# MOTOR POWER, CURRENT AND TORQUE ANALYSIS TO IMPROVE EFFICIENCY OF BEAM PUMPS

by

Jim McCoy, Echometer Co.
A. L. Podio, University of Texas at Austin
Jim Jennings, Consultant
Bill Drake, Echometer Co.

## ABSTRACT

A power/current transducer for measuring both power and apparent current permits an operator to obtain a more complete analysis of the performance of a motor powered pumping unit system. Power and apparent current are acquired and displayed during a single stroke to aid in the analysis of pumping unit efficiency, cost of electricity, proper balance and torque. Power measurement, for induction motors, showing both consumption and generation are much easier to analyze than apparent current data from a conventional clamp-on amp meter which does not distinguish between consumption and generation.

Power transducers require the measurement of current in two legs of a 3-phase system. In addition, voltage probes must be attached to each of the three phases. The phase relationship between the current and voltage is processed electronically to obtain a voltage signal proportional to power. This signal is digitized at a rate of 20 times per second and displayed as a plot of power per single pumping unit stroke. Apparent current is also obtained and plotted for additional analysis.

The power data is easily processed to obtain gearbox torque without the need for pumping unit geometry nor polished rod loads.

Field data are given for examples of motor performance including cost of electricity with and without generation credit, an under balanced unit, an overbalanced unit, an under loaded motor and other conditions.

## INTRODUCTION

The effort to reduce lifting costs in beam pumping operations has focused the attention of production personnel to reduction of electrical power consumption [1,2,3]. A recent study[1] shows that properly operated beam pumping systems provide very good efficiencies in the order of 1.1 to 1.4 kW-hr/bbl when lifting fluid from 4300 to 6700 ft respectively. Equivalent submersible pumping systems exhibited efficiencies of the order of 1.8 to 2.5 kW-hr/bbl. This study shows that when properly designed and operated, the beam pumping systems exhibit overall efficiencies of the order of 57%, where overall efficiency was defined as the ratio of the power out of the system ( based on net depth of lift, fluid gravity and production rate) to the power into the system as measured kW-hr.

Unfortunately a large number of pumping systems are not properly designed nor properly operated to achieve such a high efficiency. One of the reasons stems from the fact that it is not customary to routinely take measurements of electrical power consumption of individual beam pumping units. The one electrical measurement that is commonly made in the oil field is motor current, using a standard clamp-on amp probe, with the objective of adjusting the unit's counterbalance. Normally current data is displayed at a rate of one reading per second and corresponds to the average of the apparent motor current over the last second or is presented on an analog meter.

The majority of operators do not have readily available means of determining the true electrical power consumption of a given beam pump and thus cannot establish whether it is operating efficiently or the motor is oversized or even if the unit is properly balanced.

The principal objective of the system described in this paper is to provide accurate means to determine the electrical performance of a beam pumping system based on acquiring power data with the Well Analyzer system[4] and a specially designed power transducer. The Well Analyzer is a PC-based data acquisition and analysis package that allows automatic measurement of annular fluid level, calculation of producing bottom hole pressure, measurement of polished rod dynamometer data and calculation of downhole pump dynamometers and includes the measurement of motor current and power.

## ELECTRIC MOTOR PERFORMANCE DURING A SUCKER-ROD PUMP CYCLE

The cyclic nature of the pumping system and the variable loading which is dependent on the mechanics and efficiency of the down-hole pump and sucker rod string, result in a continuously variable current flow over a pumping cycle. This translates in the fact that averaged values of apparent current are not indicative of the actual power usage and requirements. Moreover to reduce torque loading, counterbalancing of the rod load plus one half of the fluid load is commonly used and most installations exhibit torque reversals during the pumping cycle even if properly balanced. This means that during portions of a pump stroke the prime mover drives the gear box and that during other portions the gearbox drives the motor. In the first case the motor is using electrical power, in the second case it is generating electricity. The most common indication that this reversal in current flow is taking place is the widely observed "gearbox backlash". The clanking sound which may be noted in the gearbox at such times is due to the transfer of load from the front side to the back side of the gear teeth. The conventional clamp-on current meter (transformer) is incapable of differentiating between the current flowing from the line to the motor or from the motor to the power line. In order to determine the actual power utilization it is necessary to make additional measurements that yield information regarding the instantaneous power factor and voltage. Such measurements are not commonly made because of the complexity and cost of the additional equipment.

In electrified oil fields, most beam pumping units are powered by three-phase induction motors which exhibit performance characteristics similar to those shown in Figure 1. In this figure, three parameters are plotted as a function of the motor speed in RPM: the torque, the apparent or actual line current and the efficiency. The motor is rated at an operating point near the maximum efficiency and at such a current so as not to exceed the recommended operating temperature.

The torque produced by the motor varies from a large quantity at zero (locked rotor) and speeds below 1000 RPM then rapidly decreases to zero at the synchronous speed ( 1200 RPM).

Correspondingly the motor current is a maximum at zero speed and reduces to a minimum at the synchronous speed. This minimum current generally is of the order of 1/3 of the motor full load rated current and is defined as the magnetizing current which is used in providing the motor's rotating magnetic field plus thermal losses. At synchronous speed the motor current is lagging very near 90 degrees the voltage applied to the motor's stator windings.

The motor's efficiency is defined as the ratio of output to input power. It ranges from zero at locked rotor conditions ( power = torque * angular velocity) then increases to a maximum near motor rated speed and decreases sharply to zero at the synchronous speed.

The diagrams also indicate that if the motor is driven past the synchronous speed into the regenerative region the current and efficiency curves are nearly mirror images of the motoring curves relative to the synchronous speed. The torque is also mirrored but with the opposite sign. This indicates that torque is required to drive the motor past the synchronous speed and that the motor is essentially acting electrically as a generator and mechanically as a brake.

Applying these characteristics to the cyclical nature of the beam pumping system the following may be concluded:

- Since the polished rod load is cyclical so will be the torque on the reducer. The relationship between torque and motor current will thus result in a cyclical motor current.

- The motor's RPM will also exhibit a cyclical behavior with its speed varying in the vicinity of motor rated speed and synchronous speed, if the motor is properly sized.

- If the reducer torque becomes zero during the pumping cycle the motor will tend to run at its synchronous speed. At this condition the motor current will be minimum.

- If the unit's counterbalance and inertia are sufficient to reverse the torque on the reducer, the motor will be driven into the regenerative mode. The current will increase in proportion to the speed in excess of synchronous speed. This power is returned to the distribution system and will be used by other wells when several are operated from a common meter. (Power companies usually install ratcheted (detented) meters to prevent credit for back-driven power).

