ADVANCED ROD PUMP CONTROL, NEW PATENT PENDING TECHNOLOGIES THAT OPTIMIZE PRODUCTION, REDUCE MAINTENANCE, AND SAVE ENERGY WHEN APPLIED TO ROD-PUMPED WELLS

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INTRODUCTION

The use of Variable Speed Drives to control Rod Pumps has been tried with varying results. The success has been limited due to issues such as surface equipment reliability, regeneration, voltage and current harmonics, poor power factor, and premature Rod, Tubing, and Pump failure.

This paper describes a unique technology that combines the latest advances in power electronics with patented firmware and application software solutions resulting in optimized production and reduced maintenance and energy costs for heavy oil, high gas content and "problem" wells. The technology eliminates pump-off and allows the operator to maintain the fluid level at a predefined level above the pump, maximizing pump fillage, while accurately controlling the rod speed at all times preventing premature rod failure. This new technology also produces a near unity power factor and a minimum of voltage and current harmonics and allows the use of more cost efficient high efficiency NEMA B motors.

PROBLEMS RELATED TO THE USE OF VSD'S

The benefit of different up and down stroke speeds is well known in the industry. This has been achieved primarily through the use of asymmetric surface units such as the Lufkin Mark II but also through the use of Variable Speed Drives (VSD). The use of VSD's to control the number of strokes per minute as well as different up and down stroke speeds have been tried with varying success. Given the ability to easily change the strokes per minute, it is easy to unintentionally induce greater stress on the rods and thereby reduce the reliability of the equipment when the intention was the opposite. Increasing the speed of the up stroke can result in compressive rod loads leading to the rod cutting the tubing. The strokes per minute have always been viewed as a constant rather than a variable when designing a rod pump. In order to successfully apply VSD technology it is necessary to identify the relationship of frequent change of speed and the stress induced on the rods.

The longevity of primarily the rods, but also the pump and tubing, is inversely proportional to the amount of stress the rods are subjected to. The two types of rod failures are tensile or fatigue failures. Tensile failures occur when the maximum allowed load of the rod is exceeded.

This type of failure will typically only occur if the pump is stuck. Fatigue failures, the most common type of rod failure, are caused by cyclic load changes reducing the strength of the rods over time. Apart from protecting the rods from any mechanical damage before installation that could be the start of a fatigue crack, the most important thing is to keep the stress range and the number of cycles to a minimum. The stress range can be defined as the difference between maximum and minimum load, within each stroke. The stress range will be constant as long as the conditions remain the same. Any change in well conditions or changes in the pump set up, such as the strokes per minute, will change the stress range. The load cycles are the number of times the load changes direction. Ideally there should only be one load cycle per stroke. The application of VSD's on rod pumps is a potential threat to the rod string since the varying of strokes per minute may directly affect the stress range of the rods as well as the number of load cycles.

MINIMIZING THE STRESS RANGE

For a closer understanding of the relationship between strokes per minute and the stress range we need to look at the actual change of speed of the rod string itself. The speed of the rod string at a specific position is directly related to the strokes per minute and the geometry of the pumping unit. With a fixed geometry and a fixed speed, the rod speed and rod load will be constant at a specific position, provided that all other conditions remain the same. If the rod speed at a specific position could be controlled, that would then allow the operator to control the rod load at that particular position. Hence, the ability to accurately control the rod speed within each stroke independent of the pump geometry would give operators the means to minimize the stress range and number of load cycles at different production rates. This could be used to increase reliability of the equipment in problem wells, allow the increase of production in wells now limited by strokes per minute or increase production for wells with varying conditions.

ROD SPEED CONTROL CHALLENGES

With the notion that in order to ensure the reliability of the equipment it is not enough to just control the strokes per minute. It is necessary to accurately control the rod speed, within each stroke regardless if the motor is driving or regenerating. The ability to accurately control the speed of the motor and thereby minimizing the stress range and load cycles within each stroke has until today been very hard to achieve. This has mainly been due to two reasons:

1. Commonly used Scalar (PWM), or Flux Vector VSD's can not react fast enough on quick load changes to accurately control the rod speed without the use of encoder feedback from the motor. Encoders are expensive and unreliable in oil field applications.

2. Technology to accurately control the speed of the rods at regeneration, typically during the up stroke, has also been espensive and unreliable. The most common practice when applying VSD's has been to use braking resistors, regeneration units, or in many cases nothing at all.

These two limiting factors have prevented the development of VSD applications that not only allow the user from changing the strokes per minute and different speeds at up and down-stroke, but also prevent premature rod failure.

NEW ADVANCED TECHNOLOGIES

The ABB ALC 600 Rod Pump Controller are using two unique technologies to solve the problem of accurate control of the rod speed within each stroke.

