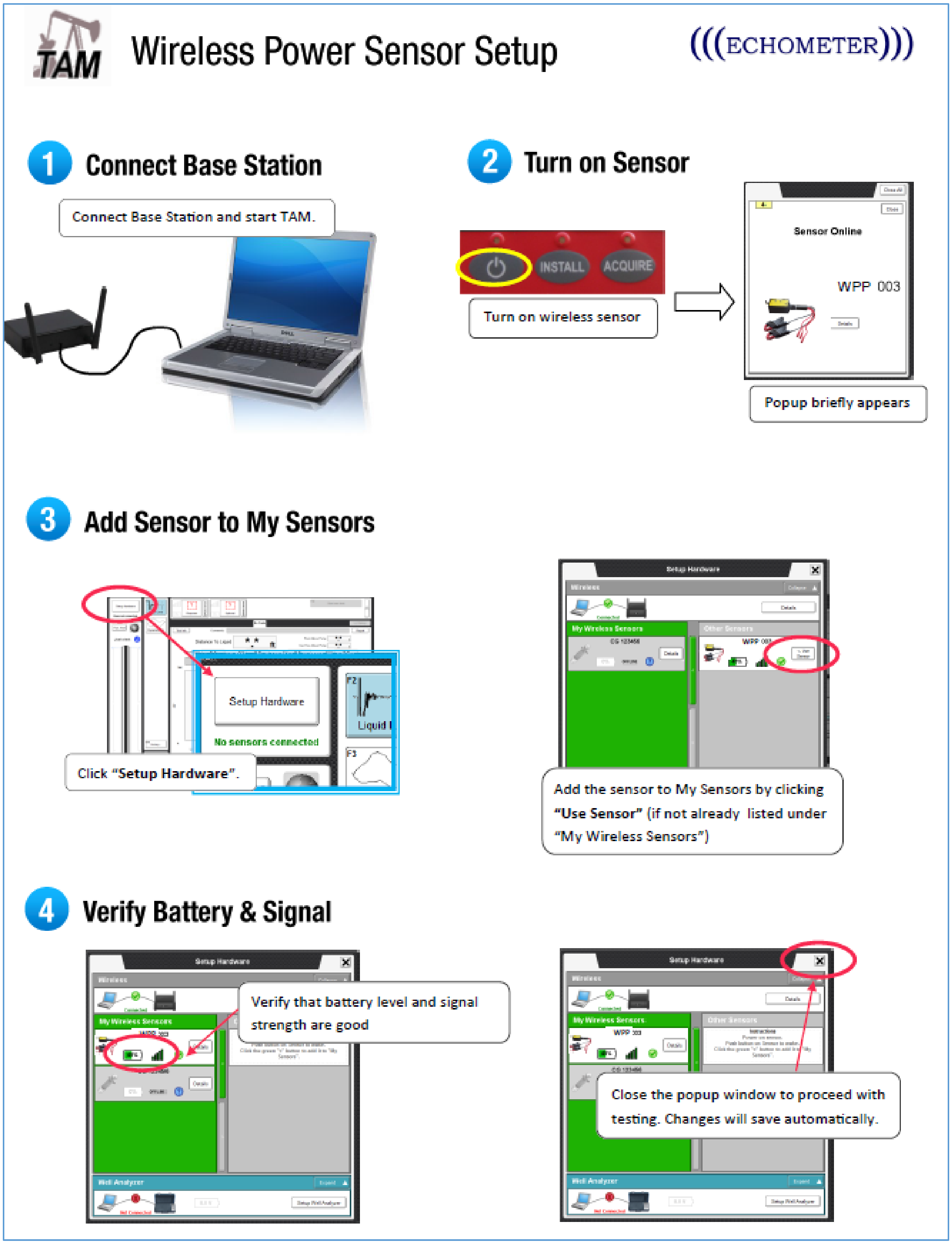


Figure 3 – Quick Guide for Setup of Wireless Power Probes

Wireless Power Probes Installation Options

There are two wireless systems for power acquisition: 1) Portable Power Probes and 2) Permanently Installed Power Probe Connector.

Portable Wireless Power Sensor

The conventional off-the-shelf instrument generally used to measure current flowing to a motor consists of a split-jaw current sensor (Figure 4), installed around one of the power wires, which feed electricity to the electric motor.

Figure 4 – Typical Split Jaw Current Sensor

The Echometer Wireless Motor Power measuring system is provided with a wiring harness that permits installing two split-jaw current sensors and three voltage clips once the switch box has been opened. All the safety considerations discussed earlier must be implemented when installing the sensors as shown in Figure 5.

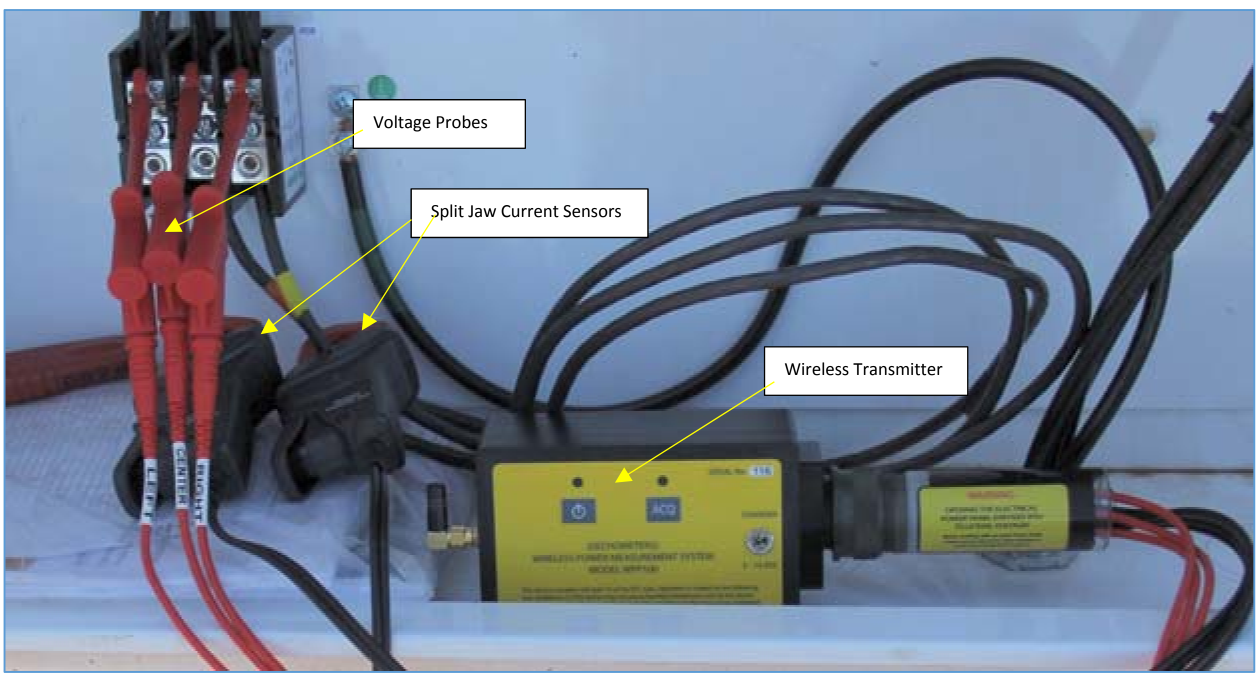


Figure 5 – Portable Wireless Power Probe Installed Temporarily inside Switch Box.

Portable Wireless Power Harness Installation Recommendations

When using the portable wiring harness to complete motor power measurement, the following steps should be followed:

1. Turn off the pumping unit and wait for the motion to stop and for the cranks to come to rest. Set the brake.

2. Disconnect the main power switch and open the switch box carefully.

3. Visually inspect the wiring, fuses, cables, relays, switches etc., looking for indications of loose connections, overheating, damaged insulation on cables, and any other clue that suggests possible electrical faults. If there are any doubts about the safety of the wiring, stop the test and report the findings to a supervisor, or have a qualified electrician repair the problem.

4. Using the cable harness, attach the current probes with care by clamping them around the leftmost and rightmost cables coming from the line and going to the motor. Note the marking on the current probes that indicate which side of the current probe faces the power line or energy source. If the current probes are not installed correctly, the system will indicate power incorrectly. For the best results, the probes should be attached to a section of wire which is straight and fits in the center of the probe.

5. Ensure that the jaws are completely closed and that the wire is centered within and perpendicular to the jaws. A slight loss of signal can occur if not installed properly.

6. Attach the voltage sensing clips to the left, center and right terminals as shown in Figure 5.

7. Connect the cable harness to the Wireless Power Sensor and press the ON/OFF switch to verify the battery condition.

8. Once communication with the TAM software is established and verified, the system is ready for use.

9. Release the brake

10. Connect the main power switch

11. Turn ON the pumping unit motor

<u>Permanently Installed Power Probe Connector</u>

Permanent installation of the current and voltage sensors within the electrical switch box and connecting the corresponding wires to the external feed-through mounted on the side of the switch box, as shown in Figure 6 , insures increased safety of the Wireless Power Probes and allows a field technician who may not be approved to open the electrical switch box to attach the Wireless Power Transmitter to the external connector without having to turn off the pump, disconnect the main power switch and open the electrical switch box.

The Wireless Power Sensor uses two current probes that consist of toroidal secondary transformer coils that are permanently installed surrounding the leftmost and rightmost wires that feed power to the motor. The two current transformers are isolated by double insulation from the motor power.

Their millivolt output is fed (via the white wires) to the pins of the electrical connector that is mounted on the side of the electrical switch box as shown in following figure. The measured current is the average value of Phase C stated in RMS units assuming a sinusoidal waveform.

Split jaw transformers   Permanent Current/Voltage Connector   External Feed-through

Figure 6 – Permanent Power Probe Installation

Three voltage leads (black wires) are connected directly to the terminals on the downstream side of each of the three fuses and fed to the permanent connector pins through a resistance of 664 Kohms. At 480 Volts RMS, the RMS current is limited to 0.72 mA to ground, which is a safe value.

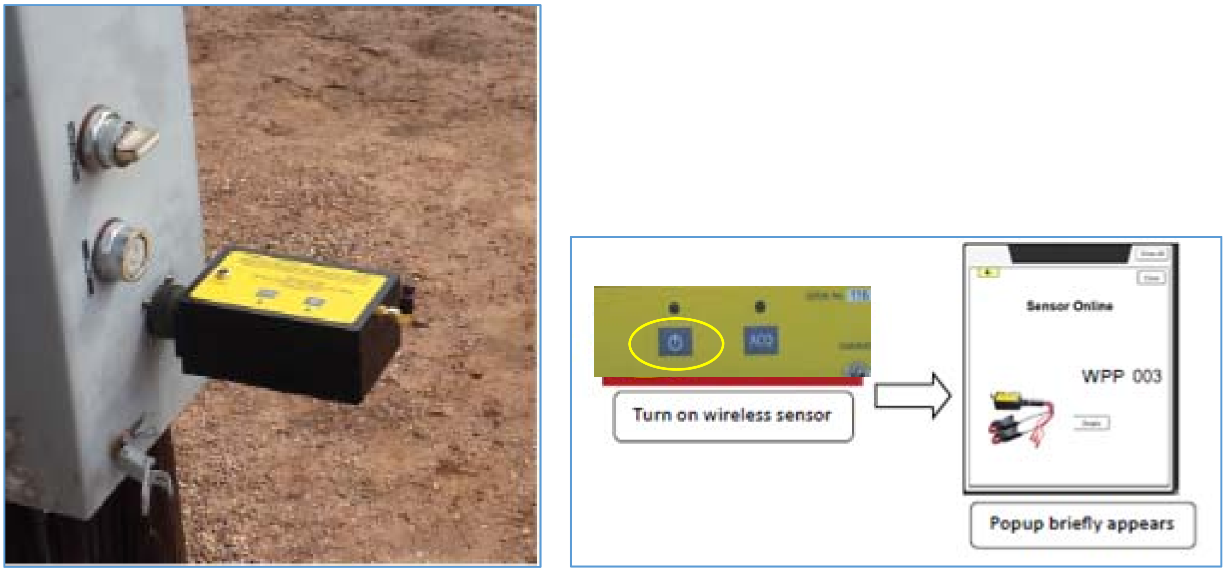


Figure 7 - Wireless Power Transmitter Connected to Switch Box and Communicating with TAM

To complete the power measurement, simply remove the sealed connector cover and attach the Wireless Power Transmitter making sure the pins make good contact by hand tightening the locking nut until snug. Press the ON/OFF switch and verify the battery charge. Then verify communication with the base station that is connected to the laptop that is running the TAM program. Ensure that the sensor is in line of sight of the base station for best wireless communication.

Data Sampling and Transmission

The power, voltage, and current readings are the average of the last two power line cycles. They may be sampled at various rates but have little meaning if sampled above the power line frequency that normally is 60 Hz. The data is transmitted to the Wireless Base Station that is connected to the USB port of the user's laptop computer.

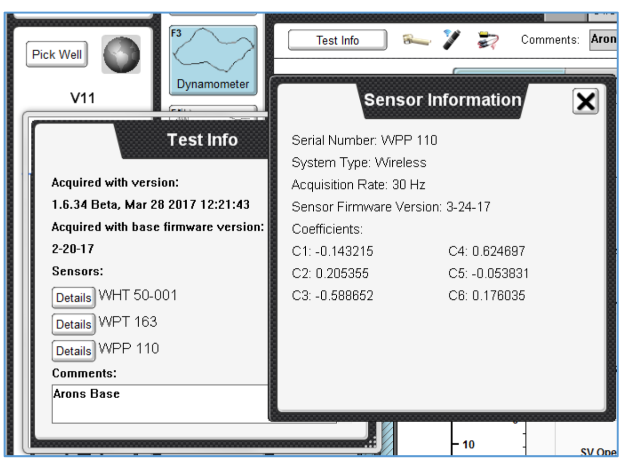


Figure 8 - Wireless Power Sensor Details

Generally the power measurement is performed in conjunction with acquisition of dynamometer, fluid level and tubing pressure data.

The corresponding sensors must be installed and added to the "My Wireless Sensors" column of the "Setup Hardware' tab.

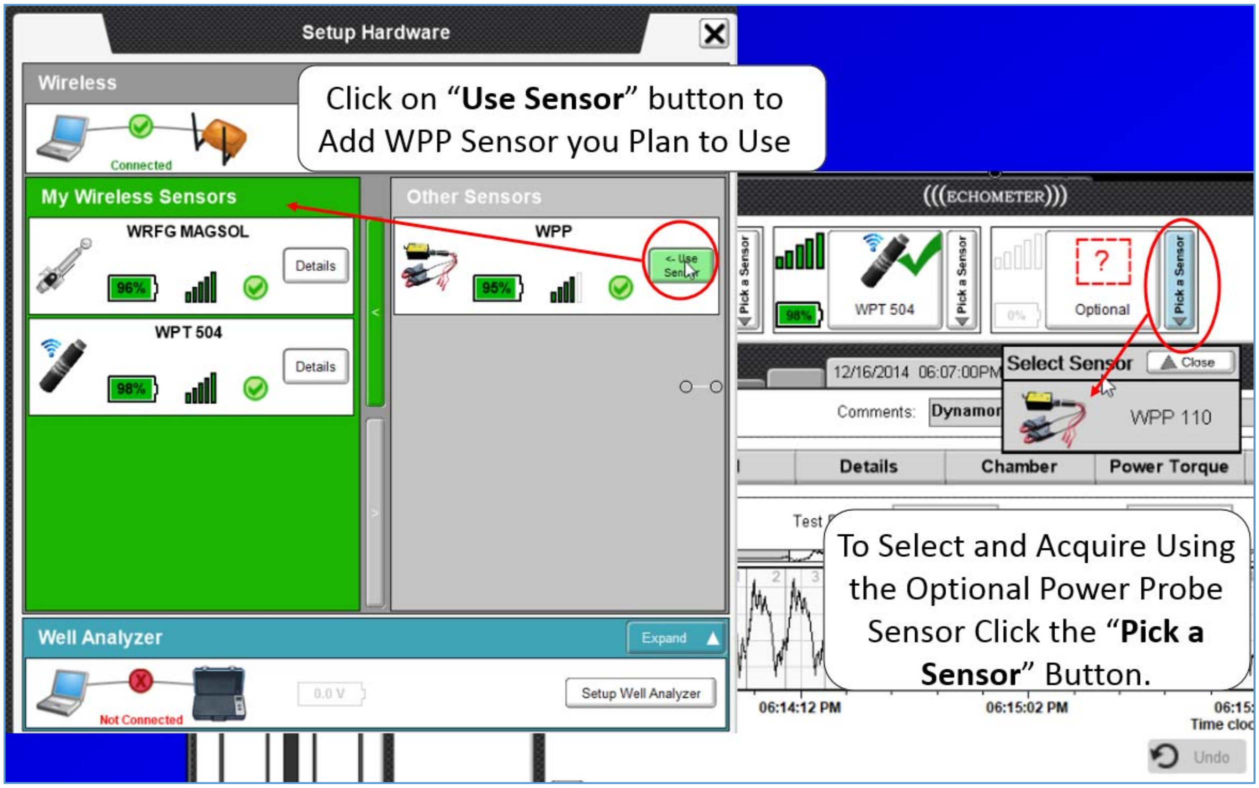


Figure 9 - Wireless Power Transmitter added to Setup Hardware Tab

The following section illustrates the sequence of steps when wireless sensors are used to acquire a set of dynamometer, power, tubing pressure and fluid level records with the objective of performing a complete analysis of the performance of the well and the pumping system.