Given these relationships it becomes apparent that measurement of motor speed (assuming no slippage between the motor sheave and the V-belts) is a possible means of inferring the pumping unit torque curve over a pumping cycle. The calculation requires knowledge of the specific motor performance curves such as those shown in Figure 1. Moreover if the unit's geometry and inertia are known it is possible to convert the torque into polished-rod load and thus generate a dynamometer diagram without requiring direct measurement of the polished rod load . This method has also been applied to the design of pumping systems[5] whereby predictive dynamometer algorithms have been extended to calculate the electrical requirements of a given system.

Unfortunately the majority of operators do not have ready access to electrical motor performance curves that can be applied to the analysis of their pumping systems. On the other hand most operators are familiar with and have used motor current measurements to check the counterbalancing of the beam pumps. It thus appears that a method that allows determination of electrical power consumption, motor loading, motor efficiency, etc. from measurements of motor current would be a useful technique for controlling the cost of beam pumping operations.

Ideally such method should require only a simple clamp-on transducer around one wire only and measurements should be completed in a matter of minutes. In order to satisfy these requirements it is necessary to accept reduced accuracy. Such a system has been developed[6] and testing has shown that for the majority of cases the calculated power is within 25% of the actual power. Thus these measurements can be used as a means for monitoring that the pumping system is operating within guidelines or if not, the result will give an indication that a more detailed and accurate measurement of power is required.

## DIRECT MEASUREMENT OF MOTOR POWER

In a 3-phase 3-wire system when the motor loading is variable and time dependent, accurate measurement of power requires measurement of current flow in two of the three phases and voltage sensing in all three legs. Therefore a power sensing transducer will have to include two clamp-on current probes and three voltage sensing leads as shown in Figure 2. The current and voltage signals are combined electronically to generate signals which are proportional to the power P1 and P2. In a perfectly balanced electric system P1 is equal to P2. However in the case of variably loaded synchronous motors P1 and P2 will differ and in some cases they might be of opposite signs. The net power is the algebraic sum of the measured power quantities.

The ratio of the measured power values is the power factor as follows:

$$P.F. = 1 \text{ when } P1 = P2$$

$$P.F. = 0.5 \text{ when } P1=0 \text{ or } P2 =0$$

$$P.F. = 0 \text{ when } P1 = -P2$$

The power factor angle is given by the following relation:

$$\Theta = \text{Arc Tan} [\ 1.732(P1-P2)/(P1+P2)]$$

the power factor is of course the Cosine of the angle $\Theta$.

## POWER TRANSDUCER

The power transducer thus consists of a set of two clamp-on current probes which are interconnected. In addition the transducer has three voltage sensing leads which are connected to the three power lines. The individually measured power can be combined to produce an output signal proportional to the total power. The transducer multi-pin connector is attached to the Well Analyzer via a multi-conductor cable. This cable provides the necessary excitation voltage to the transducer's electronics and connects the transducer's output to the analog to digital converter as shown in Figure 3.

Installation of the transducer requires that the operator make the necessary connections to the terminals inside the switch box. Correct procedures include the use of insulating safety gloves (provided with the power transducer) and making sure that the main power switch and circuit breaker are open and that voltage lead connections are made only to the terminals on the motor side of the main switch. Whenever possible after making the necessary connections, the switch box door should be shut prior to closing the main switch and circuit breaker and starting the pumping unit.

As an added measure of safety, before installation of the transducers the operator should load the program POWER. Upon execution the software guides the operator through the set-up and installation procedure as well as through the data acquisition phase. Consistently accurate results can only be obtained if the correct procedures are followed and thus the program has been designed to help the operator follow the optimum sequence of steps.

As shown in Figure 3, the clamp-on probes are connected to adjacent lines. Voltage sensing leads are then attached to each of the terminals as follows: the black lead is connected to the line where there is not a clamp-on probe; each red lead is connected to the terminal where its corresponding clamp-on probe is connected. The operator should make certain that the jaws of the current probes are fully closed and attached to a reasonably straight section of wire. Although the measured values are not affected by varying the location of the probes it is recommended that they always be attached in a consistent manner, for example: the large probe connected to the middle wire, the small probe connected to the right wire and the left wire left free with only the black lead attached to its terminal. Consistency of installation will result in that measurements taken at different times will be more reliable. Also, the operator will become accustomed to follow the recommended procedure and thus will be less likely to ignore safety rules.

Data acquisition is approximately synchronized with the pumping cycle by starting the digitizer when the counterbalance weights are at the top and vertically in line with the crank shaft. For this position the polished rod is approximately at the bottom of the stroke. This requirement compensates for variations in the geometry of the crank and insures that the starting point of the data is always near the point where the counterbalance effect is zero. This allows calculation of the effect of changes in counterbalance position on the torque curve with a minimum of assumptions. Data is acquired for two complete strokes of the pumping unit in order to calculate the pumping speed and to insure that the unit is operating at steady state. Figure 4 is shown to the operator during acquisition as a check of the quality of the data. Should the apparent current and power waveforms seem different in each of the two strokes, the data should be discarded and re-acquired. The pumping speed is computed by determining the elapsed time between the maximum power peaks in the two successive strokes and converting it to SPM. This quantity is used in the calculation of the torque from the measured power as described in the next section.

The software digitizes the signals at a rate of 20 per second and processes the values to generate graphic displays of the power and apparent current per pumping cycle. Figure 5 shows the display for a typical conventional pumping unit.

In this, and all subsequent figures, the solid curve represents the power while the dotted line represents the apparent current. Note that for this well, the power becomes negative (generative) at the top of the stroke. The cost of electricity is displayed with and without credit for generation. If several wells are operated from the same meter, generated electricity will be utilized by other pumping wells. Generally, if only one well is present on a meter, no generation credit exists. Also displayed is the power cost per barrel of oil and the cost per barrel of total liquid pumped.

Most motors have a full load amp rating. This number is obtained from the name plate and displayed. The RMS or Thermal value of the acquired apparent current is calculated to allow comparison of the actual loading to nameplate thermal rating. The nameplate horsepower rating is given along with the approximate input horsepower. Input horsepower is determined utilizing the power signal not including credit for generation. The approximate output horsepower is assumed to be 85% of the input horsepower.

The recommended minimum motor horsepower is calculated using a design cyclic load factor (CLF) of 1.375 for NEMA "D" electric motors and conventional beam pumps. For other configurations the user should refer to accepted rules of thumb.[7]

In general, a NEMA C motor and multi cylinder engines will require about 38% more horsepower rating. For NEMA D motors and slow speed engines used with uniform torque units (Mark II ) the motor rating can be reduced by 20%. For NEMA C electric motors and multi cylinder engines used with uniform torque units, the minimum rating should be increased by 15%.

