TRUE INTELLIGENCE AT THE WELLSITE

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ABSTRACT
Although the expression only used today, many times it seems the may not be g well operations. This paper will review the features and benefits of a built-in Flux Vector Drive for Beam Pumping. The Flux Vector Technology incorporated in this controller is different from an off-the-shelf Variable Frequency Drives in that it is designed and built for Oil Field Applications and includes application specific software and firmware, which provides the operator with a unique tool that brings a new meaning to te Intelligence.

This to control the speed of the pumping unit in each direction of every stroke – in order to meet a pre-described pump fill target. The drive also controls rod-force, by slowing or stopping the unit when a predetermined minimum or maximum rod stress is reached. **A** bridle separation limiter prevents rod float by automatically adjusting the down stroke speed. The gearbox ratio calculator automatically computes the overall ratio between the motor and crankshaft throughout each pump stroke. These features, along with many others included in this Flux Vector Drive, will be reviewed in this paper and case histories will detail actual benefits to the operator.

INTRODUCTION

The focus of this paper is on Flux Vector Drives installed in beam pumping applications. For a number of years, companies have worked to produce a variable speed drive that could optimize a beam-pumping unit by controlling the speed of the motor. While several companies focused on this type of Variable Speed Drive controller, their efforts did not produce a reliable product that could bring intelligence to the well site under varying conditions. Recently, a motor control drive has been introduced to the market, which utilizes a new technology called flux vector control that delivers its control based on torque, rather than speed. Before expanding on the flux vector drive, this paper will examine the need to control a beam pumping well and review some of the history of these optimization efforts.

PUMPING UNIT CONTROL HISTORY

In a typical reciprocating rod pumped well, the two cycles of the positive displacement pump are referred to as the up-stroke and down-stroke. During the up-stroke, the plunger and then closed traveling valve are lifted with the rod string by the pumping unit on the surface. During this part of the stroke, the fluid above the plunger is forced into the tubing and lifted towards the surface. The standing valve is opened, which allows well bore fluids to enter the barrel tube, or compression chamber. As the system begins the down-stroke, the standing valve closes, trapping fluid between the standing and traveling valves. At some point in the down-stroke, the pressure between these valves will build to a point that is greater than the fluid load in the tubing, which is holding the traveling valve ball on the seat. When sufficient pressure is built in the compression chamber, the traveling valve is opened and the compressed fluid is displaced through the plunger into the tubing.

Many oil wells are operated so that the fluid level in the well bore is drawn down to the rod pump, to relieve back pressure off the formation and allow more fluid to enter the well bore. As a result, the rod pump can out run the well's ability to give up fluid, which results in fluid pound. This common problem results when the compression chamber does not completely fill up with fluid on the up-stroke. During the next down-stroke, the plunger and closed traveling valve only meet the resistance of foam or gas, which is in the upper portion of the compression chamber. Once the traveling valve runs into the fluid, it usually results in a pounding effect, which creates a shockwave that may be felt at the surface. Any man-made equipment in the wellbore or connected to the wellhead can experience premature failure due to this pounding. The rod pump, sucker rods, tubing, tubing anchor, and gearbox are among the most expensive items that can experience a catastrophic failure due to fluid pound. Over the years, to avoid the costly results of pounding fluid, many ideas and modifications were applied to the downhole configuration and many surface control devices were created.
As automation began to gain popularity in the oilfield, controlling pumping units through time clocks, with reduced fluid pound as one of the goals, was the status quo. The lease operator would be responsible for the analysis (educated guess), which would determine how long a pumping unit should run before shutting down and then how long it would stay down before returning to operation. These units were required to s the line each time the time clock timed out, which could

create a high demand on the electrical system and components. While this "low-tech" system was capable of improving a wells performance, it was not a very reliable way to optimize the system.

Eventually the Pump Off Controller (POC) was introduced, which had the ability to shut down a well based on certain predetermined conditions. The POC was measuring the load on the polish rod, throughout the pumping cycle and plotting it onto a dynamometer (dyno) card. This dyno card was then used to define the "undesirable conditions" that would shut the pumping unit down. The actual numbers used to create a dyno card are produced by external devices, which measure the load and position of the polish rod, during the pumping cycle. These devices are located on different parts of the surface equipment and are attached to the POC via electronic cables. Many users have been incorporating Variable Frequency Drives to control the speed of their rod pumped wells, but the speed decision was totally dependent on the operator's best guess after reviewing the POC’s parameters. This method has merit, but well conditions change frequently. The operator would set the speed controller and shut off parameters only to find the well conditions had changed and again human intervention would be required.

With the advent of smaller, more powerful computers, the POC evolved into a Rod Pump Controller (RPC), which was capable of gathering data from other external devices. This data could be brought in as an analog input and combined with the load and position information that the RPC was collecting. We had entered an era where a computer was hired to sit on a location and keep a watch for things like fluid pound, gas locking, and excessive vibration on the pumping unit. The RPC allowed the lease operator to leave some of his intelligence at the wellhead, so that his experience could be used to control the well - even when he was not physically there.