Example - Setting up Wireless Acquisition of Motor Power, Dynamometer, Tubing Pressure and Fluid Level Records.

Step -1- Open TAM Select Well and Connect to base.

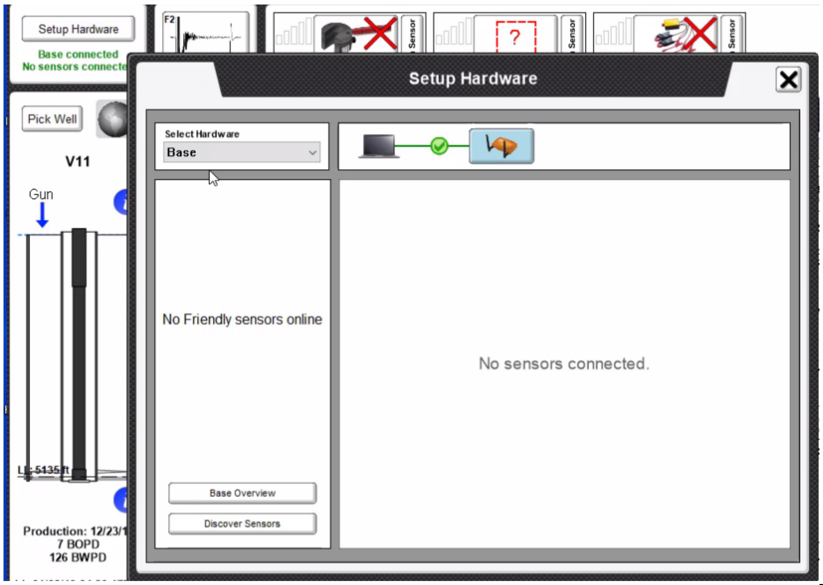


Figure 10 Setup Hardware

Step - 2 - Discover Sensors

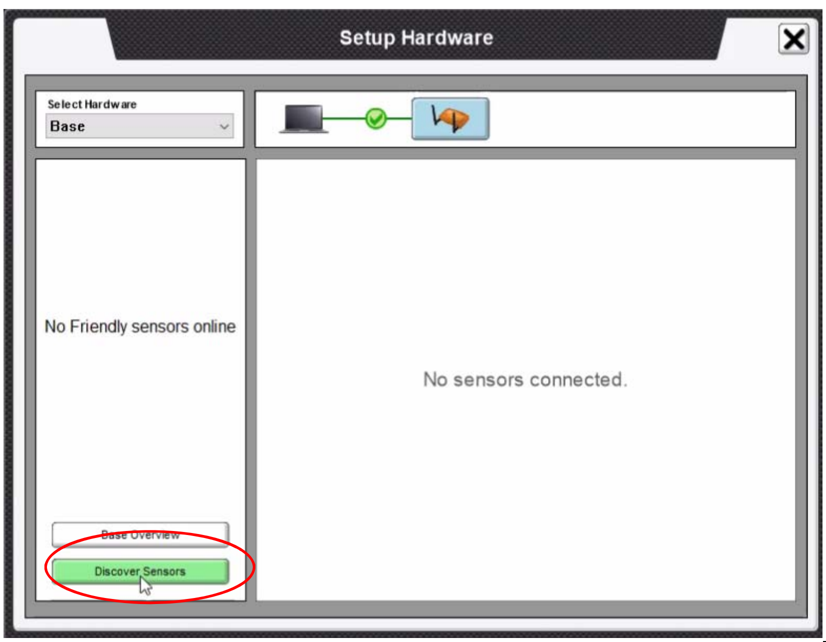


Figure 11 Discover Sensors

Step - 4 – Turn ON sensors and Pair with Base

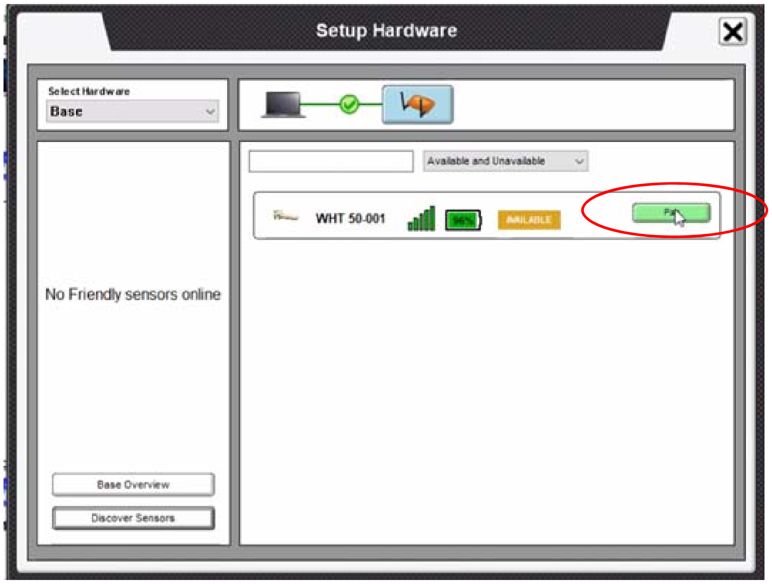


Figure 12 Setup Pair Sensors

Generally for a complete analysis of well performance will use dynamometer, motor power, fluid level and tubing pressure sensors.

Step - 5 - Check communications, battery and perform zero if necessary

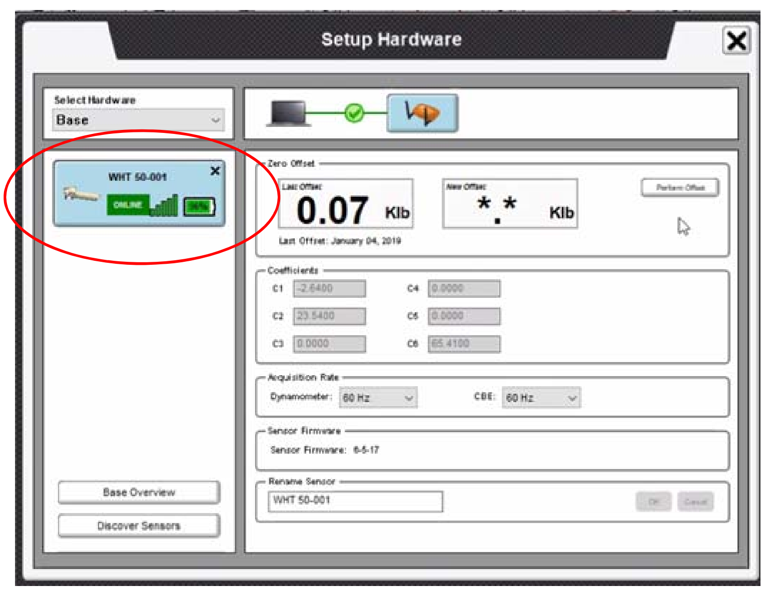


Figure 13 Sensor Checks

Step - 6 – Perform Zero Offset and Save

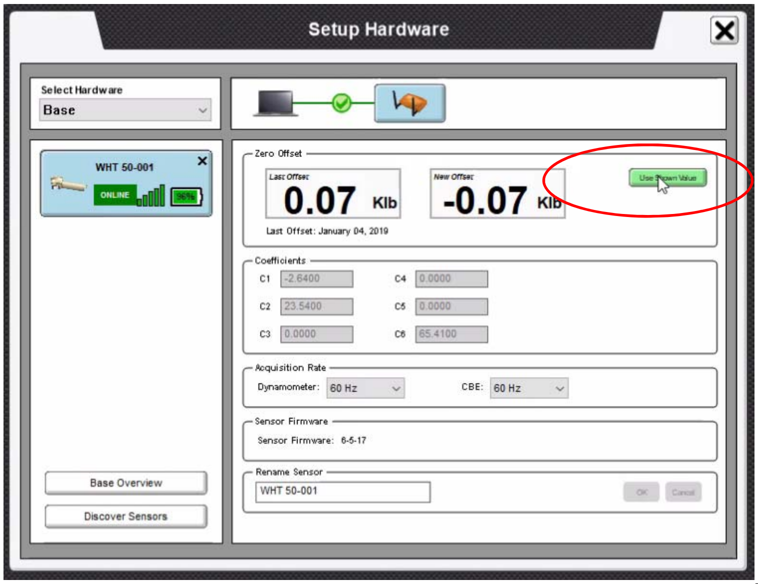


Figure 14 Zero sensors

Step - 7 – Continue to add and Pair the Sensors to be used

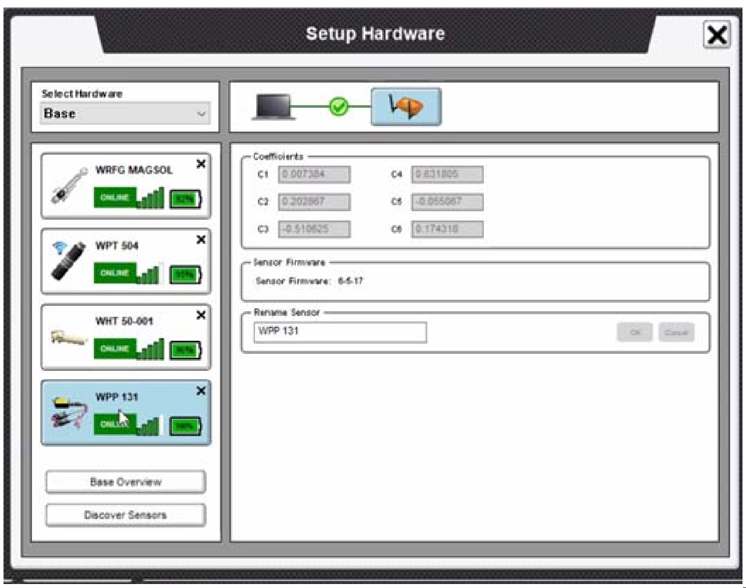


Figure 15 Setup Completed

All sensors have been activated, are communicating with the Base and are ready to be used.

Step - 8 – Open dynamometer Module and Select Optional Sensor

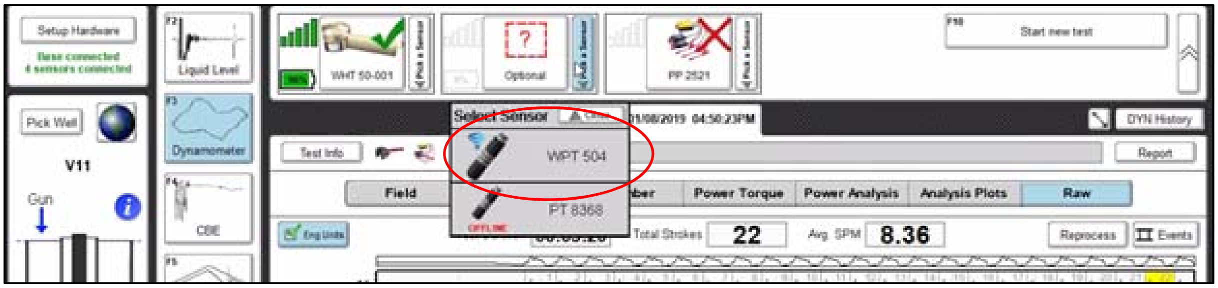


Figure 16 Select Optional Sensors

Step - 9 – Select Wireless Power Probe

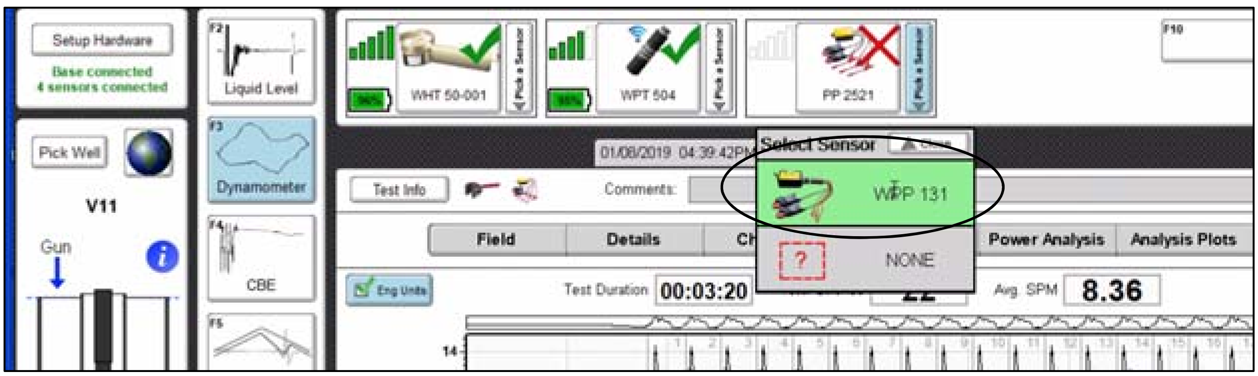


Figure 17 Select Power Probe

Step - 10 - Start Dynamometer Data Acquisition

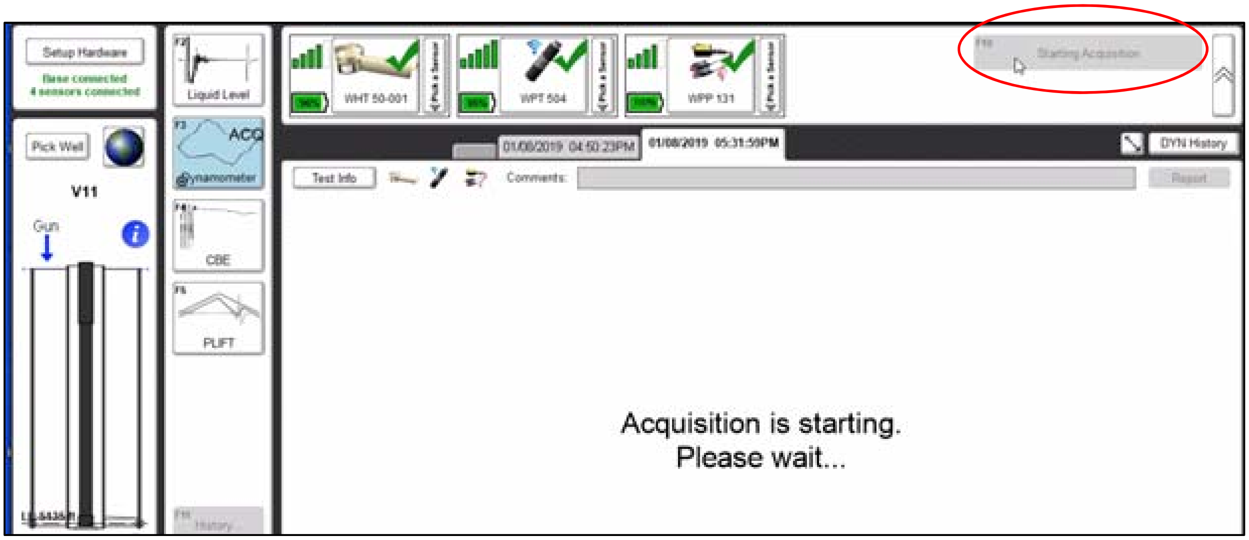


Figure 18 Start Acquisition

It is recommended to start DYNAMOMETER data acquisition BEFORE turning ON the pumping unit so that the first pump stroke can be recorded and analyzed. The pumping unit has been stopped during the time required to install the dynamometer sensor so that liquid has accumulated in the annulus. The initial strokes are indicative of the severity of gas interference and other potential problems experienced by the pump.