Instead of using Scalar (PWM) or Flux Vector type VSD controls, ABB uses Direct Torque Control (DTC). DTC is a patented technology that can accurately control the speed of a motor independent of torque changes without the use of encoder feedback from the motor. The DTC technology calculates motor variables 40,000 times per second allowing for 100 times more accurate speed control than Scalar Control type VSD's and ten times more accurate speed control than Flux Vector Control type VSD's. The ability to instantly change the speed of the motor independent of torque gives the controller the unique capability to protect the rods from stress resulting from load changes as well as the ability to accurately control the rod speed within each stroke.

In addition to the accurate and torque independent speed control achieved by DTC, the Rod Pump Controller is also the first to use an active front-end configuration. The active front-end technology, used for many years in heavy industrial applications, gives several distinctive benefits to the user. First, the active front-end in combination with DTC ensures accurate rod speed control regardless if the motor is driving or regenerating. The 40,000 per second motor load calculations ensure step less transition between driving-regenerating-driving conditions. Second, the regeneration gives the controller the unique capability to quickly slow down the rod speed independent of the inertia.

A well-known side effect when using a VSD is the generation of line harmonics. The use of an active front-end in combination with an input filter results in a minimum of both voltage and current harmonics. The active front-end also has the added benefit of producing near unity power factor regardless of motor load. The use of a VSD also allows for the change of costly NEMA D motors to less expensive more energy efficient NEMA B motors.

The combination of Direct Torque Control (DTC) and an active front-end result in the unique ability to control the speed of the motor independent of motor load. This gives the controller the capability to not only protect the rod pump from damage generated by sudden load changes, but also the ability to increase reliability by continuously minimizing the stress range and load cycles on the rods. This capability is used, by the **ABB** patented Rod Saver software to increase reliability of the equipment in problem wells or allow the increase of production in wells limited by maximum pumping speed.

ROD SAVER OPERATION

The Rod Saver software gives the operator the capability to control the speed of the rods within each stroke and thereby minimizing the stress range and load cycles. The software allows for user-configurable speed changes within each stroke.

Typically, the first speed change would be set just before the pump reaches the fluid level in the tubing. This will ease the stress on the rods related to entering the fluids. The required speed change is entered into the software by defining the position as a percentage of the stroke and the speed as a percentage change of the set speed. The second speed change in the down stroke is set closer to the bottom of the stroke. This change will reduce the stress on the rods when reaching the bottom and can be used to prevent tagging of the pump. The third position would be set close to the top of the stroke reducing rod compression. The set up of the Rod Saver software is an interactive exercise and is done with the pump operating at the optimum fluid level and the pump pumping at the desired speed.

The operator makes the changes in small increments while viewing the dynacard and monitoring maximum and minimum rod loads. The user will also manually monitor the polished rod and the surface unit in order to achieve a minimum of vibrations. The set up of the system is hands on and the operator receives immediate feedback after making adjustments. When the operator is satisfied with the setup he can now start to increase the speed of the pump, in small increments, to verify that the pump is well balanced even at higher strokes per minute. The increase of stroke rate may require further adjustment of the Rod saver software.

The Rod Saver software working with DTC and the active front end is the first tool for operators to minimize the rod stress range and load cycles and to allow reliable operation at higher production rates or in varying well conditions without making mechanical changes.

The illustrations at the end of this report (Figurel. and Figure 2.) illustrate a well running at 11.5 SPM with and without the Rod Saver software. The card illustrated in figure I shows several load cycles within the stroke when operating the pump without the Rod Saver software. This state of operation will shorten the lifetime of the rods. The second card taken a few minutes after the first card shows the same well operating at the same strokes per minutes but with the Rod Saver software active. This clearly illustrates the effectiveness of the software in reducing the number of load cycles and producing a much-improved card.

LIMITATIONS OF PUMP OFF CONTROL

The control of rod pumps has evolved over the years. The technology has gone from no control and a pumping rate well below the inflow from the formation, to the use of timers and Pump-Off Controllers (POC's). The POC technology has increased the production rate and also protected the pump from stresses related to extended fluid pound. However, the constant starting and stopping of the pump and the five to ten strokes before the controller pumps off the well, is a source for unnecessary stress on the equipment. The constant change of the fluid level does not ensure maximum inflow from the formation.

POC's in combination with VSD's have been applied in order to improve production and to prevent the pump from pumping off. These efforts have been limited first of all due to the limitation of existing VSD technology as discussed previously in this paper. The second reason for the litnited success is the fact that POC's were designed to start and stop the pump. The single control point designed to shut off the pump at a specific load versus position, limits the use of the POC to control the VSD. This makes it very hard for a POC/VSD combination to control the fluid level in wells with gas problems, or any other type of frequently changing well conditions. Another problem has been the combination of equipment from different manufacturers used in these applications. Neither the POC manufacturers nor the VSD manufacturers have had the resources or willingness to fully integrate the two individual types of equipment into one working system.