As time pasted, someone decided that if one computer at the wellhead could make such dramatic improvements in efficiency and at the same time, provide a reduction in failures, then two computers should be better. Thus, the host system arrived. This Surveillance Control and Data Acquisition (SCADA) monitoring software communicated with the RPC every day to retrieve certain data about the pumping system. Included in this data were alarms, calculated production, calculated equipment loads, status of wells, and the ability to remotely control any well in the system. Real-time data could also be retrieved at any time, so that a well analyst could remotely access a system and see exactly what was going on with a particular well. Now the lease operator's intelligence (programmed into the RPC at the well) and the well analyst's intelligence (defining specific conditions for alarms and providing remote analysis using software in the host) are combined to insure a well is really optimized. At this time, the industry turned the comer on optimization through automation - or so it was thought.

What the previously mentioned systems could not do was change the speed of a pumping unit to match the inflow of a well. They could control how long the unit ran and how much time it was idle before it started, but they did not truly optimize the surface equipment - on every stroke. With the introduction of Flux Vector Drive into rod pumping applications, the opportunity came to control the speed of the pumping unit on every stroke with wellsite intelligence. The Flux Vector Drive's computer, which is located next to the pumping unit, is able to perform calculations on every stroke and then determine how fast the unit should run on the next stroke. Beyond doing the calculations and controlling the speed of the unit on each stroke, the unit can independently control the speed on both the up-stroke and the down-stroke - even if it means two different speeds. The Flux Vector Drive slows a unit down until a predetermined pump fill target is achieved, then ramps up the speed until the pump fill slips below another defined point. With this ability, the rod pump has a say in the speed of the unit. If it is filling to an acceptable level, speed the unit up. When the Flux Vector Drive begins to sense fluid pound during the down-stroke, the pumping unit slows down until the target fill is reached again. This is wellsite intelligence.

The next section of this paper will explain how the Flux Vector Drive is capable of controlling the well as described above.

WHAT IS A VARIABLE FREQUENCY DRIVE?

When variable frequency drives were first introduced they were designed to control the voltage to an AC motor. The idea was to provide a voltage to the motor that is proportional to its speed, hence, volts-per-hertz control. The assumption was to let the motor speed/torque curve take care of the load. This is accomplished when the motor naturally slows down (slips) due to the load. Under this condition the motor is actually running slower than the drive is commanding. Some volts-per-hertz drives provided a means to increase the commanded speed (frequency) to obtain the requested speed (slip compensation). They also provided a voltage boost that increased the voltage (volts-per-hertz ratio) to the motor for applications that were difficult to start. The idea was to provide voltage above the motor's terminal voltage and then use this additional voltage to provide additional current to the motor. The motor used current to provide torque. **A** current regulator may have been provided to limit the current output so the motor is not over loaded. The voltage supplied to the motor may also vary according to the AC input voltage. The major disadvantage of a volts-per-hertz drive is that it does not control the torque of the motor.

A Flux Vector Drive is designed to control the torque of the AC motor, by controlling the current supplied to the AC motor. An AC motor's current is composed of two components, a magnetizing current and a torque producing current. The magnitude and phase angle of these components determines the amount of torque produced. The job of the Flux Vector Drive is to manage these two components to obtain the optimum control. This is done by first maintaining the ideal magnitude of the magnetizing current. When operating below the base or rated speed of the motor, this magnitude is constant. When operating above the base speed, this magnitude should decrease inversely proportional to the motor speed. The magnitude of the torque-producing component is determined by a closed velocity loop. The job of the closed velocity loop is to generate an error signal in response to the motor's speed variation from the ideal or commanded speed. As a load is applied to the motor there is a natural tendency to slow down. To overcome this, more torque is required at the motor shaft. The closed velocity loop provides the signal to the Flux Vector control that indicates more torque is required. The phase angle or slip between the magnetizing and torque producing current is determined by the motor speed and required torque. With this information (required torque, required magnetizing current, and motor speed) the Flux Vector control then computes the required motor current. A closed current loop is then used to insure that this current is achieved.

The advantage of the Flux Vector Drive is that: (1) it produces only the torque required for the application regardless of the AC line voltage variation, (2) actual motor speed is derived, (3) actual motor torque is derived, and (3) limits can be placed upon the torque based upon mechanical constraints of the mechanism being driven. In the case of a rod pumping system limits on rod load or gearbox load can be accurately maintained.

To improve performance, Flux Vector Drives incorporate fast switching IGBTs (Insulated Gate Bipolar Transistors) power electronics, DSP (Digital Signal Processing), and PWM (Pulse Width Modulation). While the Flux Vector control provides the ability to control torque in an AC motor, the combination of the IGBTs, DSP, and PWM are what give the drive its superior response characteristics. These characteristics provide the high performance control that was previously only available in DC motors. IGBTs are extremely fast semiconductor switches which can be switched very rapidly at high current levels. This feature provides a truer waveform approximation, improved current regulation, and reduced noise. The complex and extreme numbers of mathematical equations are performed within the DSP – at a rate that may exceed 1000 calculations per second.