Step - 11- Display of Raw Data

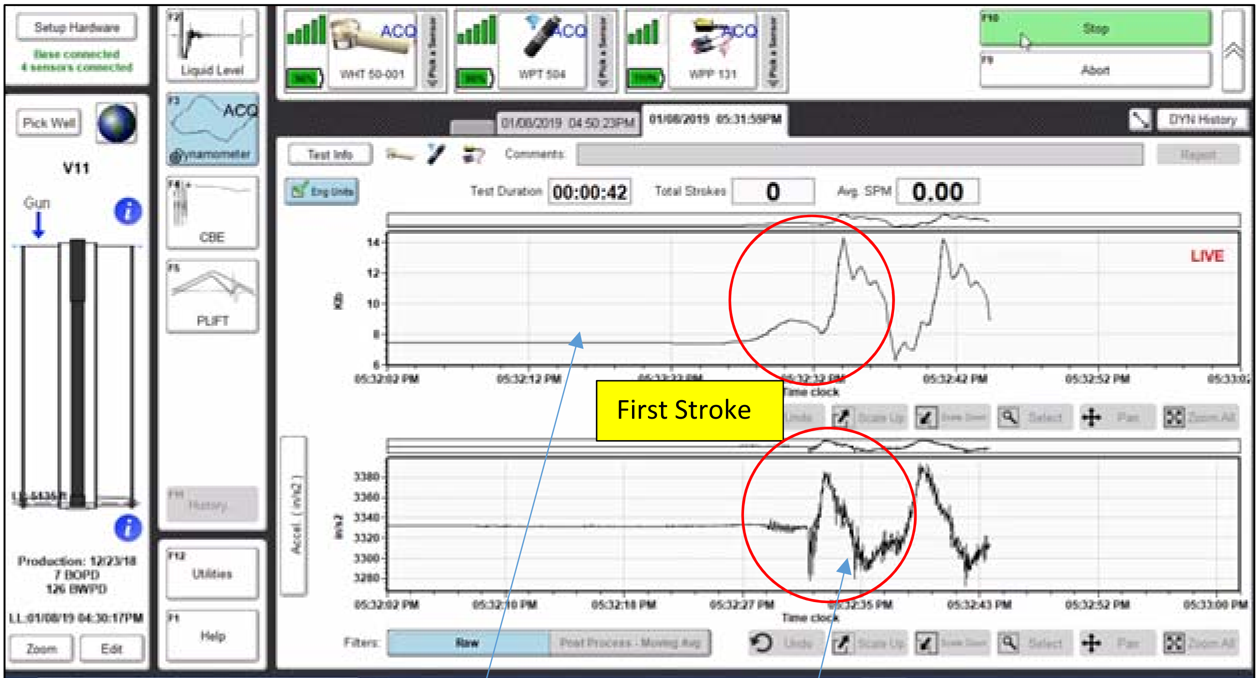


Figure 19 Live Raw Data Display

By default, the program displays Polished Rod Load and Acceleration as a function of time for at least two strokes and then switches to dynamometer cards presentation as shown in the following figure.

Step - 12 - Live display of Surface and Pump Dynamometer, Power and Tubing Pressure

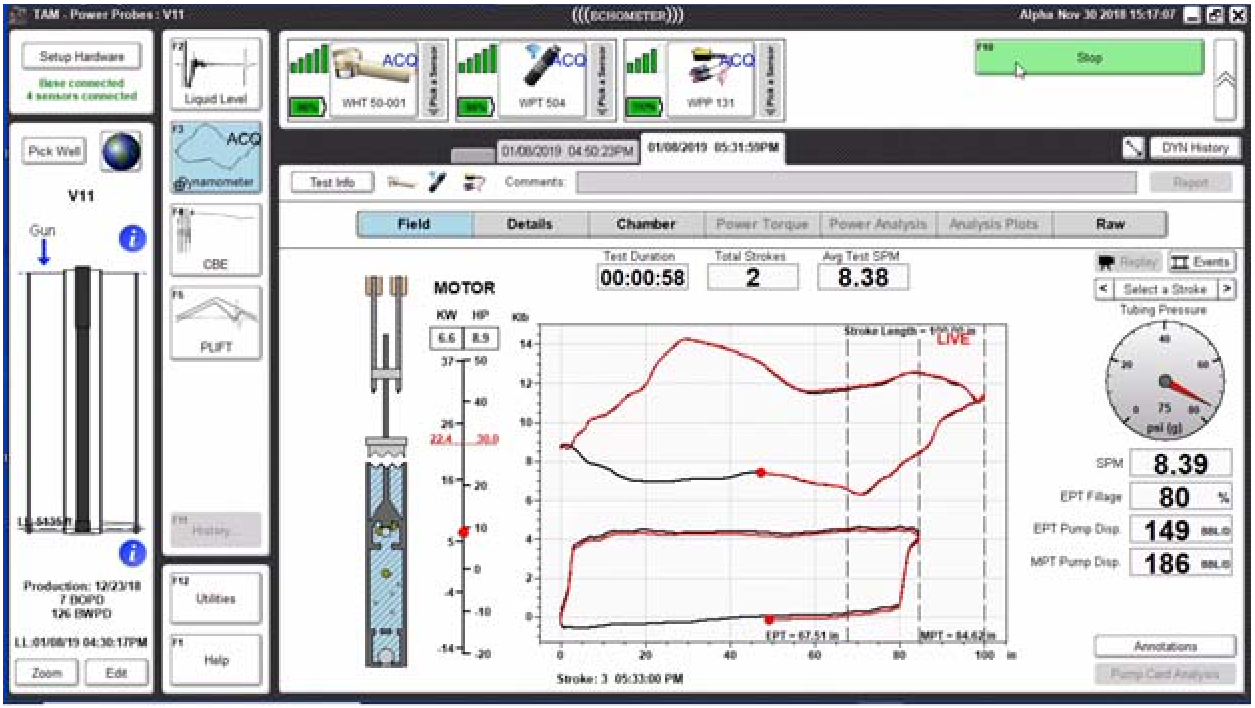


Figure 20 Live dynamometer display

The figure of step 12 is a capture of the live screen during the third down-stroke of the pump (in red) after recording the second stroke (in black). The red dots indicate the instantaneous positions and loads of the polished rod, the plunger and the instantaneous value of the motor power on the vertical MOTOR scale. By selecting the RAW data tab it is possible to monitor in real time these variables for quality control.

Step -13- Data Quality Control

Live Power Raw Data

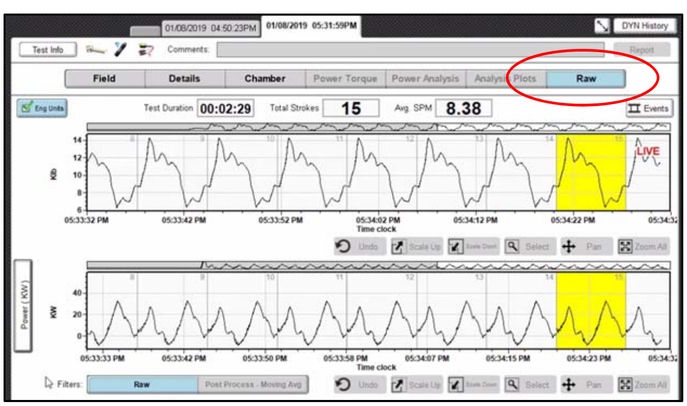


Figure 21 Power Data

Live Motor Current Raw Data

Figure 22 Motor Current Data

Live Tubing Pressure Raw Data

Figure 23 Tubing Pressure Data

Step -14- Simultaneous dyno and fluid level

Fluid level records may be acquired in TAM without interrupting acquisition of dynamometer and power data as displayed in the following figure.

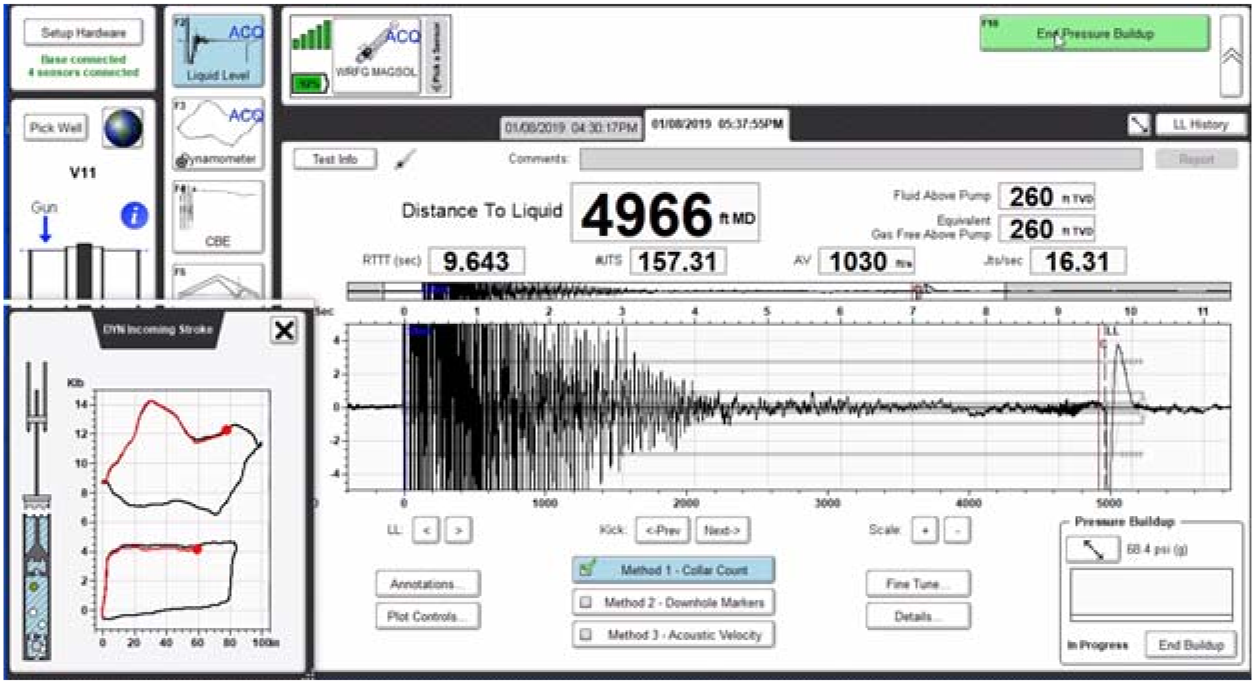


Figure 24 – Simultaneous Fluid Level and Dynamometer Live Display

This feature is very useful for correlating changes in fluid level with pump operation such as monitoring the pump fillage while setting up a pump-off controller or monitoring inflow during an extended valve test. A fluid level shot may be acquired at the start of the pump ON time and at the start of the OFF time and the change in fluid level may be used to estimate the volume of liquid that has entered the annulus.

Step – 15 - Valve Tests

Simultaneous acquisition of dynamometer and motor power while performing valve tests provides positive indication of the times when the motor was stopped by viewing the data in the RAW data tab as shown in the following figure.

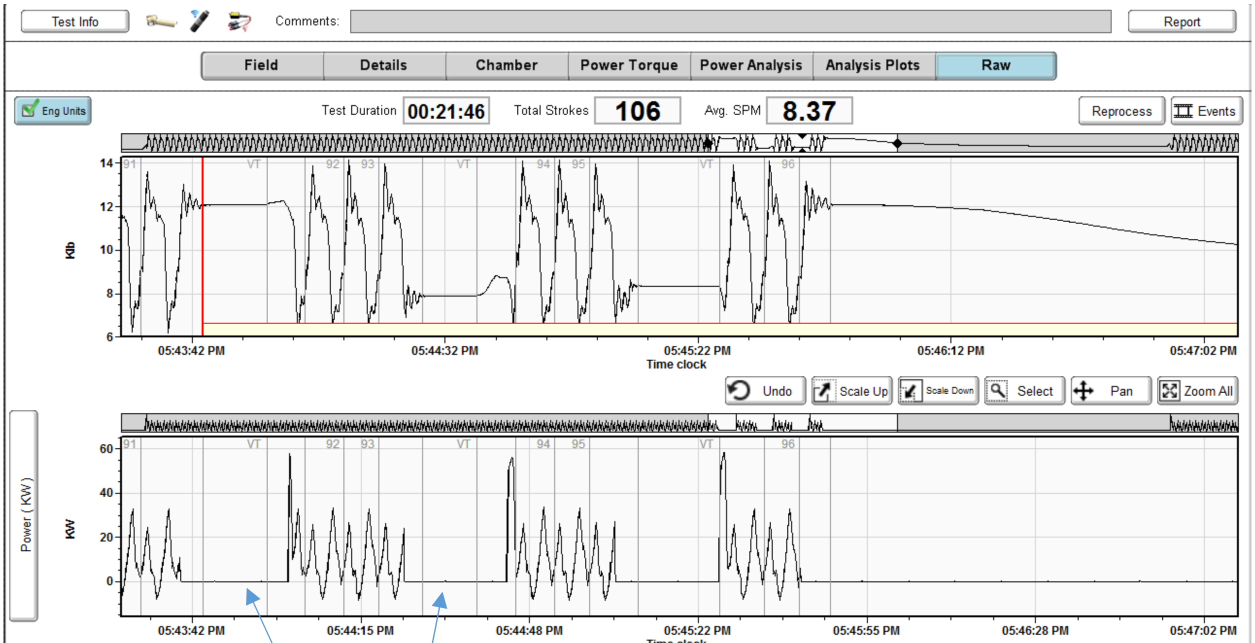


Figure 25 Raw Polished Rod Load and Power Data during Valve Test

Note the power value drops to zero when the pumping unit is stopped. The test is analyzed in the conventional manner by clicking on the time scale, highlighted in red, to open the Valve Test analysis tab.

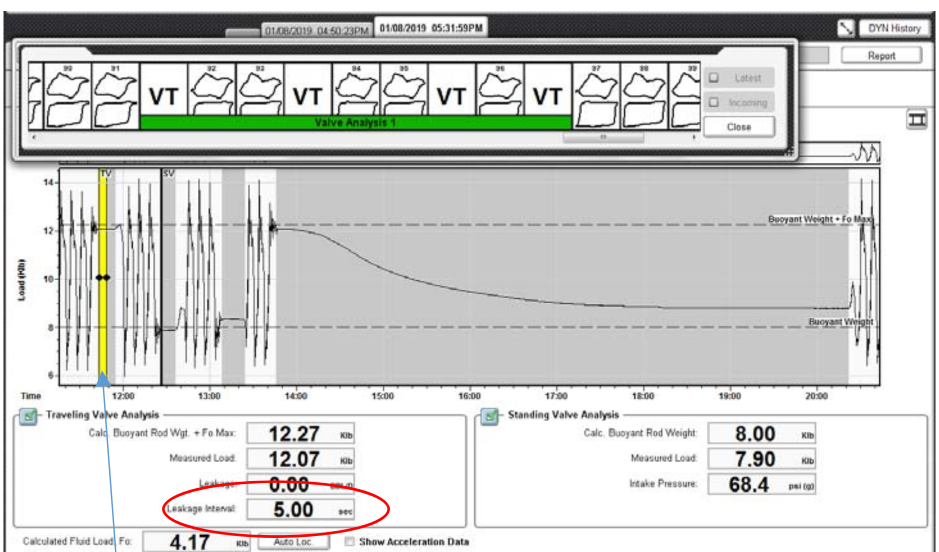


Figure 26 Valve Test

The conventional Traveling Valve test analysis, for a 5 seconds time interval, shows 0.00 Bbl/day leakage.

<u>Extended TV test and slippage</u> *(Note: The following is an important addition to the conventional TV/SV test)*

The following figure is a screen capture of LIVE acquisition during an Extended Traveling Valve test.

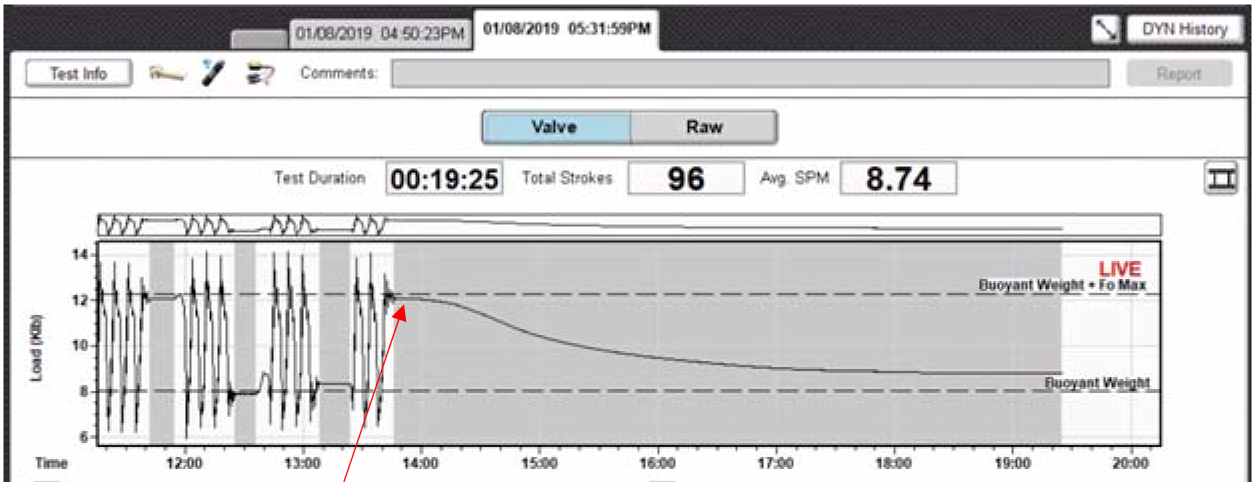


Figure 27 Extended Traveling Valve Test

It shows that after completing the second standing valve test (at time 13:50) and stroking the pump twice the polished rod was stopped on the upstroke and the brake was set for an extended period of time. The purpose of this is to monitor the rate of slippage and valve leakage when the barrel is not completely filled with liquid. In this case, looking at the 91st dynamometer card the liquid fillage is about 90% so a short (5 to 10 seconds) traveling valve test may not be indicative of the actual leakage. After about 20 seconds the load begins to decrease as liquid slips into the barrel and barrel pressure increases. This load reduction continues for about 4 minutes when the load levels off indicating that leakage of fluid from the tubing into the pump barrel has stopped.