The average KVA is calculated by multiplying the well file voltage by the average of the apparent current and dividing by 1000. The average kW is calculated by integrating the measured power over one pump cycle and dividing the area by the time per stroke. The average power factor is calculated by dividing kW by KVA.

## TORQUE CALCULATION

In beam pump analysis, the torque calculation is generally undertaken by converting the force measured at the polished rod using a dynamometer to the torque at the gear reducer. Such calculation requires as a minimum a detailed knowledge of the pumping unit geometry. In order for this calculation to yield values which are sufficiently accurate it is imperative that the dynamic torque be calculated including the effects of the inertia of all the rotating and articulating masses of the system. Such calculation has been made practical only with the advent of computers. Still it requires that accurate values of all the moments of inertia of each element be known. Experience has shown that in a large number of cases this information is not available or is inaccurate due to erroneous identification of the specific unit and its geometry.

On the other hand, direct measurement of electrical power at the motor as a function of time during a pump stroke allows a very simple and accurate calculation of the torque that the gear reducer sustains. This calculation does not require knowledge of the unit's geometric characteristics as will be shown in the following section. Power measurement corresponds to measurement of the resultant torque which is the combination of the load transmitted from the polished rod acting on the crank arm, with the torque generated by the counterbalance and including the dynamic torque due to the inertia effects.

Figure 6 shows a schematic diagram of the power transmission system commonly used in a conventional beam pumping system. Electrical power is converted to power at the polished rod by driving the gear reducer through a V-belt transmission. Assuming that conversion of electrical power to mechanical power is undertaken with an efficiency Effm then:

$$HP = ( KW * Effm) / 0.746 \quad (1)$$

where HP is the horsepower delivered by the motor to the belt drive. This is also expressed as:

$$HP = (F \times RPM \times SDm \times \Pi)/ 33000 \quad (2)$$

where:

F is the tangential force transmitted by the belt ( lb.)
RPM is the rotary speed of the motor (rpm)
SDm is the motor's sheave diameter (ft)

Equating (1) and (2) and solving for F yields:

$$F = (KW*Effm*33000)/(0.746*RPM*SDm*\Pi) \quad (3)$$

The torque into the gear reducer is equal to:

$$Tin = F * SDgb/2 \quad (4)$$

where:

Tin is the torque applied to the gear reducer, ft-lb.
SDgb is the diameter of the gearbox's sheave, ft

The torque output from the gearbox is given by:

$$Tc = Tin * GBR* Effgb \quad (5)$$

where:

Tc is the torque at the crank, ft-lb.
GBR is the speed reduction ratio of the gearbox
Effgb is the efficiency of the gearbox.

Combining equations 3, 4 and 5 yields:

$$Tc = (KW*Effm*33000*SDgb*GBR*Effgb)/(0.746*RPM*SDm*\Pi*2) \quad (6)$$

Also the crank speed can be expressed as:

$$SPM = (RPM*SDm)/(SDgb*GBR) \quad (7)$$

Which when substituted in (6) and converted to in-lb. yields:

$$Tc = ( 84484 * KW*Eff)/SPM \qquad (8)$$

where Eff is an overall efficiency of the power transmission system from electrical input to the motor to the gear reducer crank. Note that equation (8) could have been derived directly from the basic definition of Power = Torque * (Angular Velocity). However the above derivation was used to demonstrate that geometric parameters cancel out and that one only needs to measure the electrical power and the pumping speed. The only unknown is the efficiency of power conversion which for practical purposes can be estimated to be close to 73% including motor, belt drive and gearbox efficiency at peak loading.

Equation (8) is thus used to convert the electrical power measured as a function of time ( 20 per second) during the two strokes of the pump, to the torque developed at the gear reducer. The pumping speed is computed by the software and is considered to be constant although in reality it varies from 5 to 10% in the vicinity of the average. This variation corresponds to the speed variation of the motor in the vicinity of the synchronous speed due to the change in torque from positive ( motor driving the gear reducer) to negative (counterweights driving the motor into generation). Note that this reversal of torque implies that the overall efficiency Eff is less than unity when the torque is positive and it is greater than unity when the torque is negative since the generated electrical power is less than the mechanical power input at the crank. Thus the torque on the gearbox can easily be obtained from simple power measurement of less than one minute and strokes per minute.

## RESULTS FROM FIELD MEASUREMENTS

Although field application of the power measurement system has been undertaken for a variety of field conditions, testing has not been as extensive as one might wish. Nevertheless it has become apparent that the system is easily installed, data is acquired in a matter of minutes and the software provides adequate information to be able to immediately analyze the performance of the beam pump and to make a decision as to whether any remedial action is necessary to improve its efficiency.

In all the wells tested to date, power generation during the pumping stroke has always been present and was most commonly observed at or near the top of the stroke. Very often, two periods of generation are observed, the second, of smaller magnitude, near the bottom of the stroke. Careful observation of the operation of the beam pump will show that these generation periods are evidenced by gear slapping and changes in the slack of the belt drive. These correlate very well with the measured reversal in power and torque.

The following are some of the typical measurements that have been observed.

### Normally Loaded and Balanced Unit (Well 42)

Figure 4 shows two strokes of data for a C-912 beam pump operating at 9.8 SPM producing about 670 barrels of liquid per day. Dynamometer data (from a pump-off controller) indicates a normal full pump card. Note that the two cycles of data are very similar indicating that the unit is operating at steady state. The unit is balanced according to recommended standard so that the power peaks on the upstroke and down stroke are approximately equal. The peak torque on the upstroke is measured at 742000 in-LB, which is within the rated capacity of the gear reducer. Figure 5 shows the corresponding operating cost and motor loading analysis. Assuming generation credit the operating cost is of the order of $ 0.04 per barrel of fluid ( at $0.03 per kW-hr this corresponds to 1.29 kW-hr per barrel which is within the reported[1] efficiency for this type of operation). Input power to the motor is computed as 53.4 HP and considering a cyclic load factor of 1.35 the rating of the motor ( 75 HP) appears to be adequate.

**Fully Loaded Gear Reducer with Under Loaded Motor ( Well 79 )**

Figure 7 shows the power data for a C-640 unit operating at 8.6 strokes per minute and lifting about 340 barrels of fluid per day. The two strokes indicate steady state conditions which is also supported by the dynamometer card. The unit is balanced and shows a small amount of generation at the top and the bottom of the stroke. The measured peak torque of 597000 in-lb. occurs during the down stroke and is close to the gear rating.