MOTORS IN ROD PUMP APPLICATIONS

By far, the most common type of prime mover on a beam pumping well is an electric AC NEMA D motor. The motors are generally oversized and of the high-slip (NEMA D) type due to the cyclic loads generated by sucker rod systems. Therefore the motor efficiencies tend to be low and excessive energy is consumed. A NEMA D motor acts like the motor in your car. This motor starts out in 4th off the line. These motors have been used with rod pumps due to most beam units being out of balance. The extra slip is required to get the weights moving to start the pump.

On a beam pumping application, a Flux Vector Drive produces the best results (starting torque and motor efficiencies) when controlling a NEMA B AC motor, instead of the common NEMA D motor. The Flux Vector Drive accurately controls the motor's torque and speed. Experience has proven that by incorporating a NEMA B motor and a Flux Vector Drive integrated with rod pump controls, a beam pump unit that once required a r a larger electrical service to start the unit, now has a controlled soft start and a severe reduction in time and equipment to get the oil flowing to surface.
The AC motor is rugged and reliable, even when operating in some of the harshest oilfield environments. Since the AC motor is induction motor, it does not have any brushes or commutators that can wear out, so they are virtually maintenance free.

RPCs vs. Flux Vector Drives

At first glance, one may try to compare a Rod Pump Controller with a Flux Vector Drive, including the peripherals required by each controller. The first misconception is that both devices accomplish the same objective. The RPC is designed to control a unit by shutting it down when certain conditions are encountered. If the RPC is attached to an off-the-shelve Variable Frequency Drive, the drive can soft start the unit and operate the motor at a specified speed, but requires human intervention to change that speed. There is no control for an independent up-stoke speed and down-stroke speed with this type of system. Additionally, it can restart the unit and it stores important information that is recorded through out the day. The Flux Vector Drive is designed to change the speed of the pumping unit to match the conditions of the well on every stroke. It can also shut the well down and restart it like an RPC. Unlike an RPC, a Flux Vector Drive does not need a load cell to obtain rod and gearbox loads. The drive is first tuned to the motor so that accurate motor torque calculations can be performed from electrical readings (volts and amps).

The motor torque calculations are on going during the pumping cycle and they are used to accurately determine gearbox torque. Once the gearbox torque is calculated, the drive calculates the polish rod load based on the pumping unit geometry, which is inputted by the user during the drive commissioning. This load data, when combined with position data from an inclinometer or proximity switch, is used to generate a dynamometer card. Field tests have shown this method of calculating loads to be within 4% of loads measured with a calibrated load cell. While a load cell used in conjunction with an RPC may drift over time, causing bad data, these calculated loads from the drive will not drift over time.

Benefits of a Flux Vector Drive

Pump Fill - One of the main objectives for installing Flux Vector Drive on a beam pumping well is to prevent the well to pump off while running 24 hours a day, without excessive fluid pound. This is achieved by the drive estimating the pump fill (percent of the barrel full of fluid during the down-stroke) using gearbox torque, rod load, or inferred pump load. On the down stroke, when the traveling assembly encounters fluid (in a partially full pump barrel), a quick reduction in bridle load occurs. When the drive encounters this reduction in load, the position in the down-stroke is known and therefore the pump fill can be estimated.

The Flux Vector Drive will set a target fill, which is equal to the highest pump fill calculated during a running cycle. If the calculated fill falls below this value, the drive will slow the unit down in percent increments until the calculated pump fill equals the target fill, the minimum unit speed is obtained, or the minimum pump fill is calculated. Once the user-defined minimum pump fill is calculated, the Flux Vector Drive will shut down and go into a user entered dwell time. After the dwell time has expired the drive will automatically start and begin the process all over again.

If the calculated fill is equal to the target fill for a couple of strokes, the drive will begin ramping the unit speed up until a lower pump fill is calculated or the maximum unit speed is obtained. The drive will continually adjust speeds, trying to optimize the pump fill while protecting the equipment from excessive shock loading. Below are some of the conditions where the Flux Vector Drive's Pump Fill option can provide benefits to the operator:

*ViscousFluids: Some wells produce heavy oil, which can create two different problems. First, if the well shuts down the heavy oil will often stick the sucker rod pump or plug the flow line. These problems are usually time consuming and expensive to remedy once they occur. The Flux Vector Drive allows the pump to run at very slow speeds to prevent pump off but since it is running, the pump does not plug. Second, many of these wells are steam flooded, which results in cyclic production. Therefore, it is extremely difficult to design a sucker rod system to operate effectively at a single speed. Using the pump fill function of the drive will reduce the effects or solve both these problems.

*CyclicReservoirs: Some wells are located in cyclic reservoirs, such as CO, floods. The fluid level and therefore producing capacity of the well will vary over time. Sometimes this variance is wide enough that a RPC alone cannot handle the swings in production. Since the Flux Vector Drive will change speeds according to pump fill, it can handle a larger variance in production. In most cases, optimal production can be maintained with no operator intervention required.