The rate of leakage can be estimated by relocating the TV marker to the section of the load record that exhibits the largest slope as shown in the following figure.

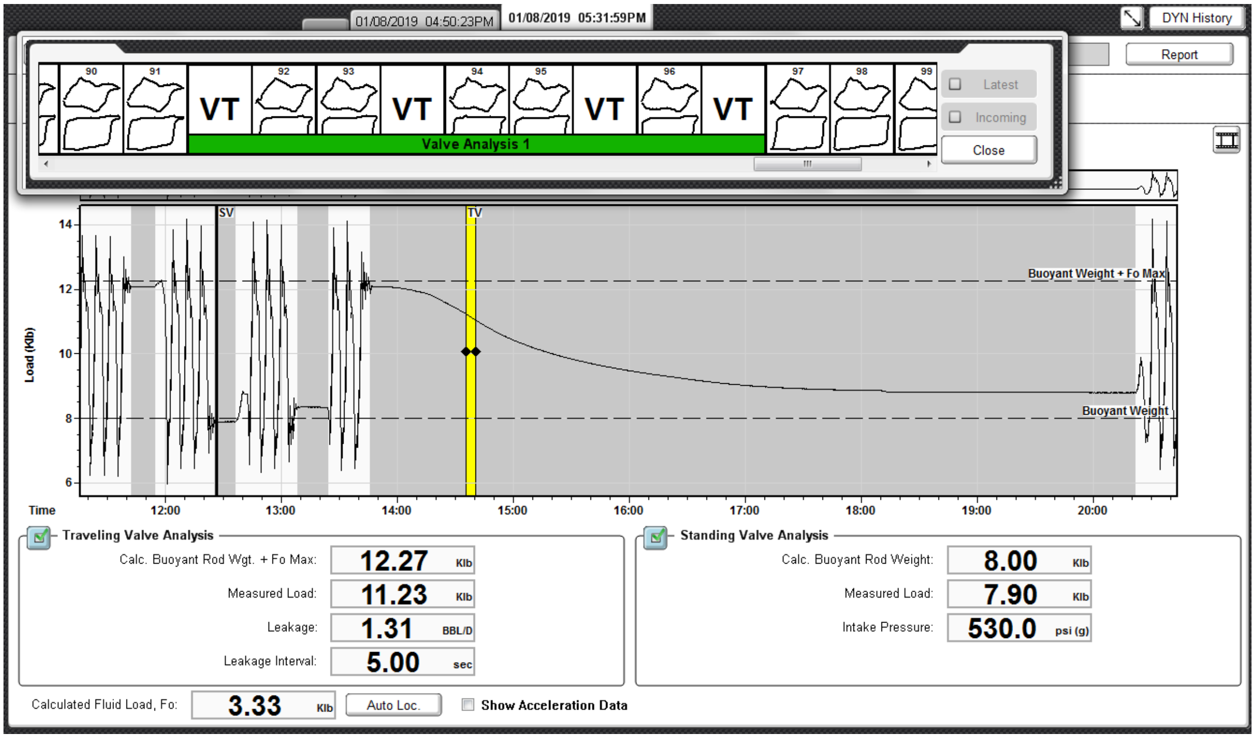


Figure 28 Adjusted Traveling Valve Test

Manual relocation of the traveling valve marker to the point where the load decrease is greatest (about time 14:40) shows that the liquid slippage and valve leakage is of the order of 1.3 bbl/day instead of zero as shown previously by the conventional TV analysis.

Step -16 - Second fluid level to check for change of annular liquid

To perform the valve tests, the pump has been stopped for a total of about 7 minutes so one should notice an increase in fluid level due to continued inflow from the reservoir assuming the standing valve is holding as observed in the valve test analysis. Since the Wireless Remote fired gas Gun is still connected to the casing valve it is fairly simple to acquire an additional fluid level record, while the pump is still stopped, as seen in the following figure of live acoustic record acquisition.

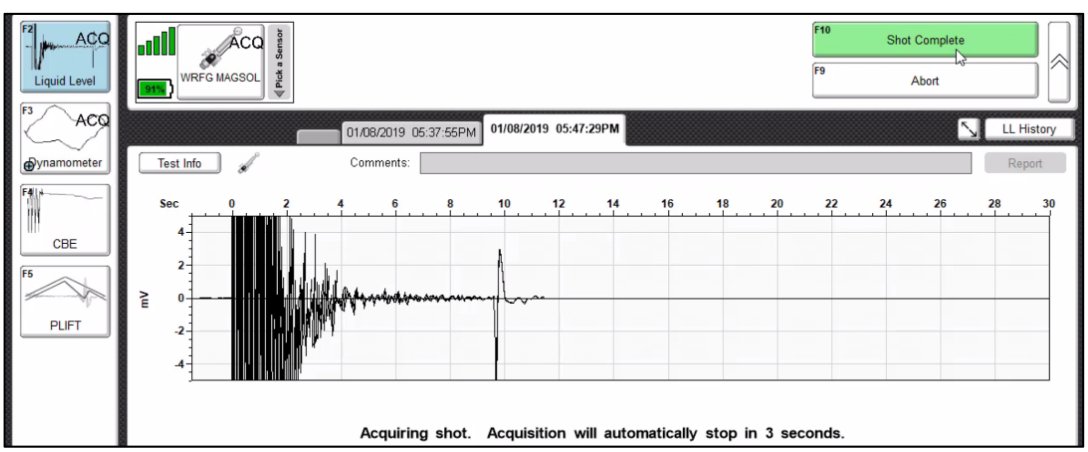


Figure 29

The following figure shows the captured Acoustic record, completed and automatically analyzed, indicating a slight increase in fluid level to 4963 feet from 4966 feet.

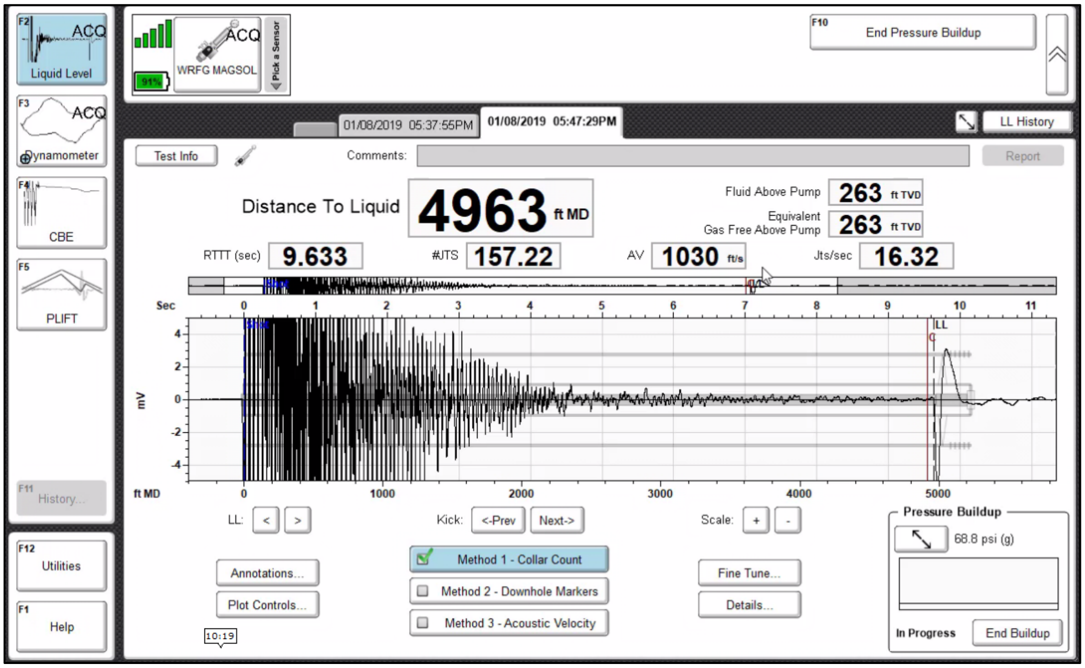


Figure 30 Fluid Level at End of Valve Tests

Annular Fluid level rose 3 feet during extended valve test that lasted about 7 minutes as seen in the overlay of the two fluid level records. This volume of liquid is a combination of leakage through the standing valve and inflow of fluid from the reservoir.

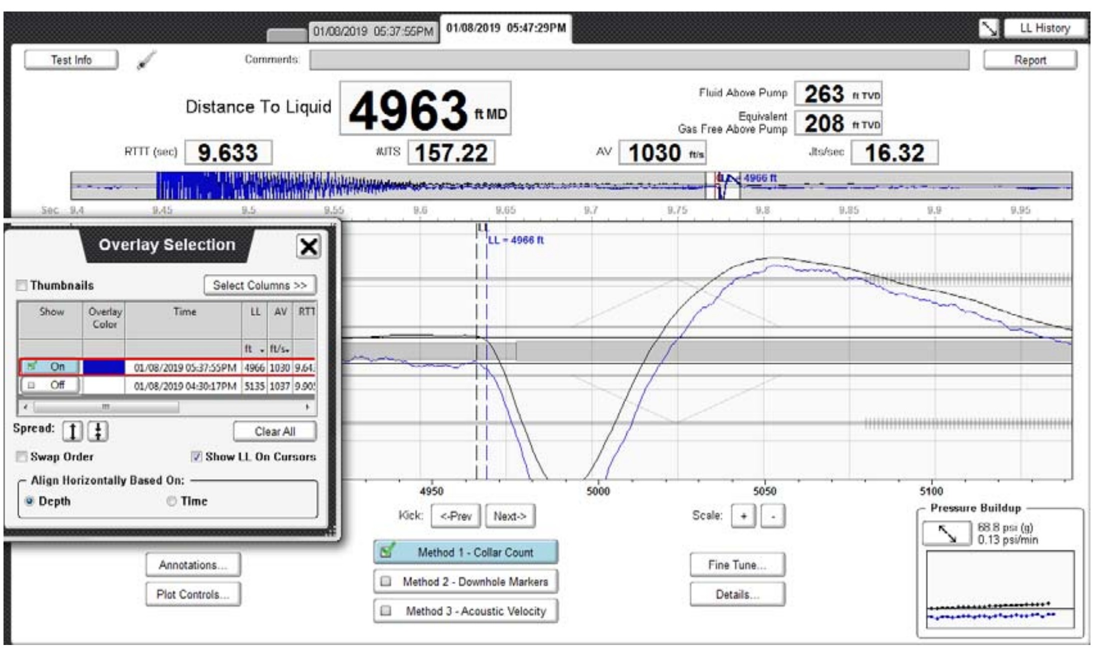


Figure 31 Fluid Level Change

This completes the acquisition of data to perform a full detailed analysis of the performance of a rod pumping well operated by an electrical motor.

Learning more about Dynamometer tests

For additional information about Dynamometer data acquisition and analysis please refer to the TAM Help and Dynamometer Features document.

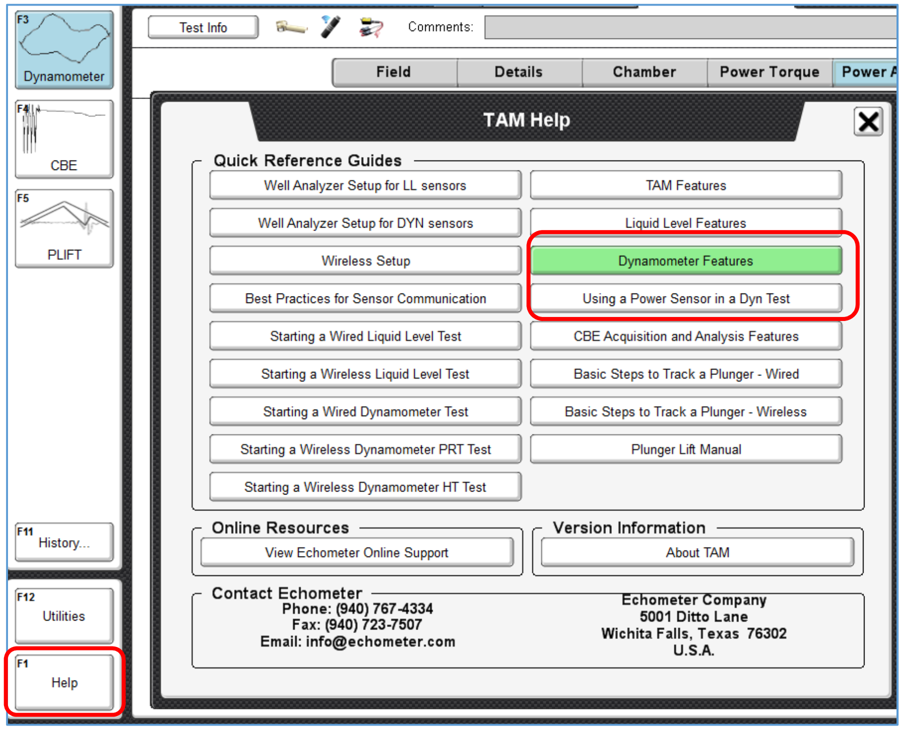


Figure 32 –TAM Help Tab

Motor Power and Current Acquisition Screens

When power sensors are connected to the switchbox acquisition of the power, current and voltage data is done automatically in conjunction with Dynamometer acquisition and each variable can be monitored in real-time using the RAW tab as shown in Figures 33a, 33b and 33c:

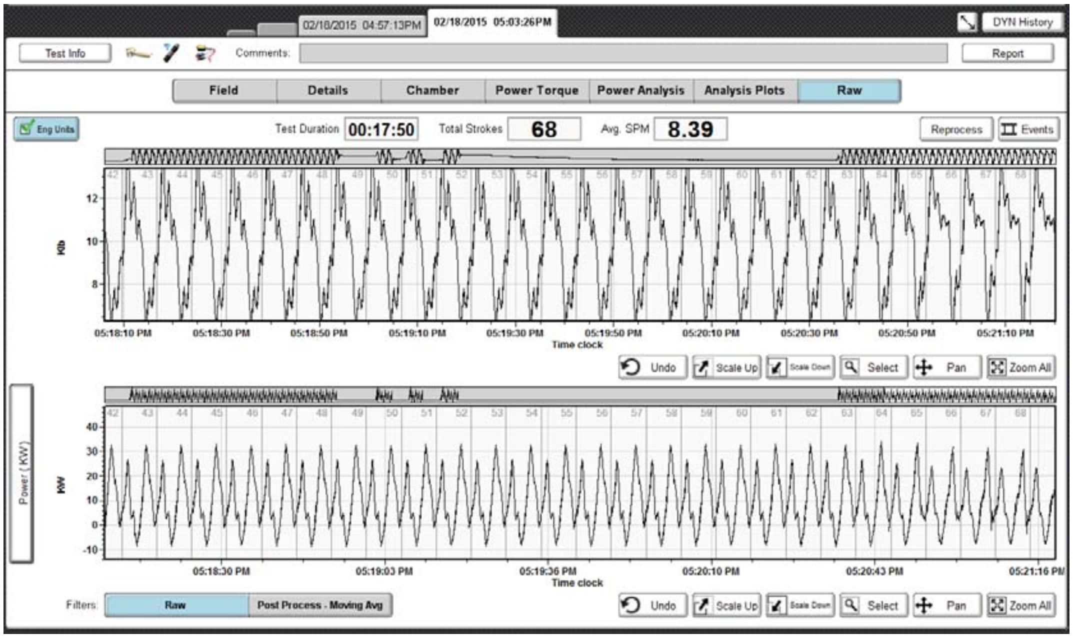


Figure 33a – Polished Rod Load (upper trace) and Motor Power (lower trace) vs. time