SINGLE VERSUS MULTI POINT FLUID LEVEL CONTROL

The dynacard capability of the ALC 600 Rod Pump Controller, is an integrated part of the product. Starting out as a fluid level controller, and not as a POC, it allowed research and development engineers to look for alternative ways of controlling the well. With the need to control the well under changing conditions, it was determined that a single point control algorithm would not be sufficient. The result of the research is the patent pending multi set point fluid level control. The multi set point fluid level control works with three individually located load versus position points. The controller, working with the Rod Saver software in combination with the fluid level control will control the strokes per minute to maintain the fluid level, as set by the operator, at a specific distance above the pump. As inflow increase to the well the pump will automatically increase the speed to maintain the desired fluid level. The same is true if the inflow is reduced. Maintaining a constant fluid level will optimize the inflow from the formation and prevent the pump from pumping off saving both energy and reducing mechanical stress.

FLUID LEVEL CONTROL OPERATION

The fluid level is controlled in a traditional way by operating around the change of the card when the pump reaches the fluid level in the tubing. What makes the multi set point control unique is that the speed is not solely defined by the dynacard in relation to a single set point. It will look at the dynacard in relation to three individually positioned set points. There are two major advantages related to this control strategy.

First, it allows the controller to not only look at what side of a single control point the pump is operating. Utilizing the three control points, the controller can determine, by the position of the card between two points, the amount of pump speed change necessary to reach the requested fluid level. If the card is close to the desired level the speed change will be less than if it is far away. This is true for both the lowering and increasing of the fluid level. As compared to POC/VSD combinations, the Multi Point Fluid Level Control operates within a range rather then from a single set point. This allows for a much more efficient and smoother fluid level control.

Second, the Multi Point Fluid Level Control is also able to detect conditions such as gas pound, gas lock, fluid pound and rod harmonics. With the three-point control the system is able to determine how many times the card crossed the two lines between the three control points and in what direction. This information is used by the controller to determine if the pump is experiencing one or more of the above mentioned conditions. At that time the controller will gradually slow down the speed of the pump until the condition has been rectified. It will then again look at the card and start controlling from the multiple fluid level control points to reach the desired fluid level. This allows the pump to work through a temporary well condition change with minimum impact on the equipment and with no operator input necessary.

The multi set point Fluid Level Control software is very user friendly and comes with an auto tuning function. The operator simply selects the card he would like to control from. This would be a card with Rod Saver Software activated and with the pump operating and the required fluid level. The controller will automatically position the three control points based on the selected card. The control points can easily be moved by the operator to fine-tune the fluid level control.

In addition to the advanced control related to the Multi Point Fluid Level Control the operator is required to enter limits to the pump operation such as maximum and minimum rod load, maximum load range and minimum fluid level. The pump will shut down if the system reaches any of the conditions as specified by the operator and will also try to restart after a user-defined period of time.

CONCLUSION

The advances of cost efficient Power Electronics and Variable Speed Drive control firmware has allowed for the development of the next generation Rod Pump Controllers. The importance of accurate control of the rod stresses when applying VSD technology for this application has shifted the leading edge development away from traditional POC manufacturers to VSD manufacturers. Applying superior technology such as Direct Torque Control firmware in combination with cost efficient active front-end technology is now opening up the possibilities for this groundbreaking development. The development of advanced application software capable of minimizing the rod stress and controlling the Fluid Level, in combination with the capability of detecting and effectively eliminating temporary well disturbances gives operators the tool to optimize production while minimizing the maintenance and energy cost. As an added benefit the new technology advance also provide a system with excellent harmonics mitigation and close to unity power factor that is always appreciated by the utility and eliminate the risk of power quality related surcharges.