*SolidProduction: Wells that make fair amounts of solids tend to have problems when operated with RPCs. Once the well shuts down, the solids held in suspension in the tubing will settle on top of the pump. These solids can stick the pump on the subsequent start up, causing potential rod and pump problems. By slowing the unit down instead of shutting down, the amount of solids fallback is reduced or stopped.

Rod Load Limiter – The Flux Vector Drive can also monitor and control the maximum (peak) and/or minimum polished rod loads during the entire pumping operation. The operator enters either one or both of these values based on historical or calculated conditions. The firmware then monitors the calculated rod loads and if the limits are reached ramps back on the pumping unit speed in an effort to stay within the limits. The operator also enters a ion time slow down (decel time) or speed up (acel time) the pumping unit. The faster this time is set, the finer the control of rod force is at the expense of gy to slow the unit down.

This function is used for wells that have periodic abnormally high or low rod loads causing premature rod failures. These abnormal loads may be caused by a deviated wellbore, solid production (such as sand, scale, or iron sulfide), emulsions, or viscous fluids. Many of these abnormal loads occur when the pump sticks during the up-stroke or down-stroke. By limiting the rod load the Flux Vector Drive can reduce the number of premature failures in wells such as these. It is even possible to record the load when a rod part occurs and set the Rod Load Limiter feature to prevent the string from seeing anything within a set percentage of the recorded load. Figures 5 & 6 show how the peak torque is smoothed out during the upstroke once the Rod Load Limiter was adjusted. The surface dynamometer cards in Figure 7 shows the changes in rod loads when the Rod Load Limiter feature is enabled. This type of control has a definite impact on the life of the rods, as it can eliminate the excessive forces typically experienced in some rod pumping application.

Gearbox Limiter – As with the Rod Load Limiter, the Gearbox Limiter feature is designed to monitor certain conditions and perform an action if those conditions are encountered. In this case, the gearbox load (defined when entering the geometry of the unit) is monitored and the torque of the unit is controlled to keep the loading within the preset range. The user configuration allows this limit to be increased, decreased or turned off, depending upon the situation.

Beam Load Limiter – The beam rating is available if the operator chooses not to use the Rod Load Limiter, but instead chooses to use that feature to establish a maximum beam loading.

Bridle Separation - This function will detect when the carrier bar separates from the polished rod clamp on the down-stroke. Once the separation is detected, the unit slow down, allowing the carrier bar and clamp to come back into contact. The separation can be detected with a proximity switch or by using the calculated polished rod load. If the polished rod load is used, the unit can be slowed down before actual separation takes place. This function is extremely useful for heavy oil applications and can be helpful when heavy solid production causes the pump to stick.

Belt Slit, - The drive will estimate the percentage of belt slip by comparing the selected gear ratio to the calculated gear ratio. As the belts slip the total gear ration will reduce. The drive can alarm and shut down based on a user editable percent of belt slip allowed.

Power Savings - Power savings are usually seen when the Flux Vector Drive is installed where a NEMA D single speed (across the line starter) system is in use. Current installations have realized between 5% and 50% power savings with the norm between 15% and 25%. The power savings come from three sources. First, it is important to balance the unit when the Flux Vector Drive is installed. If the unit was out of balance prior to the installation of the Flux Vector Drive, then some power savings can be achieved by simply balancing the unit. Secondly, the nature of this type of controller allows the operator to use a NEMA B motor in place of the NEMA D motor. The NEMA B motor is roughly 10% more efficient or has 113 less losses than a NEMA D motor. The NEMA B motor also has a smaller capital investment than a NEMA D. Finally, the Flux Vector Drive design improves the power factor. Once the Flux Vector Drive is installed, the power factor will get close to unity, usually 0.95 to 0.98. The closer to unity the power factor is, the more efficient the system is and power usage will decrease. Re-sheaving the pumping unit to run at the maximum required strokes per minute with the motor running at 1.5 times base speed can provide considerable savings. This change can result in reducing the required motor horsepower and reduce the power consumed since the sheave ratio does some of the work. Some of the current installations have seen as much as a 33% reduction in power consumption, through this alone.

CASE HISTORY 1

A major oil company in California provided results of their Flux Vector Drive installation on a horizontal well with the tubing pump set below the kickoff point (within the horizontal leg) and operated by a Mark 640 Unit. The unit was operating at 7.6 strokes per minute prior to the installation of a Flux Vector Drive. After installation of the Flux Vector Drive, the strokes per minute decreased to an average of 4.8 without impacting production.
Initial reports from the Flux Vector Drive indicated that the pumping unit was out of balance (Figure 1). The torque charts in Figures 2 and 3 reflect a significant change in maximum and minimum torque, once the Flux Vector Drive was installed. Prior to the operator installing the Flux Vector Drive, power measurements were taken to record changes in the energy consumption.