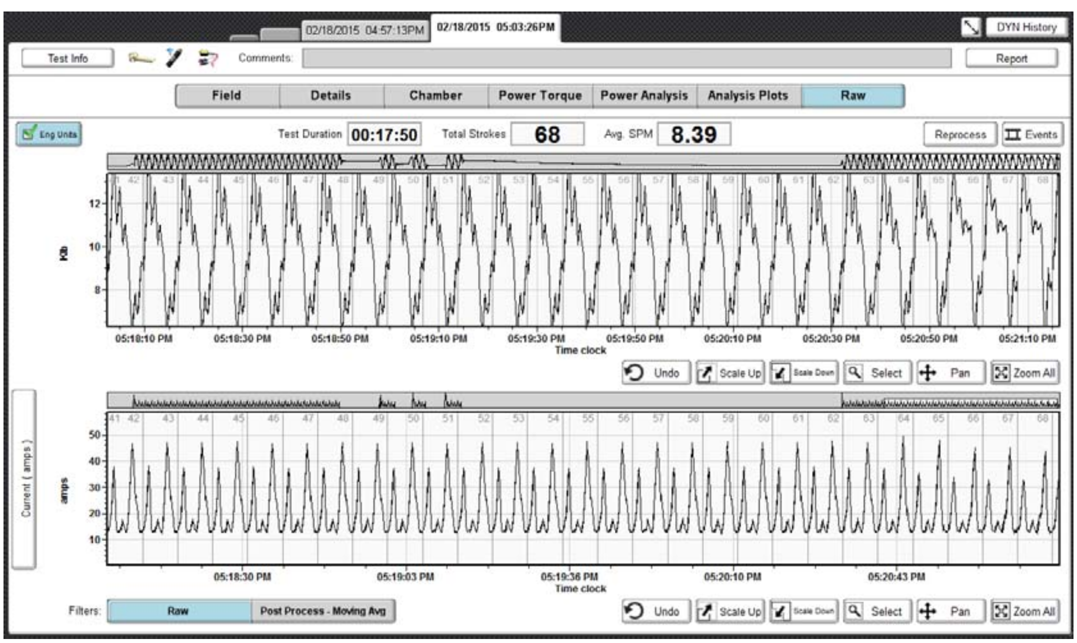


Figure 33b – Polished Rod Load (upper trace) and Motor Current (lower trace) vs. time

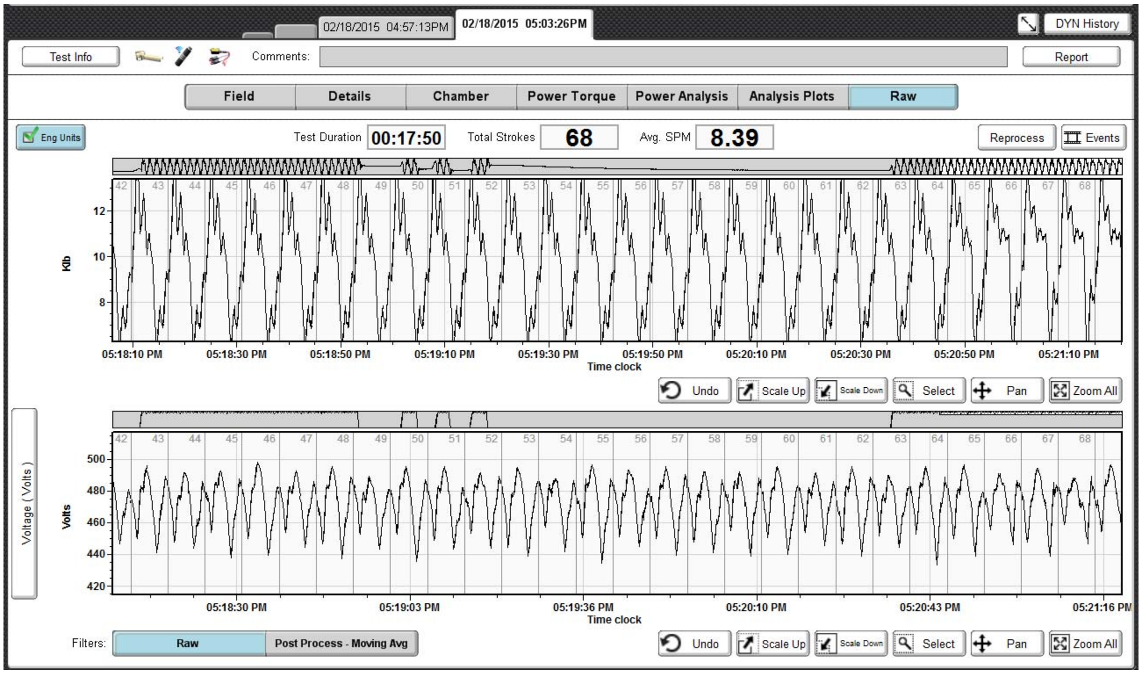


Figure 33c – Polished Rod Load (upper trace) and Motor Voltage (lower trace) vs. time

The values of voltage and current are used to compute the instantaneous **Motor Power** which is displayed in real-time as a moving red dot in the vertical slider graph in the **Field** tab.

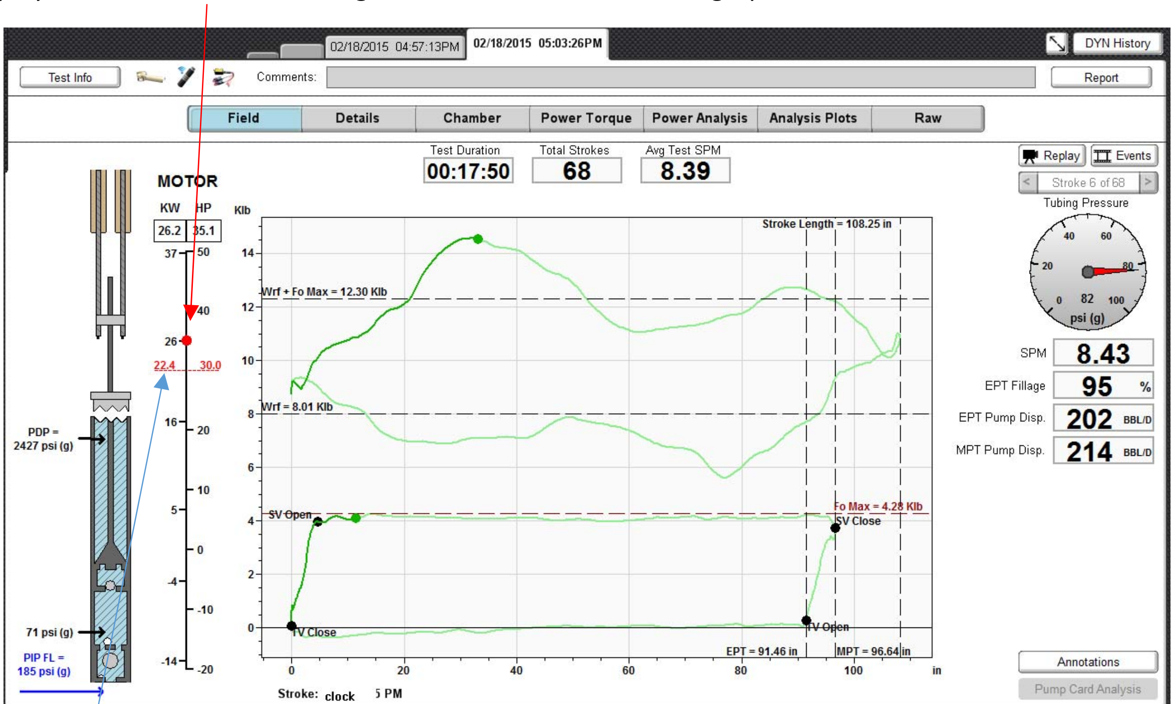


Figure 34 – Display of Instantaneous Power during Dynamometer Recording

The horizontal red line labeled 22.4 and 30.0 indicates the specific motor's power rating in kW and HP that was entered in the **Prime Mover** tab of the **Lift System** description shown in the following figure.

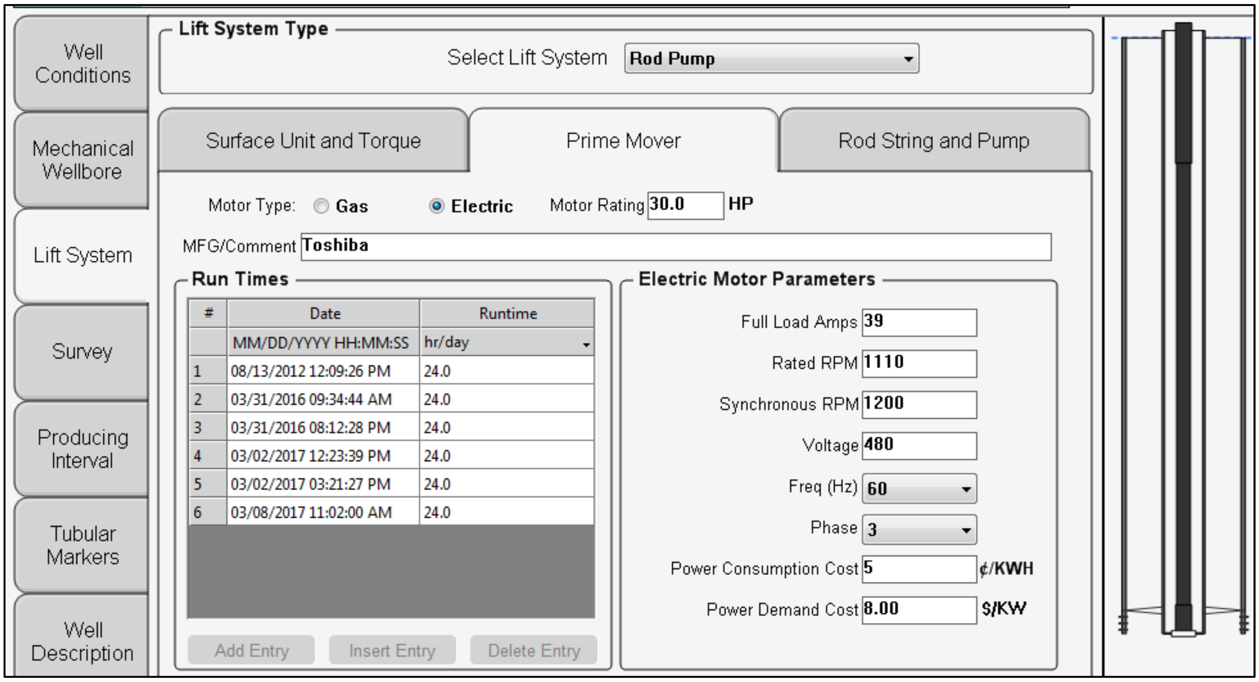


Figure 35 –Electric Motor Parameters Entry Form

The electric motor values are normally read from the nameplate of the motor that is installed on the pumping unit.

For wells using pump-off controllers, it is recommended that the user enter the run time in the table at the time the **Lift System** information is input or before the first dynamometer record is acquired. The indicated run time will be used for the power cost calculations until a change is made in the mode of operation. However, it is possible to enter or edit the run time after dynamometer records have been acquired.

Analysis of Motor Current for a Single Pump Stroke

Figure 36 shows dynamometer data acquired simultaneously with power and tubing pressure during pump stroke 62 where the barrel is almost completely filled with liquid.

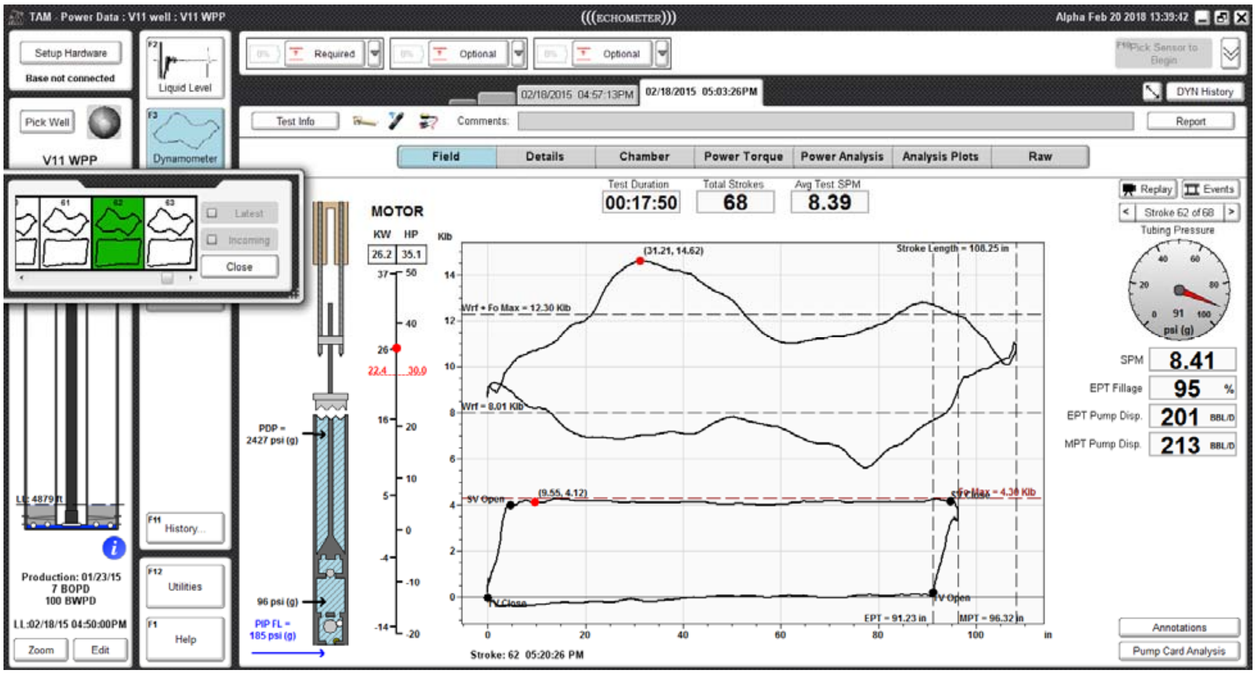


Figure 36 – Surface and Pump dynamometer acquired simultaneously with Wireless Power and Pressure sensors.

Individual strokes can be selected for analysis using the Events filmstrip and analysis plots generated as shown in the following section.

Power and Current Analysis Plots

Detailed analysis plots are available to study in detail the correlation of various mechanical parameters with the motor performance. The values to be plotted are selected from menus that are displayed by clicking on the axes labels as shown in Figure 37 to generate the plots shown in Figures 38, 39 and 40.