Figure 8 shows that the operating cost of $ 0.05 per barrel of liquid ( 1.61 kW-hr/Bbl ) is slightly greater than the previous example. Given the input power of 32.5 HP, it appears that the motor rating of 75 HP is probably in excess of the required size.

**Lightly Loaded Motor (Well 112)**

Measurements have indicated that there is a tendency to install motors which are considerably over sized in relation to the operating load. This is probably due to the need to satisfy starting torque requirements and the thought that an oversized motor will have a tendency to require less maintenance and exhibit a longer mean-time-between-failures. However, an oversized motor is less efficient as far as energy consumption and a less expensive, more efficient properly sized (smaller) motor should be used.

Figure 9 shows an example of a lightly loaded motor. This well is pumped with a C320 unit at 7.9 SPM and producing 180 Bbl of fluid per day. The unit is loaded below the gear box rating and appears to be slightly under balanced since the peak torque of 289000 in-lb. occurs on the upstroke. Figure 10 shows that the operating cost is $ 0.05 per barrel of liquid and that the motor input power of 15.8 HP does not justify the motor rating of 50 HP.

**Pumping-off Well (Well 60)**

The previous examples were taken from installations that were operated with pump off controllers. As such the normal operating mode corresponds to pumping full strokes. Figure 11 shows an example of a well with characteristic fluid pound as indicated by the sharp rise in torque at the mid point of the down stroke. This well is equipped with a high slip motor ( Econopac 5KY ) and is operated at 7.4 strokes per minute, producing an average of 80 Bbl of liquid per day. The maximum torque on the upstroke of 507000 in-lb. is within the rating of the 640 gearbox. Figure 12 shows the cost and power utilization at the pumped off condition.

## CONCLUSIONS

A transducer has been developed that allows accurate measurement of time dependent power during a single stroke of a beam pumping unit from simultaneous measurement of voltages and electrical currents at the switch box.

The data is processed and analyzed by the software and a graphic display is presented that yields the apparent current, the power and the torque as a function of crank angle or polished rod position.

Abnormal conditions can more easily be identified using the processed data. Motor loading and unit balancing can be analyzed more accurately by having a display of the apparent current, motor power and torque.

Balancing of the pumping system can be done more accurately and more easily by directly observing the torque curve instead of using the apparent current peak values as indicators of proper balance.

A general rule of thumb seems to be supported from results to date: the prime mover is under loaded unless the ratio of the maximum to the minimum apparent current exceeds a value of 2 over a pumping cycle. The maximum apparent current peak should exceed the nameplate current rating of the motor at least by 20% in order to obtain a reasonable efficiency.

Torque can be obtained quickly and easily using the power transducer without the need of pumping unit geometry and counterbalance data nor polished rod load and position measurements.

These results also indicate that if the principal objective of the measurement is to obtain accurate values of power consumption (comparable to continuous metering over time) this computer-based system should be used in a power-measurement configuration requiring simultaneous measurement of voltage and current measurement in two of the three legs. Although this configuration requires that the operator connect voltage leads to the terminal inside the switch box and thus is potentially dangerous, proper training in the correct procedure and the use of safety equipment should eliminate the risk and allow routine measurement of accurate power usage.

## ACKNOWLEDGMENTS

The authors wish to express their appreciation to the many operating companies that have willingly provided the opportunity to undertake these measurements on a variety of pumping wells.

## REFERENCES

1 - Lea, J. F. and J. D. Minissale: " Beam Pumps Surpass ESP Efficiency", Oil and Gas Journal, May 18, 1992

2 - Butlin, D. M.:"A Comparison of Beam and Submersible Pumps in Small Cased Wells" SPE Preprint 21692, Production Operations Symposium, April 7-9, 1992, Oklahoma City , OK.

3 - Kilgore, J. J. and H. A. Tripp: "Walking Beam Pumping Unit System Efficiency Measurements", SPE Preprint 22788, Annual Technical Conference and Exhibition, October 6-9, 1991, Dallas, TX.

4 - Podio, A. L, McCoy, J. N. and D. Becker: "Integrated Well Performance and Analysis", SPE Computer Applications, June 1992.

5 - Gibbs, S. G.: "Utility of Motor-Speed Measurements in Pumping Well Analysis and Control", SPE Production Engineering, August 1987.

6- McCoy et al.: "Simplified Computer-Aided Analysis of Electrical Current in Motors Used for Beam Pumping Systems", SPE Paper 25447, Presented at the SPE Production Operations Symposium, March 21-23, 1993, Oklahoma City, OK.

7- Brown, K. E.: The Technology of Artificial Lift Systems, Volume 2a, pp. 44-45, Petroleum Publishing Co. 1980.