The operator supplied Figure 4, which compares the energy usage before and after the Flux Vector Drive is installed. Note the improvement in Power Factor and Average Total Real Power. It was reported that the initial startup current is 14.4 amps, which eliminated the line start momentary current surge of about 325 amps. The requirement of 325 amps was required to get the motor running under load. Based on the measured energy savings and one expected well failure reduction, the operator reported this installation would pay out in about one year.

CASE HISTORY 2

Another major oil company in Texas installed a Flux Vector Drive, on an existing beam pumping well, with the primary objective of reducing sucker rod failures. This well experienced four rod failures over the 245 days prior to the installation of the Flux Vector Drive. During the 120-day test period, there was one rod part, which occurred before the rod load limiting software was enabled. Leading up to and through this test, the downhole equipment did not change. Prior to installing the Flux Vector Drive, the well was operating with a 100 hp motor, but due to the technical capabilities of the drive, they were able to replace the 100 hp with a 75 hp motor. Figure 9 displays a plot of rod loading (scaled on the right *Y* axis) vs speed of the unit (scaled on the left *Y* axis). This graph represents a five-hour window with the data being collected every 15 seconds. The maximum speed appears to hover just under 11 strokes per minute and the minimum speed averages about 9 spm. Seven times, mostly on the right side of the graph, the maximum load spikes up to almost 38,000 psi. At the same time, the speed of the unit drops in response to the Rod Load Limiter control of the Flux Vector Drive. This data appears to identify a sticking pump, which increases the rod load on the upstroke. The Flux Vector Drive responds by slowing the unit down to a speed less than seven strokes per minute. Because of the data points for the rod load, the slowest speed is not visible on this graph. Predictive programs run on this installation indicated the peak loads to be expected would be less than 29,000 psi. Figure 10 is a close up of the middle section of Figure 9. Figures 11 and 12 represent the economics of the Flux Vector Drive on this particular application. At the end of the test period, production had increased by five barrels of oil per day and the projected annual energy savings alone was enough to pay for the cost of the drive. The rod failure frequency dropped from 5.9 to 2.8 failures per year, which should save an estimated $7,500 in the first year.

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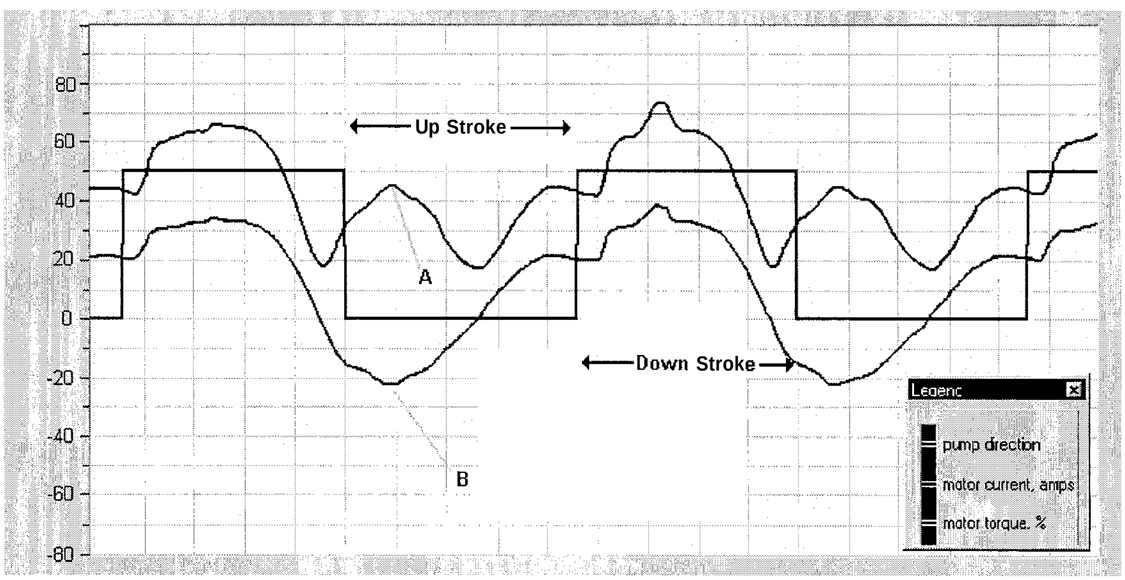

Figure 1 – Motor shaft torque indicates Pumping Unit is out of balance.