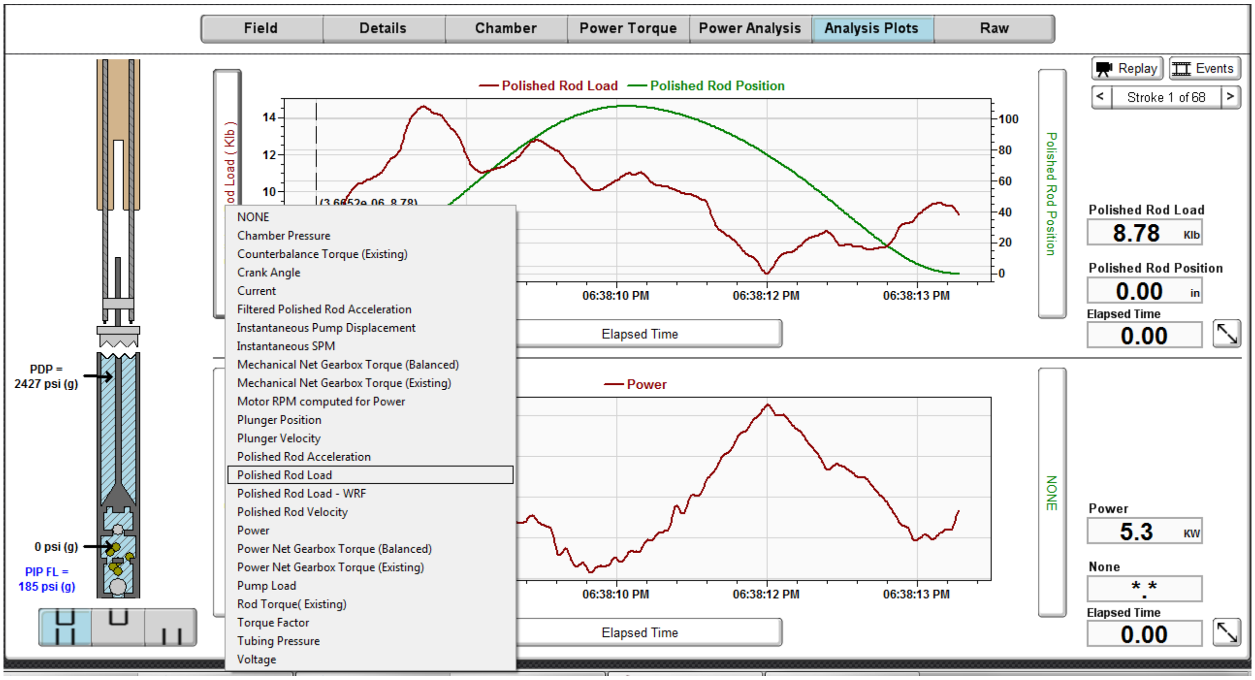


Figure 37 – Selection of Analysis Plots Vertical Axes Variables

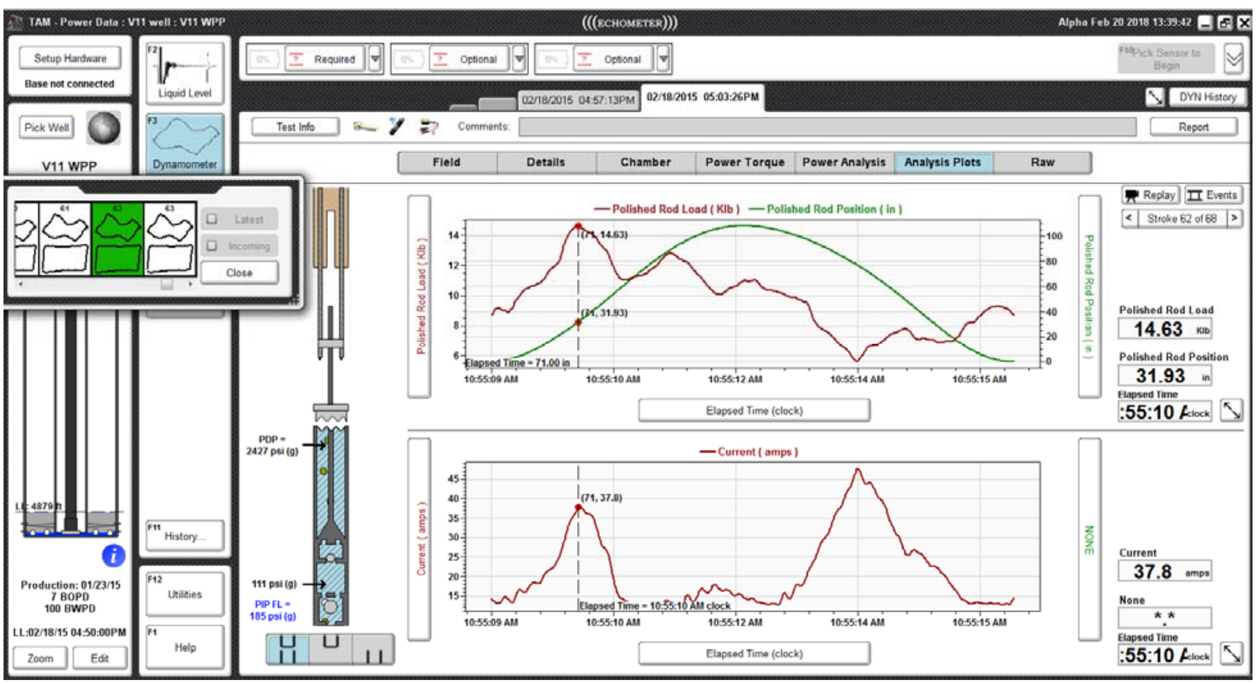


Figure 38 Polished rod load, polished rod Position and motor current versus time

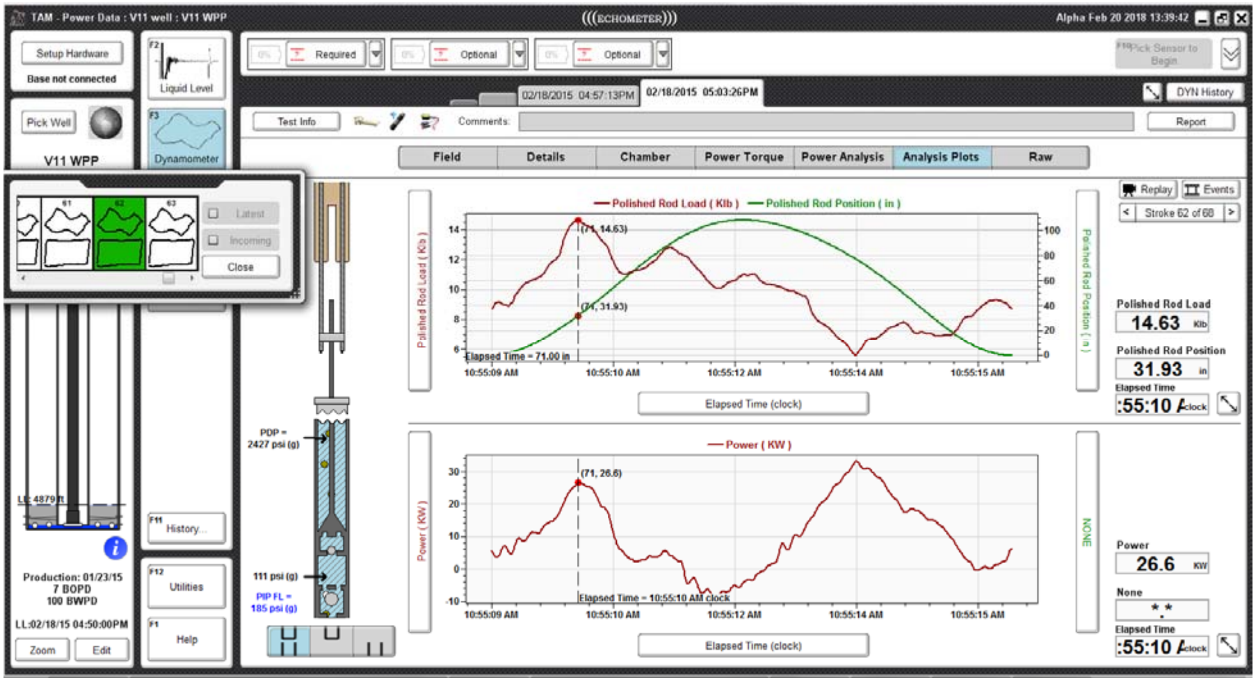


Figure 39 – Polished rod load, polished rod position and motor power versus time

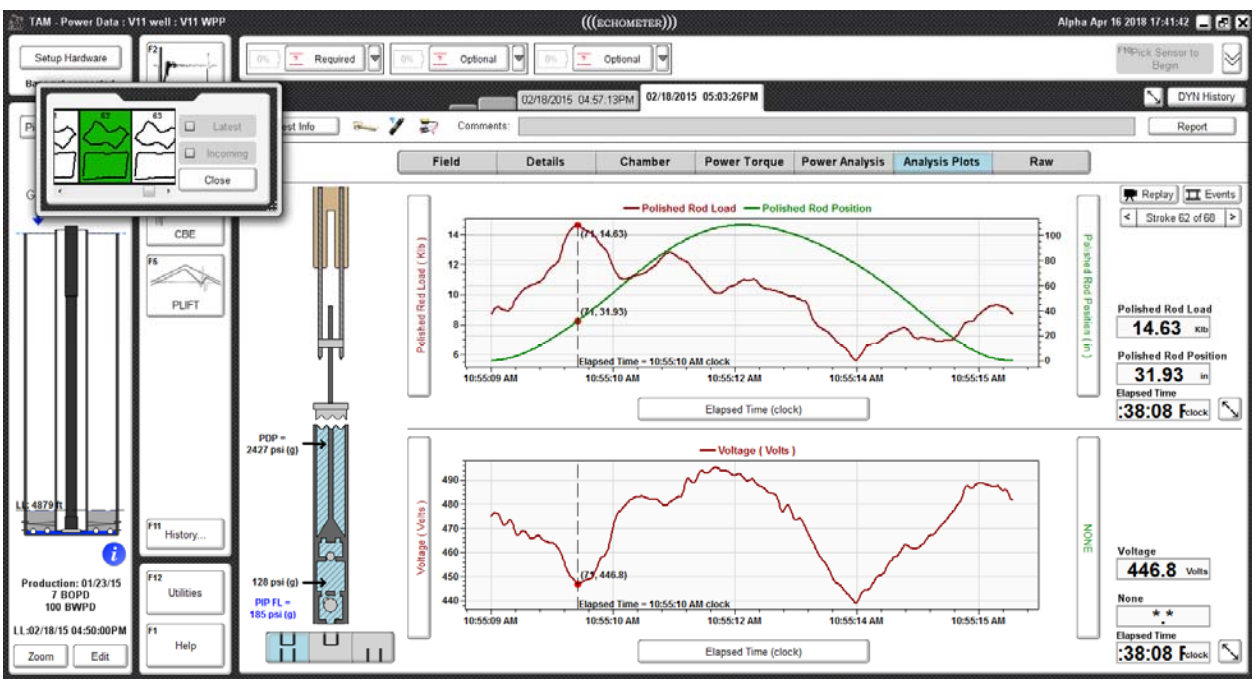


Figure 40 – Polished rod load, polished rod position and motor voltage versus time

Notice how the voltage decreases as the power increases. This is an indication of electrical line losses.

Quantitative Power and Current Analysis

In general, the operator is interested in establishing the power use and the balance condition of the pumping system when it is operating at steady state.

If the well is operated with a pump-off controller or timer the analysis should be undertaken using a stroke that corresponds to full liquid fillage. If the pumping unit is operated On-hand and the pump operates most of the time with partial liquid fillage the analysis should be done for a stroke that exhibits partial fillage.

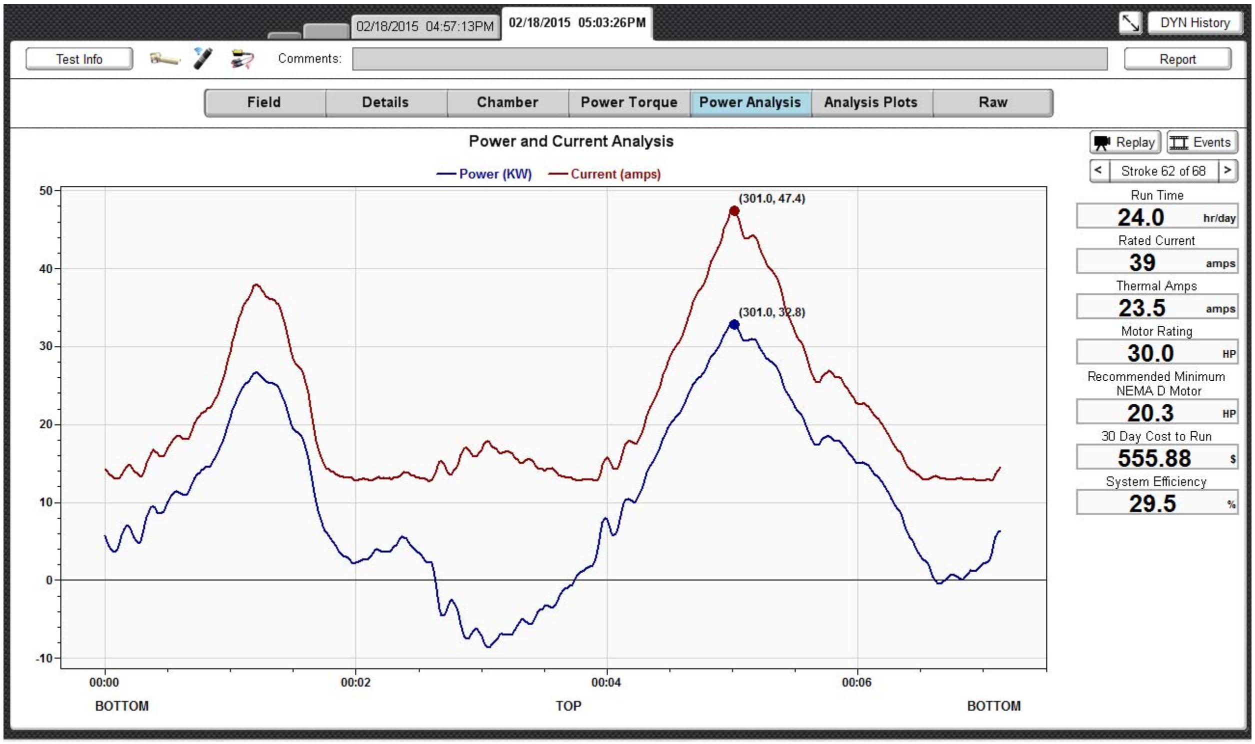


Figure 41 – Quantitative analysis of electrical motor loading, power use and operating cost

On the right side of Figure 41, the principal electrical loading and efficiency parameters are summarized. The energy cost per month, which corresponds to the indicated daily run time and based on the cost per kilowatt hour and the kW demand cost input by the user is shown.

<u>Power Analysis Detailed Report</u>

Selecting the report option from the Dynamometer Tab opens the report screen where the user may select which report to view. In the figure below only the Power and Analysis Plots are displayed.

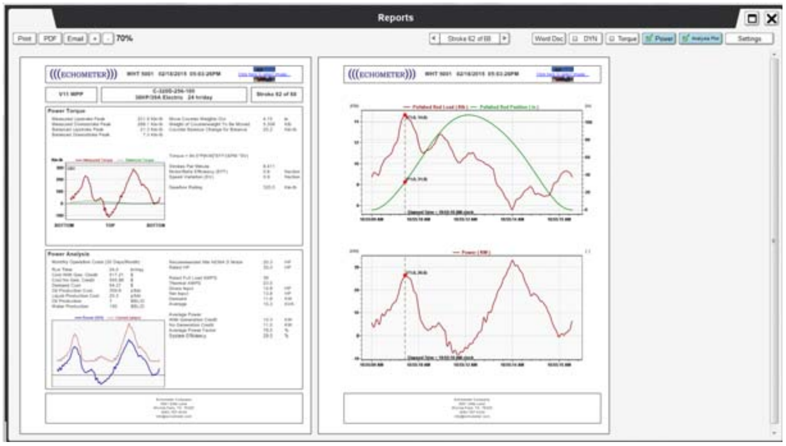
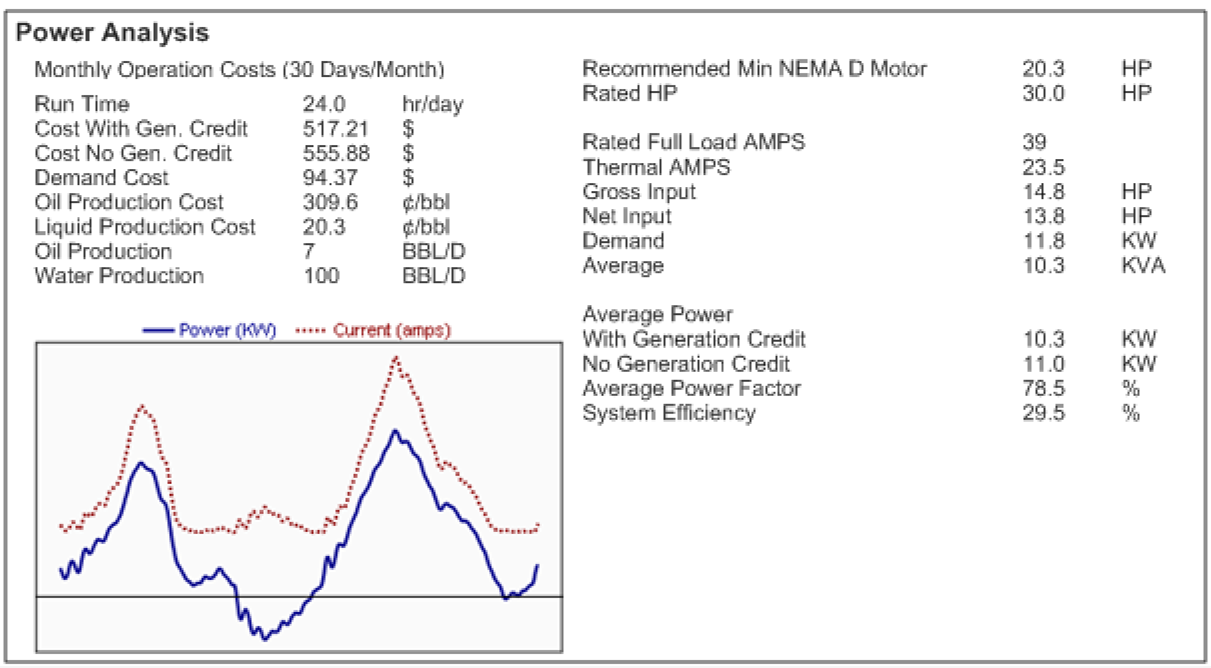


Figure 42 – Detailed Power Analysis Report

The detailed power analysis report in Figure 42 includes all relevant values required to analyze the efficiency of the system and evaluate its performance. The operating cost is calculated on the basis of a barrel of fluid pumped and a stock tank barrel of oil produced and also considers whether credit is applied for power generation during the stroke.