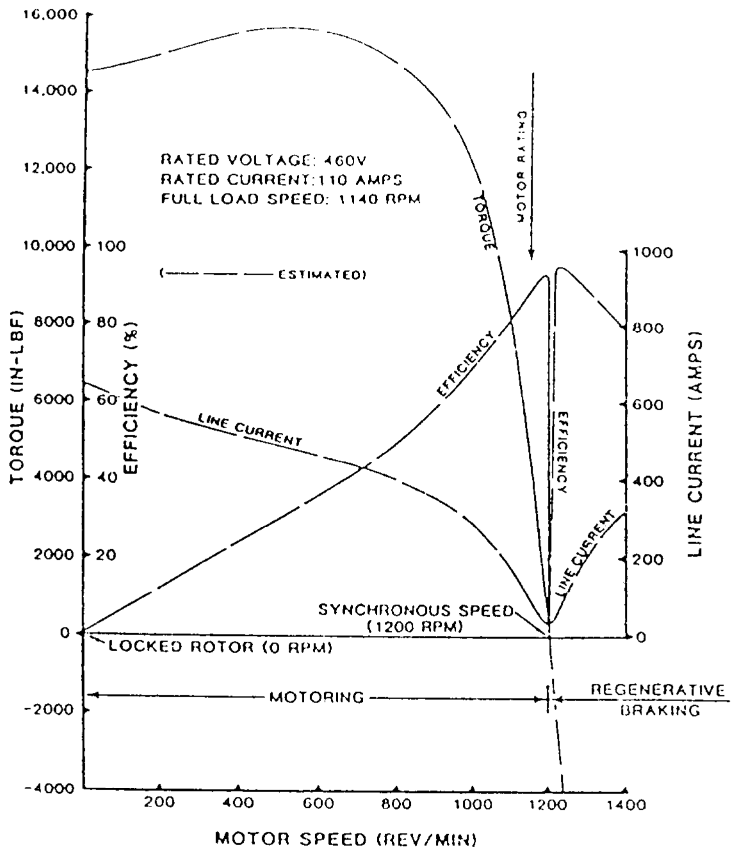



**Figure 1 - Performance curves for 100 HP NEMA-D motor**

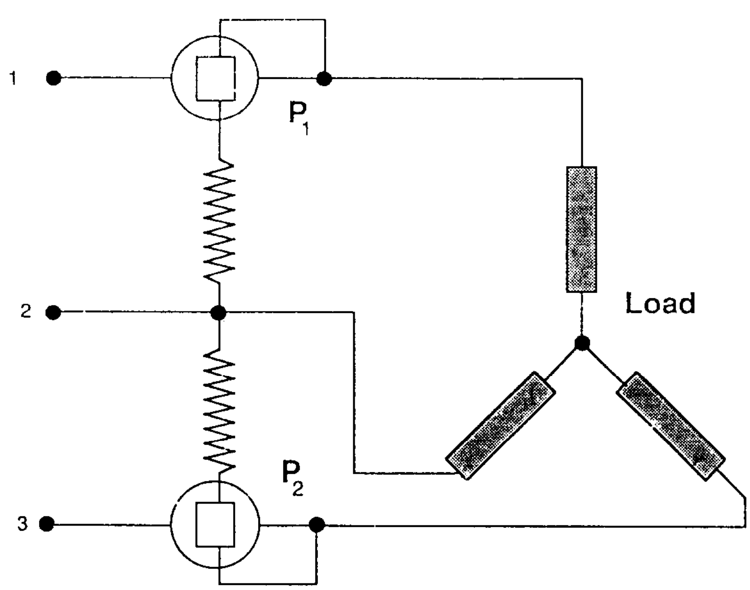



**Figure 2 - Power measurement in a three-phase three-wire system**

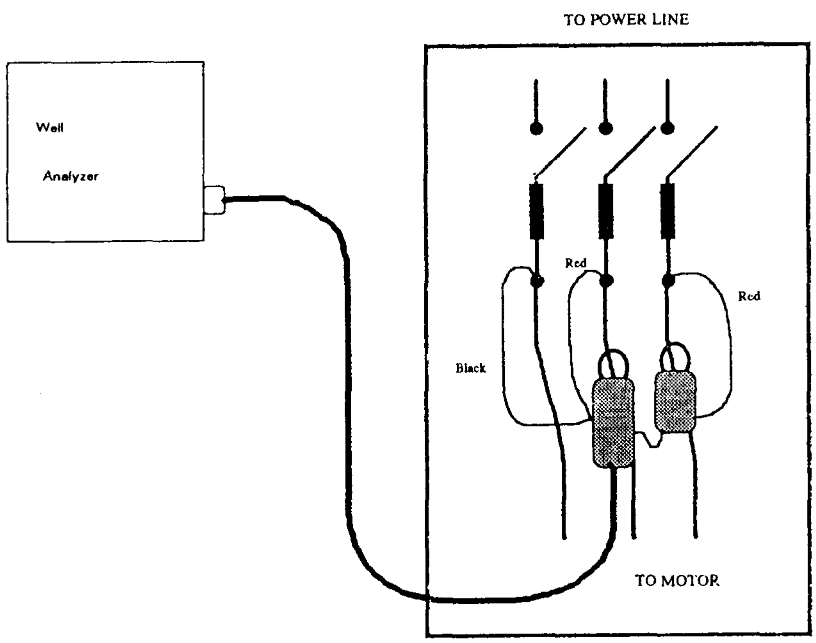



Figure 3 - Method of installation of the power transducer inside the switch box

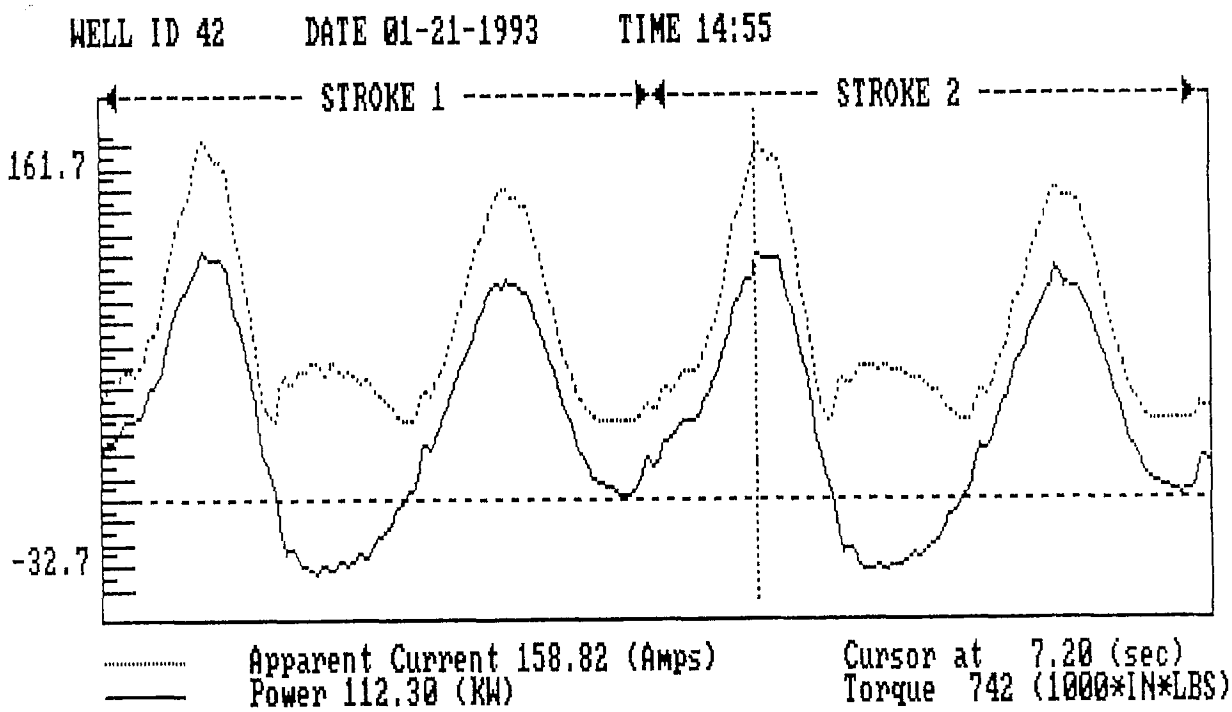
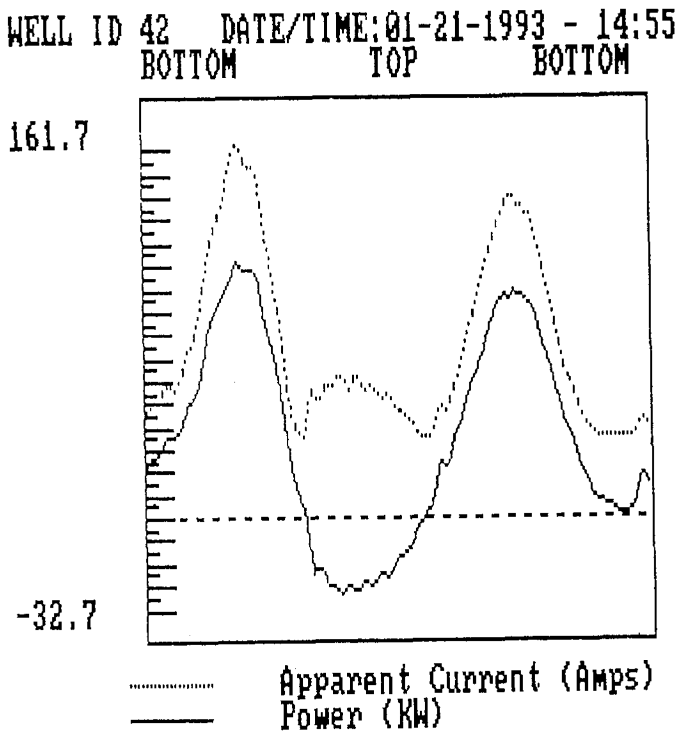