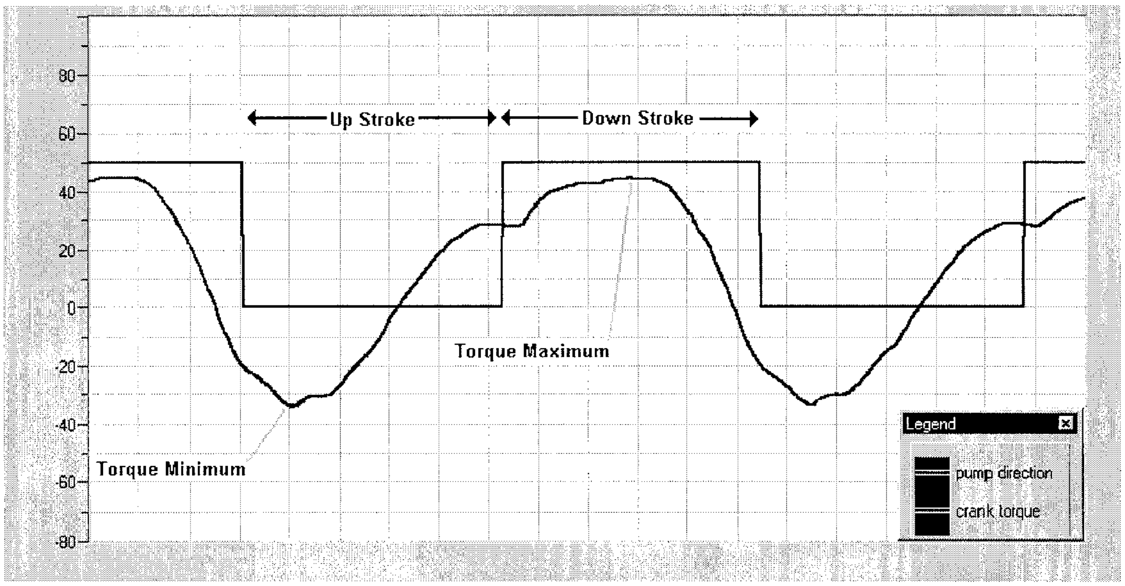

Figure 2 -Torque Chart Before Flux Vector Drive Was Installed

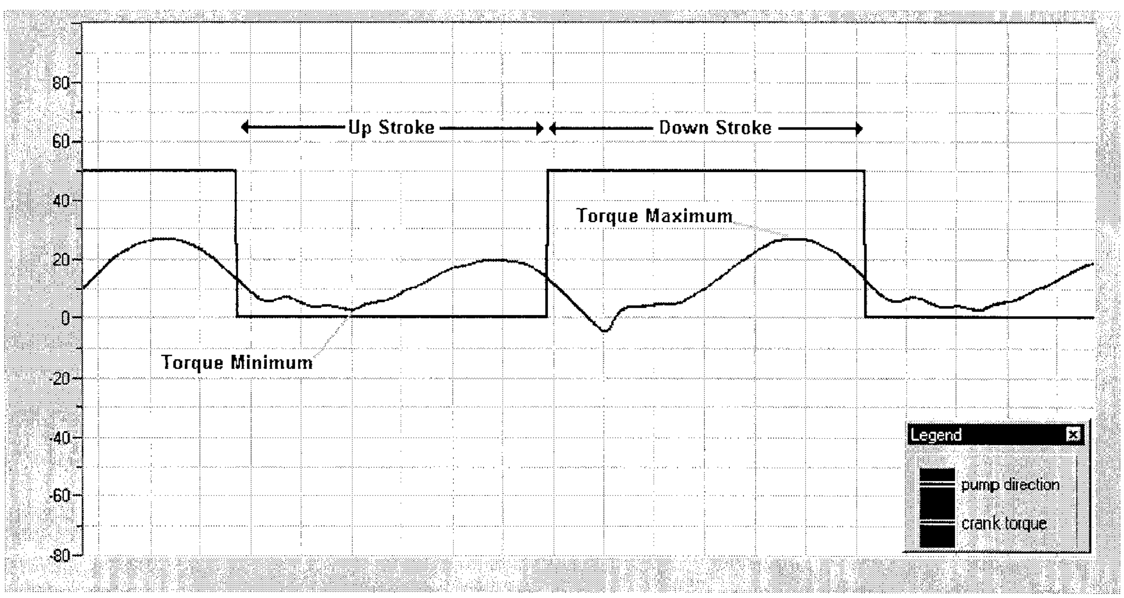

Figure 3 - Torque Chart after Flux Vector Drive Was Installed & Operating

Power Comparison	Prior to Flux Vector Drive Installation	After Flux Vector Drive Installation
Average Voltage (V)	488	491
Power Factor	0.478	0.713
Maximum Current (A)	95.88	24.92
Average Current (A)	37.33	11.05
Total Demand (KW)	2.54	1.13
Total Apparent Power (KVA)	32.13	9.51
Total Reactive Power (KVAR)	28.23	6.67
Average Total Real Power (KW)	15.35	6.78

Figure 4 - Power Benefits of Flux Victor Drive After Installed on **Rod** Pumped Well