Power Analysis

Monthly Operation Costs (30 Days/Month)

Run Time	24.0	hr/day
Cost With Gen. Credit	517.21	$
Cost No Gen. Credit	555.88	$
Demand Cost	94.37	$
Oil Production Cost	309.6	¢/bbl
Liquid Production Cost	20.3	¢/bbl
Oil Production	7	BBL/D
Water Production	100	BBL/D

Recommended Min NEMA D Motor	20.3	HP
Rated HP	30.0	HP
Rated Full Load AMPS	39	
Thermal AMPS	23.5	
Gross Input	14.8	HP
Net Input	13.8	HP
Demand	11.8	KW
Average	10.3	KVA
Average Power		
With Generation Credit	10.3	KW
No Generation Credit	11.0	KW
Average Power Factor	78.5	%
System Efficiency	29.5	%

Figure 43 – Detailed Summary Report of Power Analysis and Operating Cost

Power Analysis for Multiple Strokes with Varying Pump Fillage

In the majority of wells the pump fillage has a tendency to change significantly during pump operation so that the power and efficiency analysis should be undertaken using data for a pump stroke that is considered to be representative of the majority of pump strokes. Alternately, power data may be acquired for an extended period of time and the analysis may be performed by averaging the values for multiple strokes. The following example shows dynamometer data where fillage changes from almost 100% liquid (stroke 10) to about 60% fillage (stroke 16):

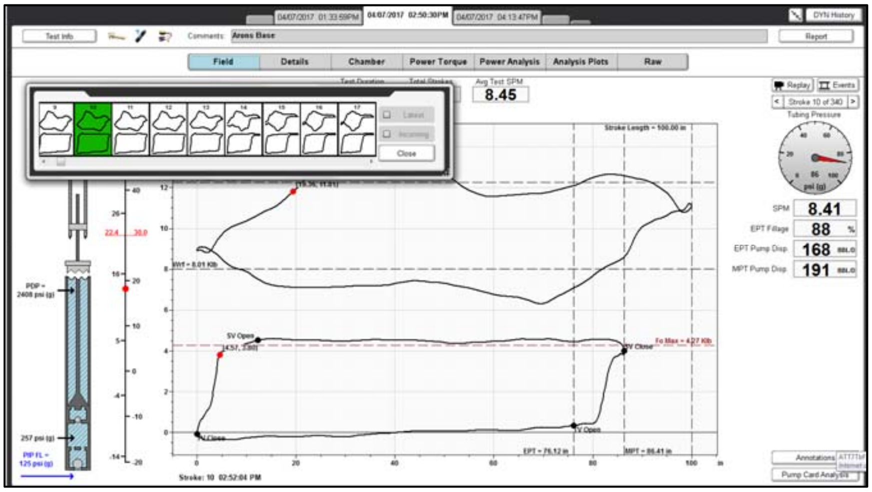


Figure 44 – Stroke 10 showing Full Pump

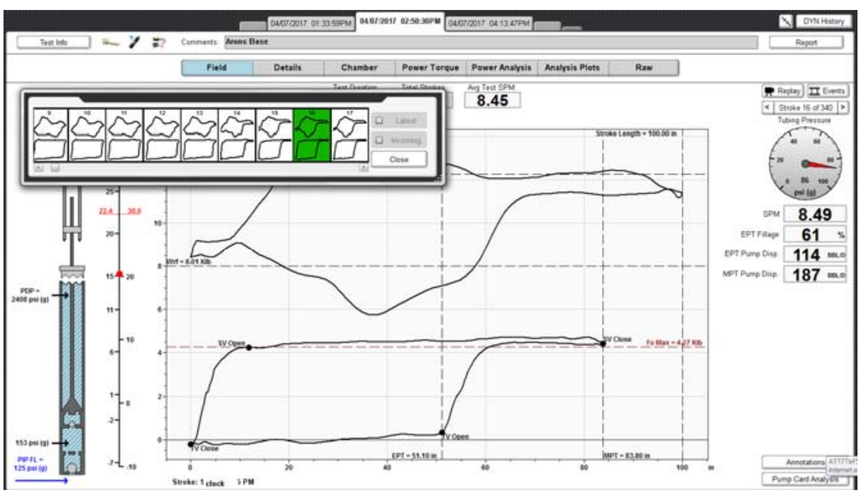


Figure 45 – Stroke 16 Showing Partial Liquid Fillage

The corresponding values of motor power and current are shown in the following two figures.

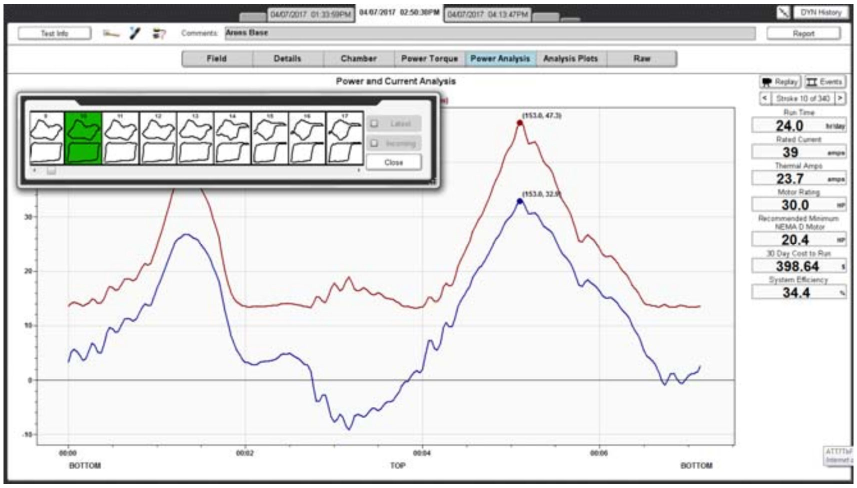


Figure 46 – Stroke 10 Motor Power and Current for Full Pump

Analysis of this stroke indicates that assuming this pump stroke and fillage are repeated during the next 30 days the operating cost would be $ 396.64 assuming 24 hour per day run time.

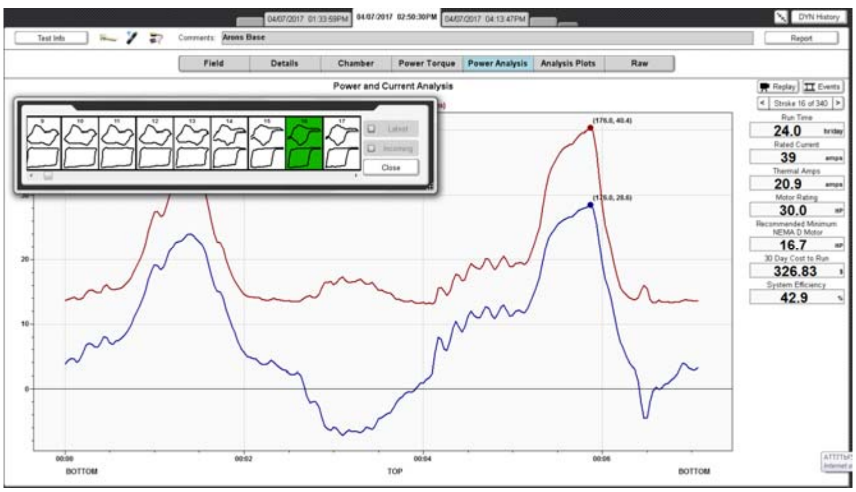


Figure 47 – Motor Power and Current for Partial Liquid Fillage

Analysis of this stroke indicates that assuming this pump stroke and fillage are repeated during the next 30 days the operating cost would be $ 326.83 assuming 24 hour run time.

The difference of $ 69.81 represents about 21%.

Therefore the user should use this analysis if stroke 16 (partial fillage) is the normal mode of operation of the pump.

When a pump-off controller is used, operating the pump only when fillage is near 100%, then stroke 10 would be the representative stroke to analyze and in this case the user should also enter the run time per day in the Prime Mover tab shown in Figure 35.

The following fillage presents an overlay of power and motor current for the two strokes. Note how the first part of the records, corresponding to the upstroke from time 00:00 to 00:04, are essentially very similar since the polished rod load is determined primarily by the weight of the rods and fluid in the tubing. During the downstroke (time 00:04 to 00:08, the start of increase in power and current is determined by the pump fillage: at the start of the downstroke for a full pump and later for the partiall fillage.

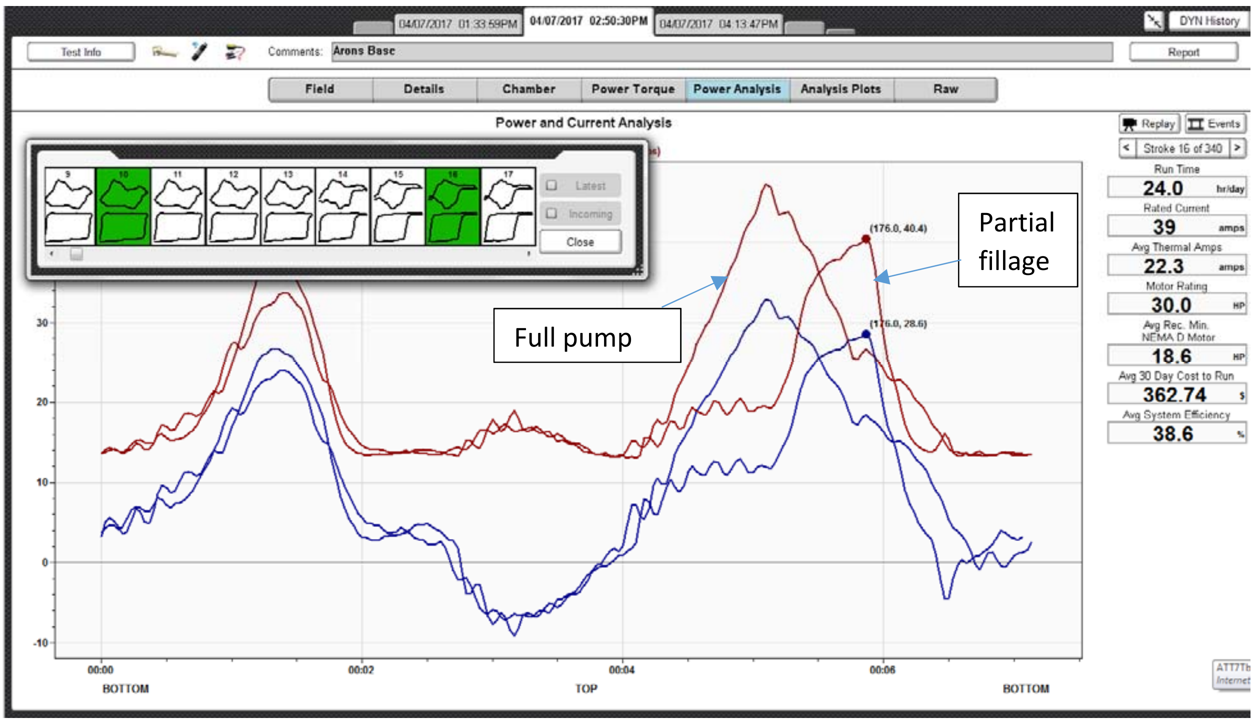


Figure 48 – Overlay of Strokes 10 and 16

The peak value of the power is higher when the pump is filled with liquid. Notice that when two strokes are superimposed, all the values displayed at the right of the figure are averages. This feature can be applied to any number of strokes as seen in the next figure where all the recorded strokes from 1 to 100 are overlaid and the averages are displayed.

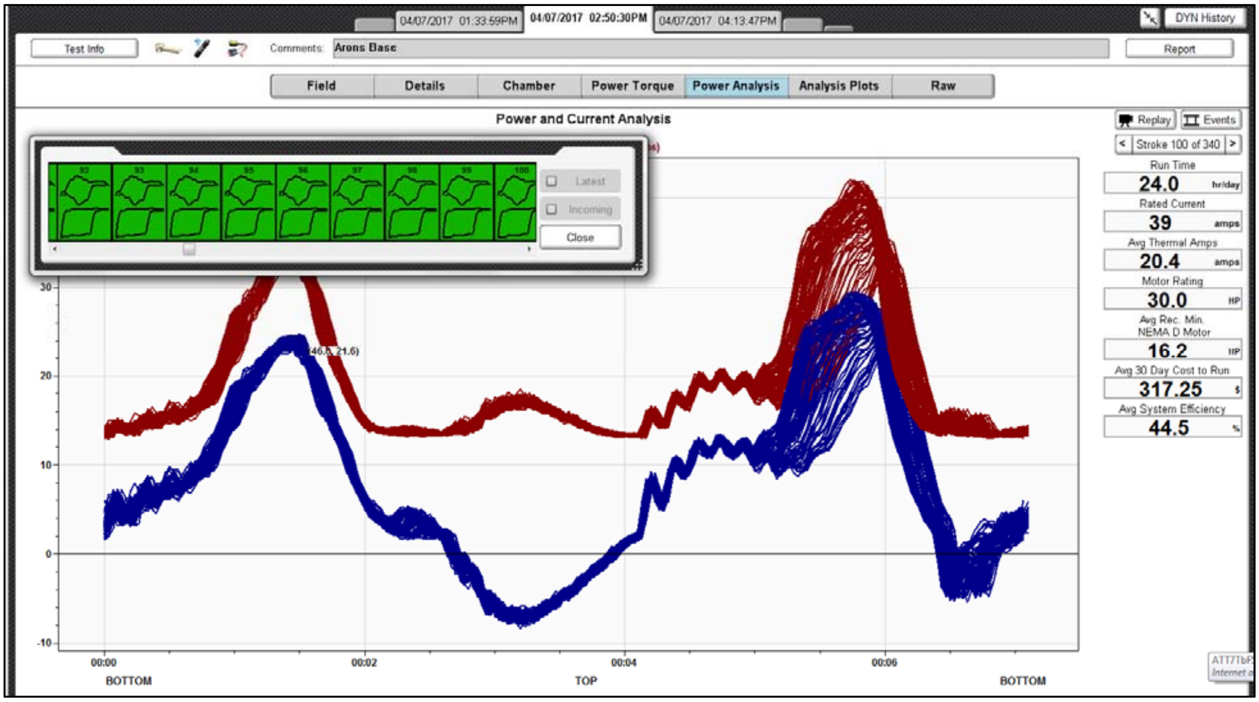


Figure 49 – Overlay of All Recorded Strokes yields Average Values

The overlay clearly shows how much variation in pump fillage was experienced. The average operating cost is computed as $ 317.25 per month which is close to the single stroke value of $ 326.23 shown in Figure 47.

Torque Calculation from Motor Power Measurement

Pumping unit counterbalancing has always been an integral part of those field activities designed to reduce operating costs. Most commonly, counterbalance adjustment has been undertaken using an indicating ammeter to monitor the peak values of motor current during the upstroke and downstroke. Adjustment to the position of counterweights on the crank is then undertaken by trial and error until the current peaks are equal. Adjustment of the counterweights is typically a tedious procedure of trial and error that often does not result in an improved mode of operation. Problems are especially prone to arise if the unit is significantly out of balance. In certain instances, the peak current indications of a common ammeter can be confusing as a result of the presence of a large generating current, which cannot be distinguished from current peaks corresponding to high motor demand.

Power provided to the motor and the net torque resulting at the gearbox are directly proportional so that measurement of power, using the wired or wireless probes, during the pumping cycle allows direct calculation of the net torque. In a beam pumping system, the instantaneous torque at the gearbox can be calculated from direct measurement of the power and the speed of rotation by the following relation:

$$T = 84,520(e)\frac{P}{N(SV)}$$

$T =$ torque (inch-lb_f)

$e =$ efficiency $(\text{dimensionless fraction})$

$P =$ power (kilowatts)

$N =$ pumping speed (spm)

$SV =$ speed variation factor (dimensionless)

The efficiency (e) of power conversion by the motor and power transmission through the belt drive and the gear reducer varies with each installation and with the loading of the system. In general, efficiency decreases as loading decreases. For a normally loaded and properly installed system, the efficiency has been estimated at 77% but can be much lower if the unit is not properly maintained. The calculation also requires knowledge of the instantaneous crank speed. This quantity is directly related to the average pumping speed (N) and is multiplied by the speed variation factor (SV), which is determined from the dynamometer measurement as the ratio of the minimum to the average crank speed. If dynamometer data is not available, the speed variation factor is assumed to be unity.

The TAM default values of efficiency and speed variation can be modified by the user using the **Power Gearbox Torque Calculator** that is accessed by clicking on the button at the lower right of the **Power Torque** tab shown in Figure 50.

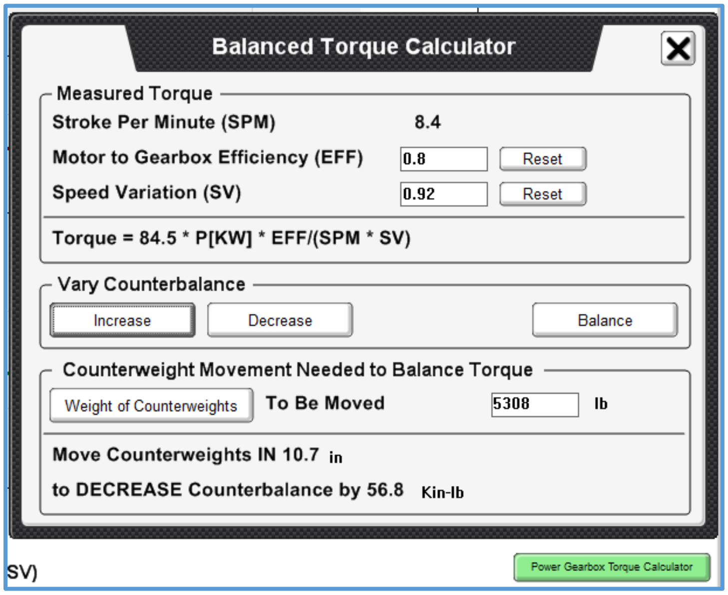


Figure 50 – Pumping Unit Balancing Calculator

Gearbox Balancing Analysis

The power requirement on the upstroke should be balanced against the power requirement on the downstroke for more efficient operations. To balance the pumping unit, using power measurement data, the operator does not have to know the pumping unit API dimensions, weight of counterbalance CBE or CBM, or center of gravities of counterweights and cranks; all that is needed, is to know is the weight of the existing counterweights that can be moved.