Figure 4 - Display of power and current after acquisition over two strokes of the pumping unit




| | |
|---|---|
| **POWER/CURRENT ANALYSIS** | |
| ---- COST PER MONTH ---- | |
| WITH GENERATION CREDIT. | $ 772 |
| NO GENERATION CREDIT... | $ 889 |
| COST PER BBL OF OIL.... | 156¢ |
| COST PER BBL OF LIQUID. | 4¢ |
| NAMEPLATE FL AMP RATING. | 99 |
| THERMAL AMPS............ | 85 |
| CLF..................... | 1.119 |
| RECOMMENDED MIN HP.(D).. | 73.4 |
| NAMEPLATE HP RATING..... | 75.0 |
| INPUT HP................ | 53.4 |
| APPROXIMATE OUTPUT HP... | 43.8 |
| AVERAGE KVA............. | 57.7 |
| AVERAGE KW | |
| WITH GENERATION CREDIT. | 34.6 |
| NO GENERATION CREDIT... | 39.8 |
| AVERAGE POWER FACTOR... | 43% |
| STROKES PER MIN........ | 9.8 |
| BOPD................... | 19 |
| BWPD................... | 651 |

Figure 5 - Analysis of power, motor loading and electrical costs

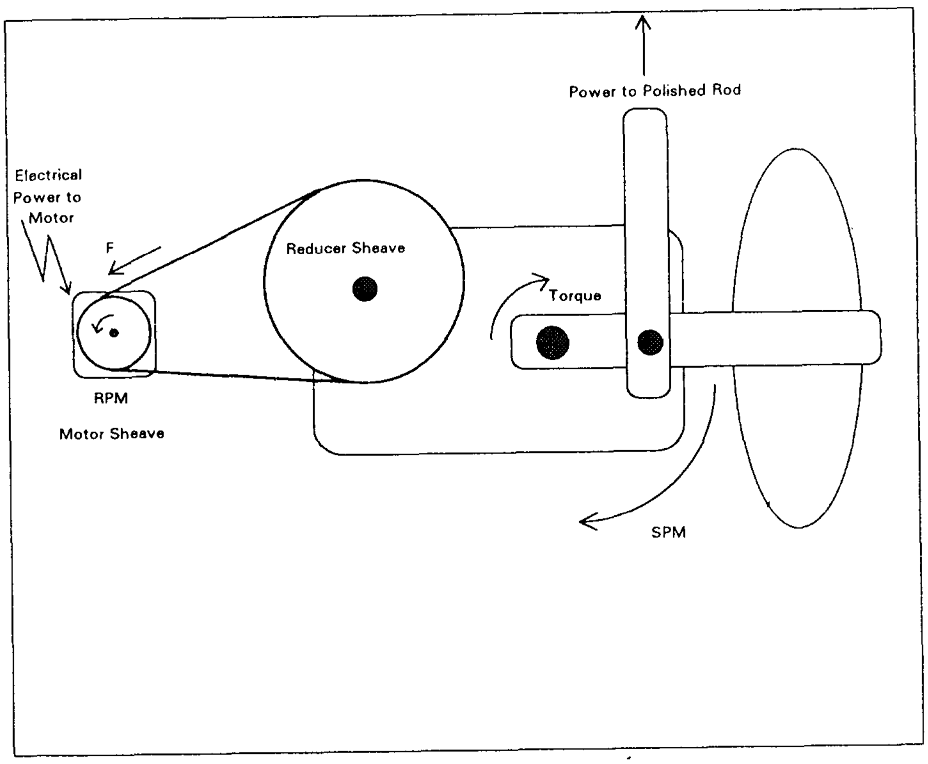



Figure 6 - Schematic of power transmission system from motor to polished rod