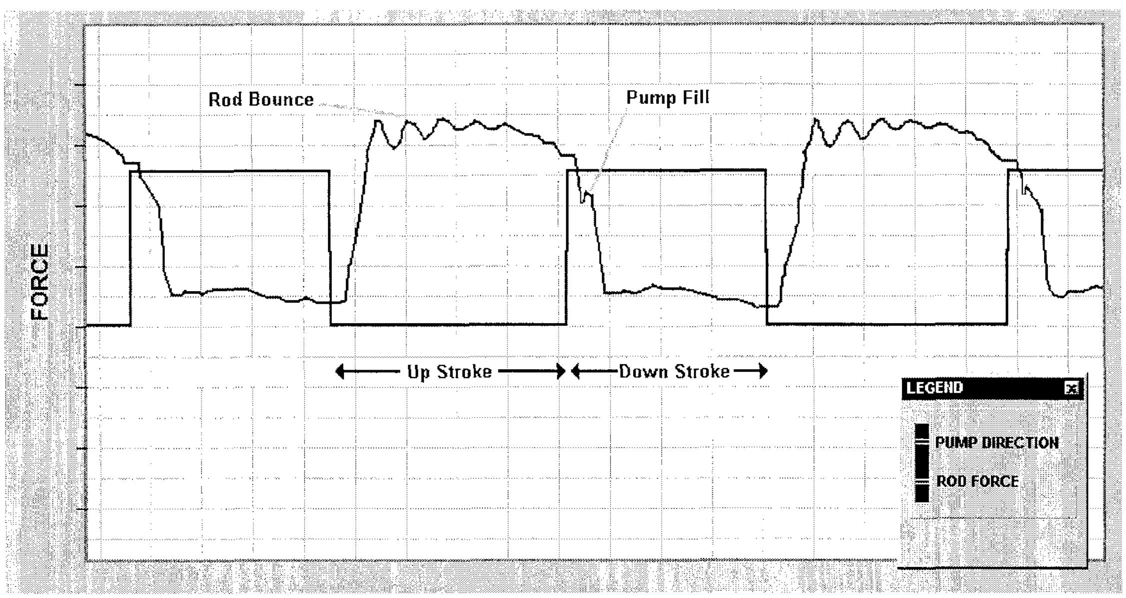

Figure 5 – Rod Load Limiter is not enabled.

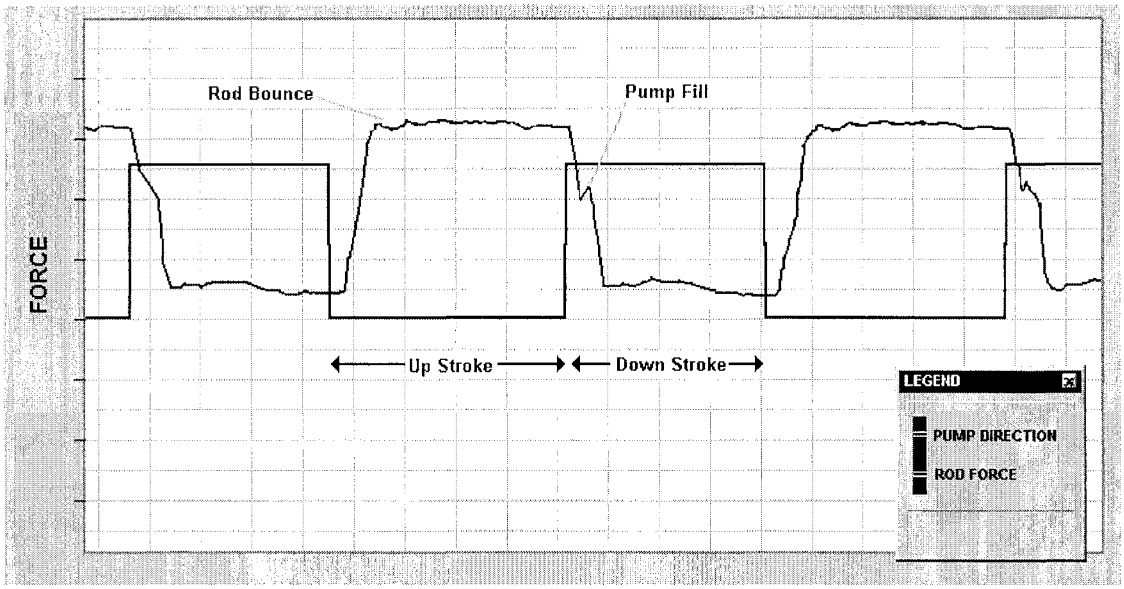

Figure 6 – Rod Load Limiter is in service.