In the following figure the red curve represents the existing net gearbox torque showing that the downstroke peak is higher than the upstroke peak torque. This indicates that more power is used to lift the counterweights than to lift the polished rod. The gearbox is OVERbalanced.

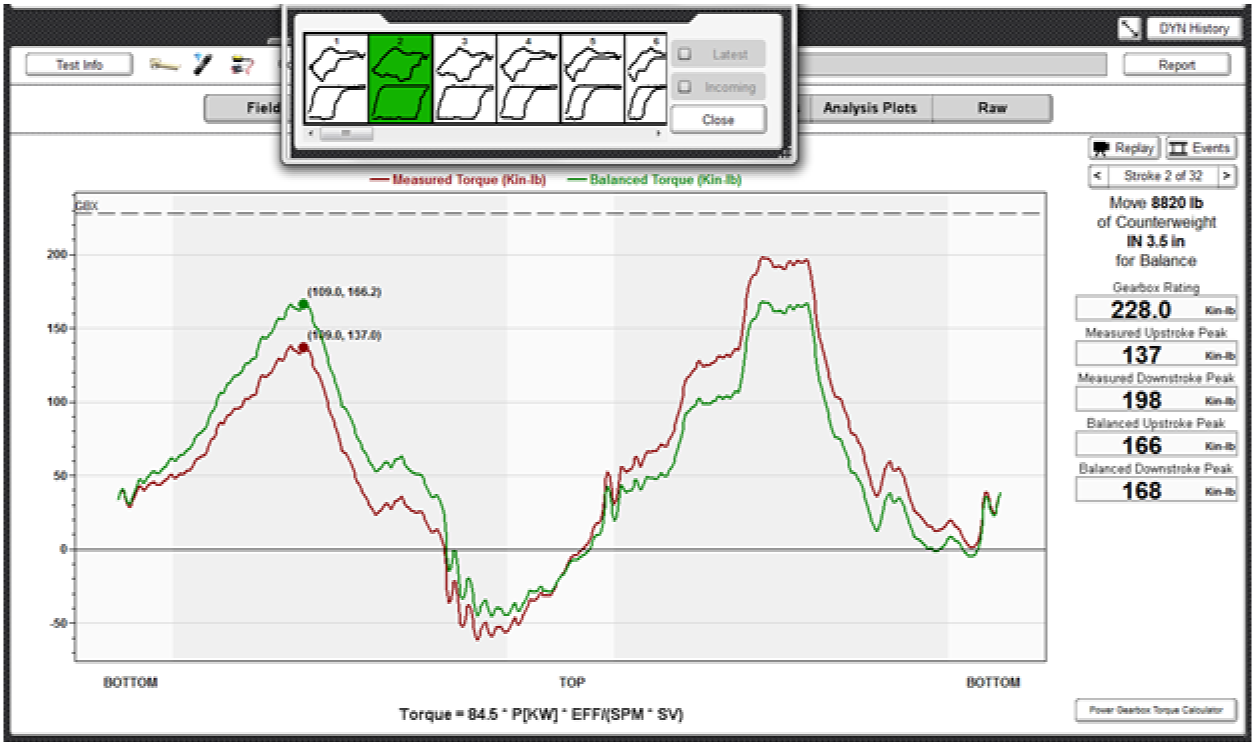


Figure 51 - Single Stroke Torque analysis from motor power measurement

On the right side of Figure 51, the tabulated torque analysis gives the upstroke peak torque and the downstroke peak torque values in thousands of inch-lbs. that occur during the stroke. The difference between these values is a measure of the unbalance of the system. If the upstroke peak is greater, the unit is underbalanced or “rod heavy.” If the downstroke peak is greater, the unit is overbalanced or “crank heavy.” In this example, the unit is slightly overbalanced and has an upstroke peak of 137,000 inch-lbs. and a downstroke peak of 198,000 inch-lbs. The torque that would be experienced if the counterbalance were adjusted so that the two peaks were equal is displayed as the balanced peak value and is estimated at 166,000 inch-lbs. Assuming that the weight of the existing counterweights that can be moved is 8820 Lbs., they all should be displaced inwards (towards the crankshaft) a distance of 3.5 inches from their existing location to achieve the balanced condition which is displayed as the **green curve**.

Torque Analysis Report

The TAM dynamometer report includes the option of generating the torque analysis based on the power measurement by selecting the corresponding button at the top left of the Report screen:

The torque analysis displayed in Figure 51 will be included in the overall report.

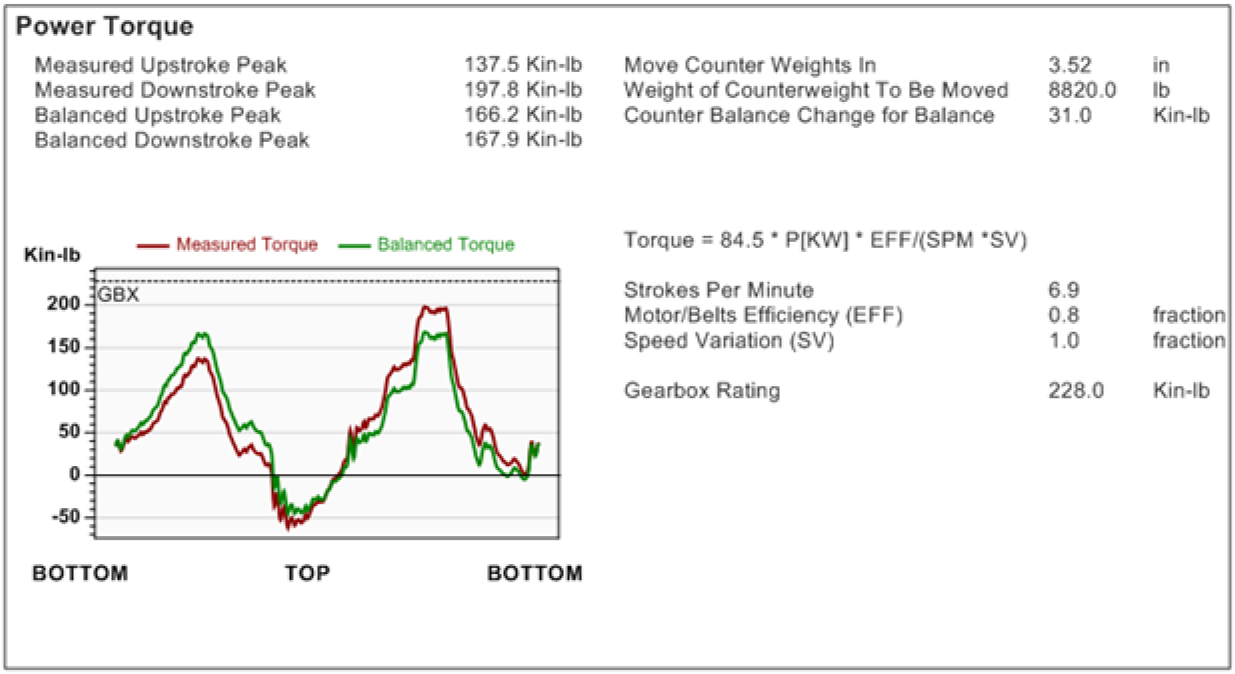


Figure 52, Detailed Analysis Report of Gearbox Torque computed from electrical power measurement

Motor/Belts Efficiency (EFF), is the ratio of the power input to the motor and the power delivered at the crankshaft.

The motor and belts efficiency is defaulted to 80% in the TAM program. Experience has shown this efficiency to be reasonably accurate for the purpose of calculating existing gearbox torque. NEMA D motors operate at a nearly constant efficiency over a wide horsepower range, but a lightly loaded motor operates with a much lower efficiency. Rewound motors do not have the same efficiency performance of a new motor depending on the quality of the repair and the efficiency may need to be de-rated or in some cases increased. When the actual efficiency is lower than the default, then calculated peak gearbox torques will be higher and the gearbox loading could even be computed to exceed the gearbox rating. Usually any error in efficiency affects the peak gearbox torques the same, therefore the distance to move the weights from their current location usually remains the same regardless of any error in efficiency.

The report also indicates the distance and direction of the counterweight movement required to change the counterbalance by the indicated amount of torque. When multiple counterweights are to be moved, each counterweight should be moved by the distance displayed by the program. The unit in the example well is equipped with 4 counterweights totaling 8,820 lbs., the analysis recommends a movement of 3.5 inches in for all counterweights.

This suggested counterbalance change should be undertaken in stages. After each counterweight is moved, a power measurement should be taken in order to check that the desired effect is being achieved. Experience has shown that proper balancing can be performed quickly when proper equipment is available.

Quality Control of Torque Analysis

Whenever a dynamometer record is acquired simultaneously with motor power data and the pumping unit that is in use has been identified correctly in the pumping unit data base and either CBE (Counterbalance Effect) or CBM (Counterbalance Moment) have been determined, then it is possible to compare the calculated values of the net gearbox torque computed from the dynamometer loads and computed from the power measurements. The **Analysis Plots** tab may be used for this purpose by selecting the corresponding left and right axes of the graph as shown in Figure 53:

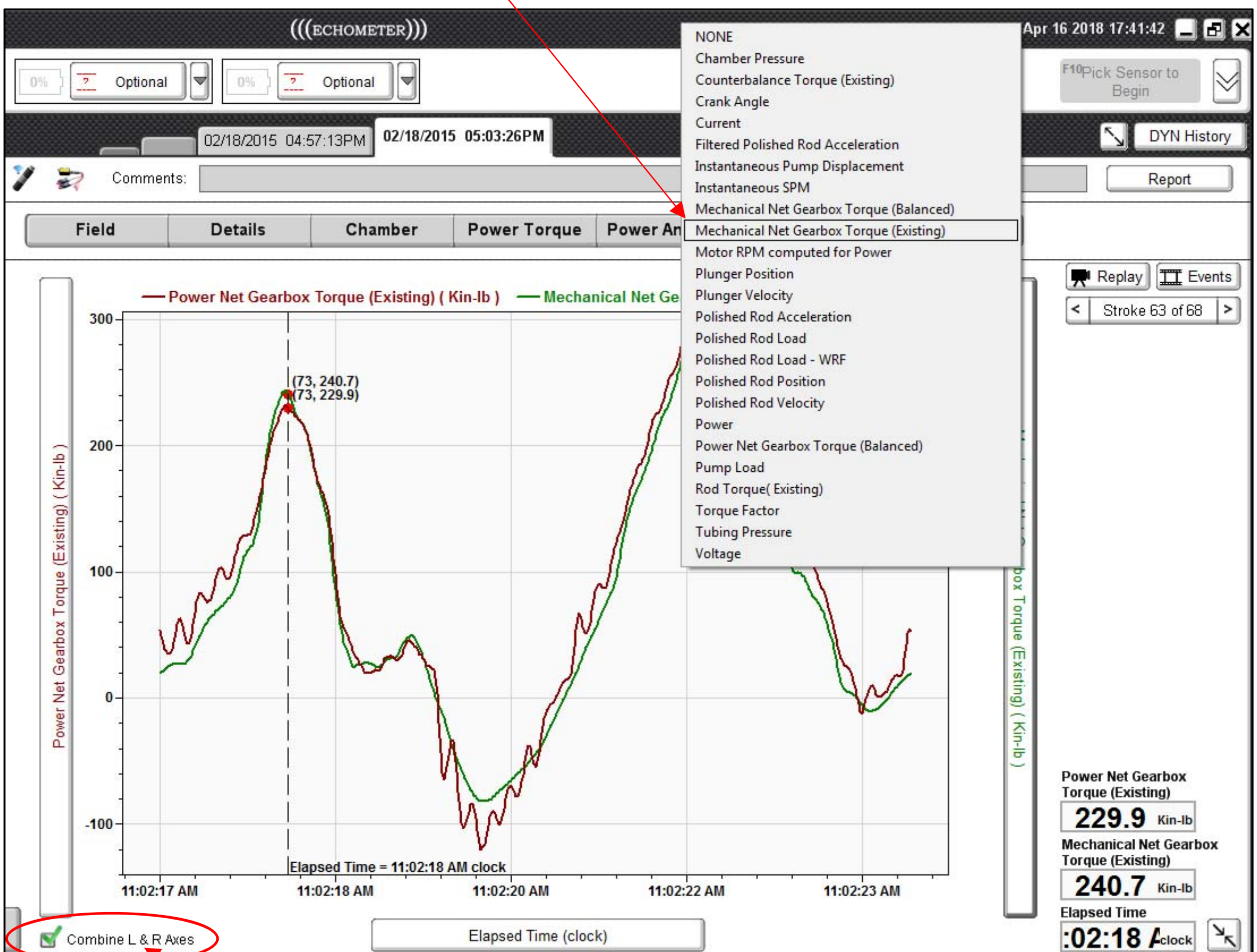


Figure 53 – Selection of vertical axes for overlay of power and mechanical torque.

The plot requires checking the "Combine L & R Axes" box at the lower left.

When all measured data and pumping system description are accurate then the two traces should have similar characteristics and values should overlay generally as shown in Figure 54. For the example the upstroke peak computed from the dynamometer indicates a torque of 240,700 inch-Lbs. while the torque computed from the measured power is 229,900 inch-Lbs. or a difference of just 4.4%.

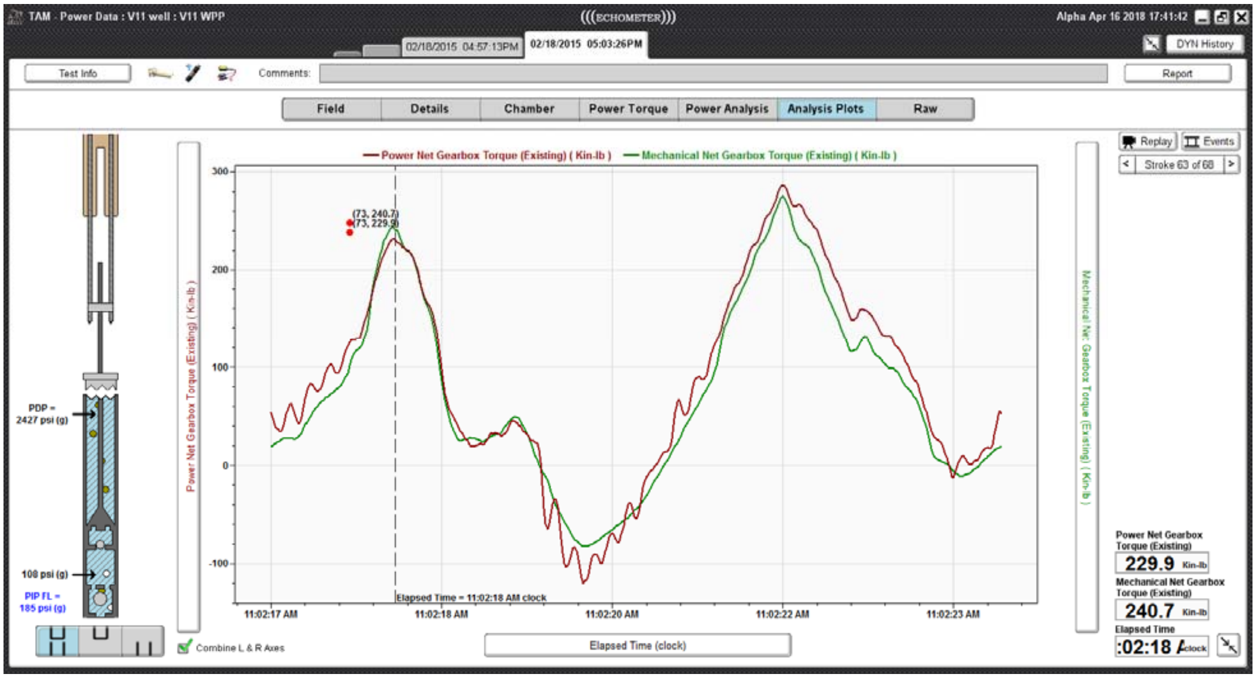


Figure 54 – Comparison of net gearbox torque computed from dynamometer and from power measurement over one stroke.

The main objective of this plot is to verify that all the data used in the calculations are accurate and in particular the following values are representative of the system being analyzed:

- Pumping Unit Selection
- Values of CBE and or CBM
- Direction of rotation of the cranks
- Efficiency of power transmission from motor to gearbox
- Speed variation during stroke
- Accuracy of Polished Rod Load and Position
- Proper installation of the power probes
- Good wireless communication or cable connection.

Problems or inaccuracies of these parameters will result in a poor overlay of the mechanical and power torque curves.

Best Method to Balance a Pumping Unit

The best method for an operator to use to balance the net peak torques on a pumping unit gearbox is to use both power and mechanical methods at the same time to determine the existing net gearbox torque. When viewing the plot of net gearbox torque from power torque overlain by the net gearbox torque from mechanical torque, it is a simple matter to visually examine the plots and look for discrepancies.