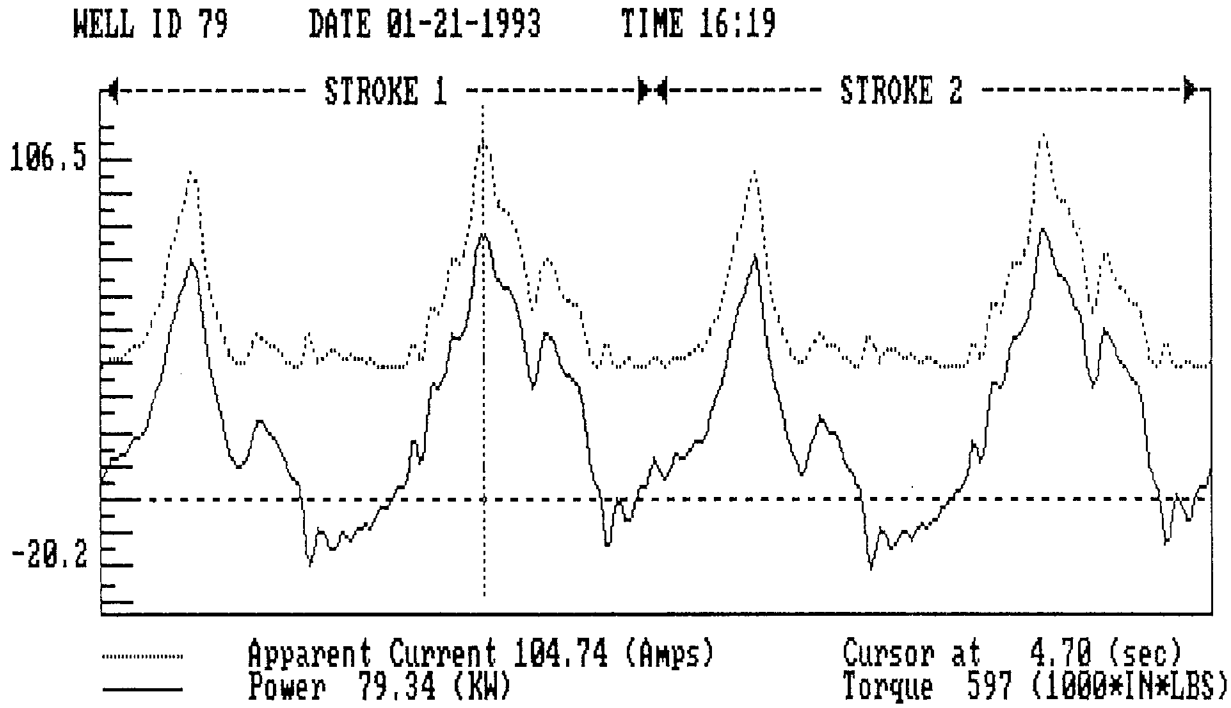
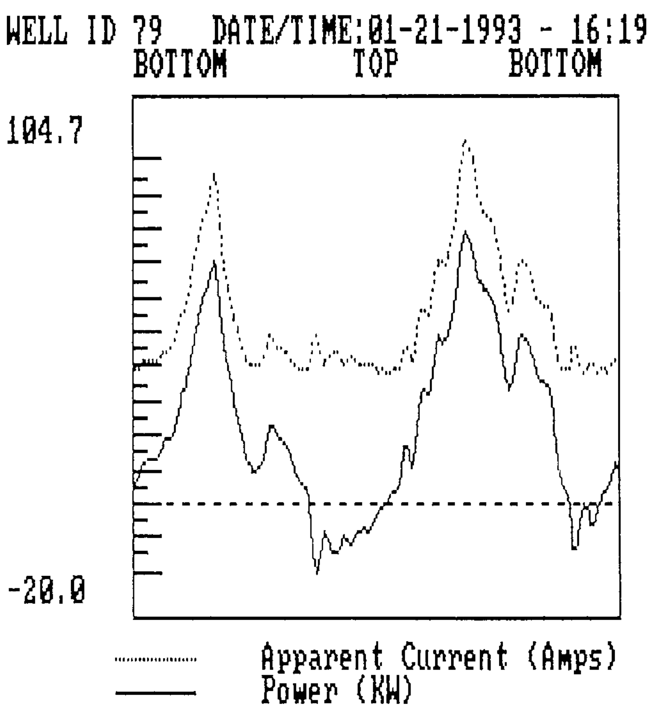



Figure 7 - Power and current data for a C-640 beam pump




POWER/CURRENT ANALYSIS

---- COST PER MONTH ----

| | |
|---|---|
| WITH GENERATION CREDIT. | $ 500 |
| NO GENERATION CREDIT... | $ 542 |
| COST PER BBL OF OIL.... | 201¢ |
| COST PER BBL OF LIQUID. | 5¢ |
| NAMEPLATE FL AMP RATING. | 93 |
| THERMAL AMPS........... | 57 |
| CLF.................... | 1.052 |
| RECOMMENDED MIN HP.(D).. | 44.7 |
| NAMEPLATE HP RATING..... | 75.0 |
| INPUT HP............... | 32.5 |
| APPROXIMATE OUTPUT HP... | 26.7 |
| AVERAGE KVA............ | 41.3 |
| AVERAGE KW | |
| WITH GENERATION CREDIT. | 22.4 |
| NO GENERATION CREDIT... | 24.3 |
| AVERAGE POWER FACTOR... | 43% |
| STROKES PER MIN........ | 8.6 |
| BOPD................... | 9 |
| BWPD................... | 333 |

Figure 8 - Motor loading and electrical cost analysis for a C-640 beam pump

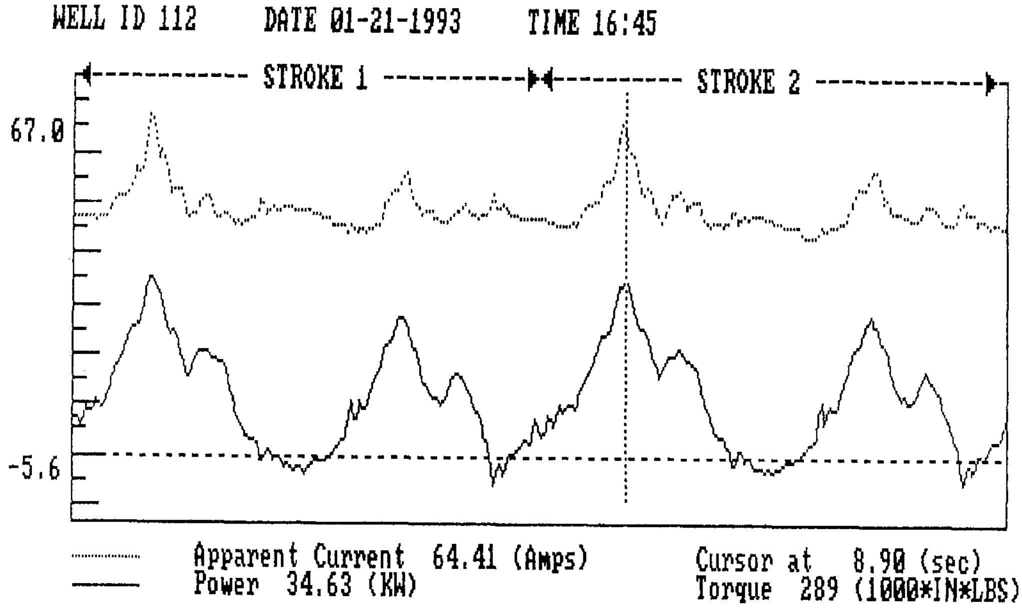
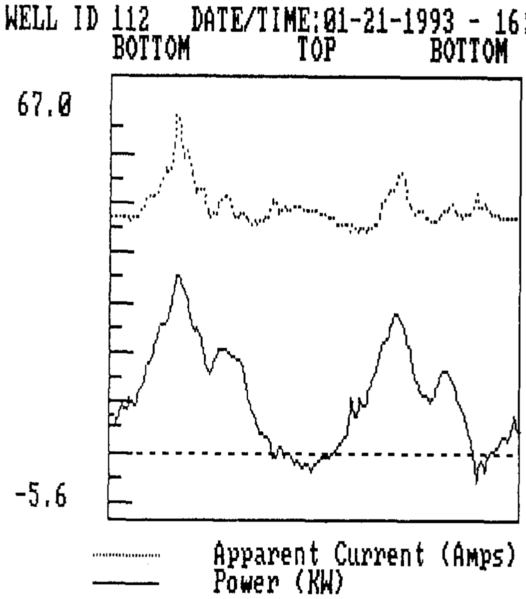