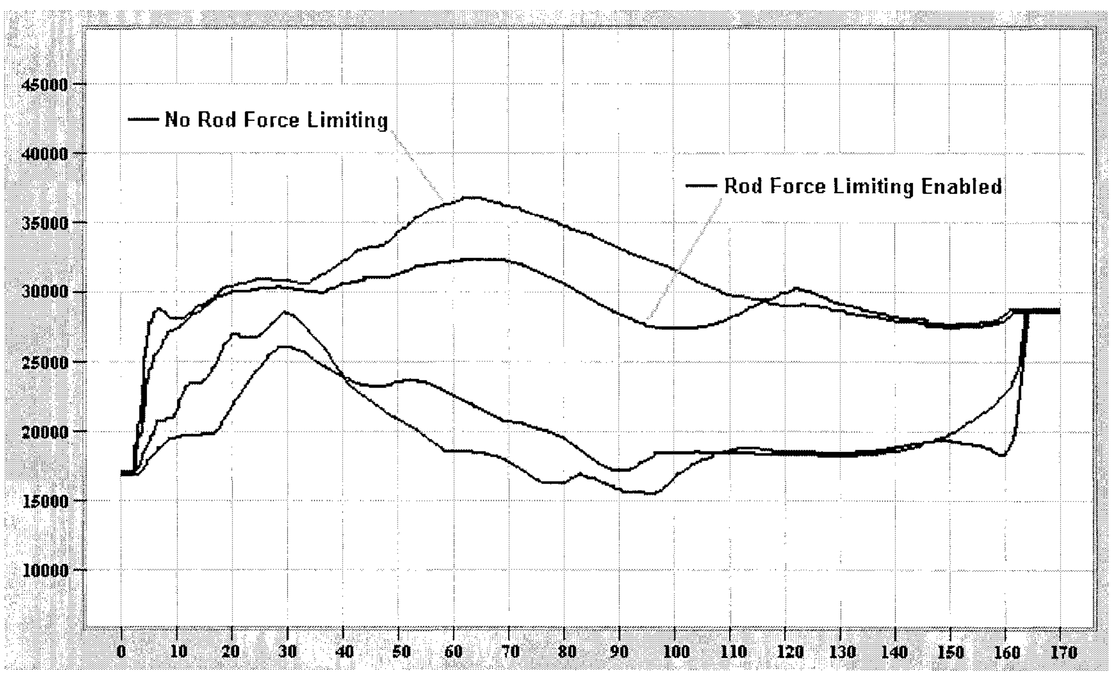

Figure 7 – Surface Card with and Without Rod Load Limiter Enabled

	Pre-Flux Vector Drive @ 6.5 spm	Flux Vector Drive Installed with NEMA D @ 6.5 spm	NEMA D replaced with NEMA B @ 6.5 spm
Average Voltage	493	494	498
Power Factor	0.443	0.935	0.929
Maximum Current (A)	111.34	106.23	91.93
Average Current (A)	76.77	36.57	33.21
Total Demand (KW)	4.82	4.8	4.34
Total Apparent Power (KVA)	65.37	30.8	28.02
Total Reactive Power (KVA R)	58.61	10.92	10.37
Average Total Real Power (KW)	28.94	28.8	26.03

Figure 8 – Changes in Power Requirements Before a Flux Vector Drive, with the Flux Vector Drive and a NEMA D Motor and After the NEMA D Was Replaced with a NEMA B

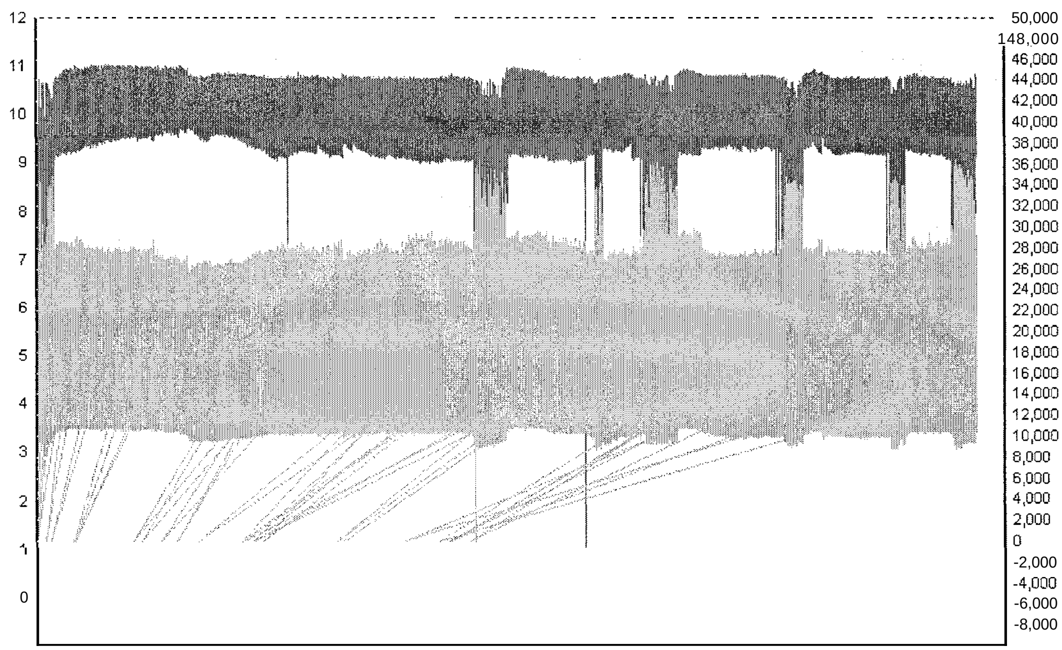

Figure 9 – Correlation Between the Increase in Rod Loads and the Decrease in Pump Speed