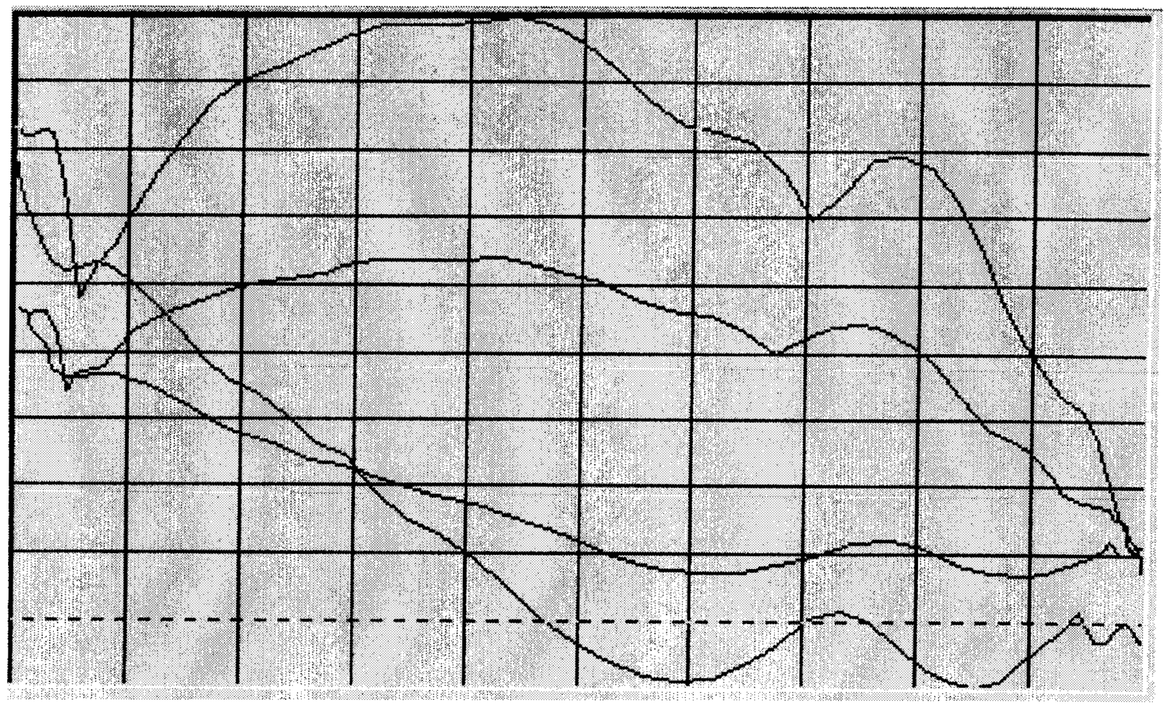

Figure 1 - Pump Running at 11.53 SPM without Rod Saver Software

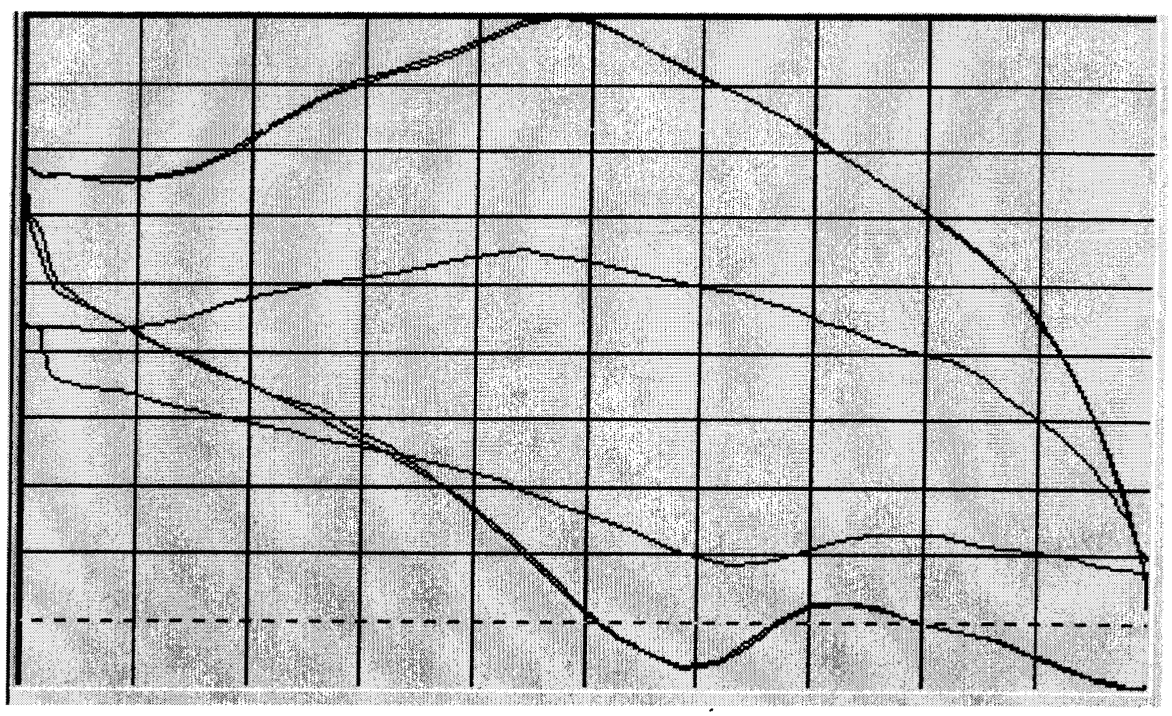

Figure 2 - Pump Running at 11.53 SPM with Rod Saver Software