Figure 9 - Power and current data for a C-320 beam pump




POWER/CURRENT ANALYSIS

---- COST PER MONTH ----

| | |
|---|---|
| WITH GENERATION CREDIT. | $ 255 |
| NO GENERATION CREDIT... | $ 263 |
| COST PER BBL OF OIL.... | 219¢ |
| COST PER BBL OF LIQUID. | 5¢ |
| NAMEPLATE FL AMP RATING. | 71 |
| THERMAL AMPS............ | 49 |
| CLF..................... | 1.003 |
| RECOMMENDED MIN HP.(D).. | 21.7 |
| NAMEPLATE HP RATING..... | 50.0 |
| INPUT HP................ | 15.8 |
| APPROXIMATE OUTPUT HP... | 12.9 |
| AVERAGE KVA............. | 37.5 |
| AVERAGE KW | |
| WITH GENERATION CREDIT. | 11.4 |
| NO GENERATION CREDIT... | 11.8 |
| AVERAGE POWER FACTOR... | 29% |
| STROKES PER MIN........ | 7.8 |
| BOPD................... | 4 |
| BWPD................... | 175 |

Figure 10 - Motor loading and electrical cost for a C-320 beam pump

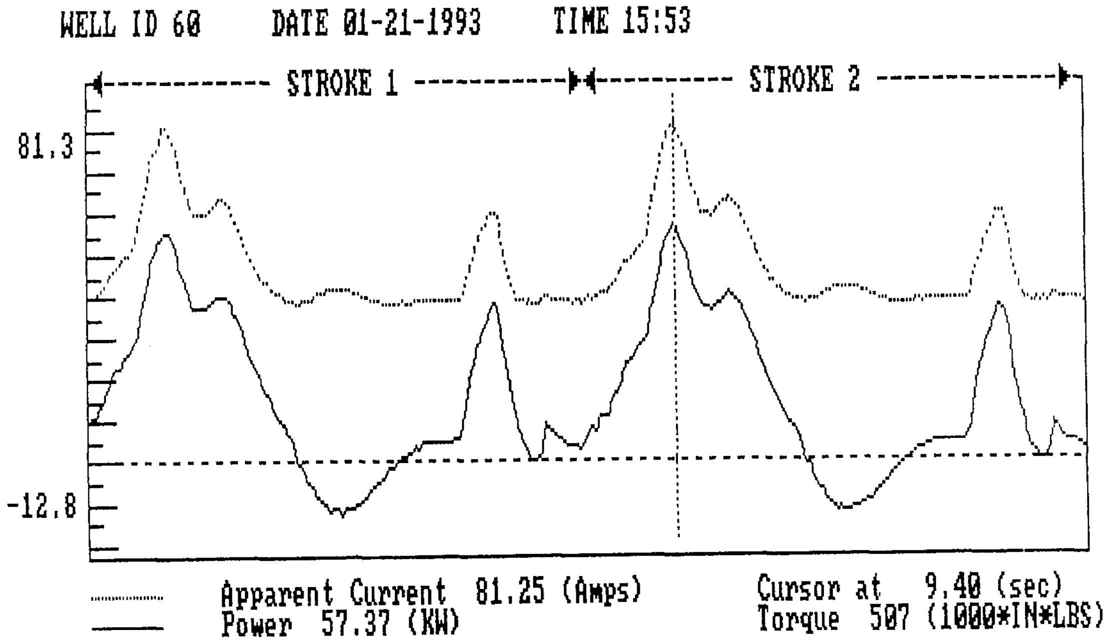
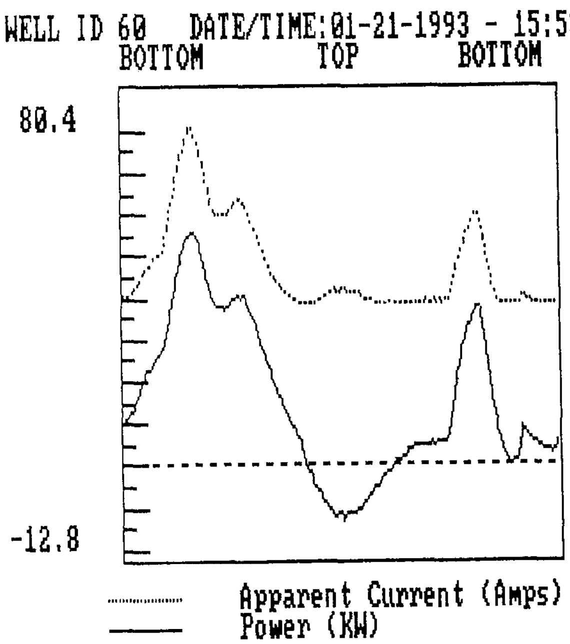



Figure 11 - Power and current data for a C-640 beam pump, driven by a high slip motor




POWER/CURRENT ANALYSIS

---- COST PER MONTH ----

| | |
|---|---|
| WITH GENERATION CREDIT. | $ 339 |
| NO GENERATION CREDIT... | $ 372 |
| COST PER BBL OF OIL.... | 88¢ |
| COST PER BBL OF LIQUID. | 15¢ |
| NAMEPLATE FL AMP RATING. | 80 |
| THERMAL AMPS............ | 49 |
| CLF..................... | 1.028 |
| RECOMMENDED MIN HP.(D).. | 30.7 |
| NAMEPLATE HP RATING..... | 0.0 |
| INPUT HP................ | 22.3 |
| APPROXIMATE OUTPUT HP... | 18.3 |
| AVERAGE KVA............. | 36.2 |
| AVERAGE KW | |
| WITH GENERATION CREDIT. | 15.2 |
| NO GENERATION CREDIT... | 16.6 |
| AVERAGE POWER FACTOR... | 34% |
| STROKES PER MIN........ | 7.4 |
| BOPD.................... | 14 |
| BWPD.................... | 68 |

Figure 12 - Motor loading and electrical power cost for a C-640 beam pump, driven by a high slip motor