PUMP-OFF CONTROL - THE AVERAGE MOTOR CURRENT METHOD

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INTRODUCTION

Ever since oil well pumps were first used in their crudest form there has been a need for controlling the pump. The controlling effort has been directed at matching the pump capacity with the well capacity. This type of control has been an objective of oil producers around the world. The value of achieving this goal has changed as the importance and value of crude oil has changed. The present conditions have placed a very high value and degree of importance on the amount of fluid produced and the lifting costs necessary to produce that fluid.

Many of the pumping problems that occur in the production of oil can be traced back to the lack of proper pump control. Some of these problems include gas locks, mechanical damage to the pump, rods, gear box and excessive power consumption. With rising costs, to correct the above problems proper control of pumps has become increasingly important. There has been a decrease in the amount of manpower available to track down these pumping problems, identify and correct them. Most oil-producing fields are being operated with fewer people today than they were several years ago.

During the years a number of methods have been tried in an effort to properly control pumping wells. These methods fall into two basic categories—fluid production measurement and load measurement. Various types of equipment have been developed during the last 20 years in order to properly control pumping oil wells. Some of the design and equipment met with varying degrees of success while other equipment and design met with total failure to meet the desired objective.

This paper considers some of the drawbacks of previous developments; and discusses at length the development of the average motor current method of controlling oil well pumps. Following the development of this method complete field and laboratory tests were run over an extended period of time to prove the method. Conclusions reached as a result of the design and testing program are stated in the Conclusions section of this paper.

PREVIOUS METHODS

Previous efforts to properly control oilwell pumps range from very crude to very complex approaches. Some of the better-known methods will be discussed to show the basic need for an improved method. The most common approaches are: (1) to monitor the load, and (2) to monitor production rate. From the information obtained in these monitoring processes analysis can be made with the objective being to determine whether the well is "pumping fluid" or "pumped-off". At this point it is necessary to define "pumping fluid" and "pumped-off" as used in this paper.

> *Pumping fluid* - term used to describe a pump operating and producing fluid at its expected efficiency, assuming adequate fluid is available at the pump inlet.
>
> *Pumped-off* - term used to describe a pump operating without adequate fluid for it to pump at its expected efficiency.

An operating pump will generally be pumping fluid when the fluid level is high enough above the pump inlet to allow the pump to fill properly. An operating pump is referred to as pumped-off when the fluid level is so low that the pump does not fill properly. These terms and definitions as used in this paper apply to sucker rod pumps, fluid packed pumps and centrifugal downhole pumps.

Load monitoring controls have resulted from monitoring pump loads at several different places in the pumping system. Some controls have used strain gauges mounted on the polished rod to determine polished rod load and detect the pumped-off condition from the measurement. Strain gauges have also been used in other places to measure load on a sucker rod pumping unit. These places include various stress points, pivot points and the walking beam. Some of these controls have met with varying degrees of success and others have met with failure. One of the problems common to strain gauge load monitoring is the instability of the strain gauge output resulting from ambient temperature variations. Another problem common to the above methods is the delicate equipment mounted on the pumping unit or polished rod. This type of equipment can be damaged easily during normal oilfield maintenance operations such as workover, bearing greasing or repair, unit balancing, etc.

There have been controls that used a motor current monitor. Motor current is probably the most desirable parameter to monitor to detect a pumped-off condition. Previous attempts to control a pump based on motor current have not been very successful for several reasons. In some cases switches were mounted on the pumping unit. Some controls only considered part of the stroke cycles and others considered only current peaks. There was no compensation for line voltage fluctuation effects on motor current.

The above is only a brief discussion showing some of the problems encountered in previous load monitoring controls. Control based on a production monitor has been a subject of interest perhaps even longer than load monitoring.

On a short-term basis some production monitoring controls have been successful. Methods of monitoring production include pressure monitoring in the flow line, flow/no-flow devices, and flow metering devices.

A basic difficulty commonly found in flow line production monitoring devices is inconsistency of performance. Paraffin, gas, erratic production and varying flow line pressure are some of the major causes of difficulty. Like switches and strain gauges mounted on the pumping unit, anything attached to the flow line is vulnerable to maintenance problems, equipment malfunctions and personnel errors.

Previous methods of controlling pumps have also pointed out some very valuable information. By studying data taken from the various pump-off sensing devices it has been possible to analyze pump conditions and predict problems.

In the development of the average motor current method of pump control, the valuable developments of previous methods were incorporated; and just as importantly, the undesirable features of other methods were avoided. The result was the development of a superior method.

DESIGN CRITERIA

Before discussing details of the operation of the motor current method, its design criteria will be discussed. These criteria were developed after consultation with people involved in oil production, engineering, research, automation and economics. Many oilfield personnel as well as private consultants have contributed to the design criteria.

Two very basic criteria emerged immediately:

1. All components and sensing devices must be kept off the pumping unit and out of the flow line.
2. The means used to sense pump-off must be a consistent indicator of a pumped-off condition under varied well and pump conditions.

The first criterion was developed as the result of numerous problems and complaints about sensing equipment being damaged during normal maintenance and repair operations. The second criterion came as a result of previous attempts to accurately and consistently detect a pumped-off condition. Sensing of line pressures and flow rate has proven to be unreliable over the long term as a pump-off indicator.

Line pressure is affected by the pump and other equipment connected down the line. Line pressure changes also result from paraffin or scale accumulation in the line. The pressure sometimes pulses in varying magnitude and frequency. Flow rate is affected by line pressure, paraffin in the line, gas, etc.

To monitor the load without attaching equipment to the pumping unit requires that the prime energy source for the pump be monitored. This represents the line of thinking and general criteria that led to the average motor current method.

FUNDAMENTAL DESIGN

It became obvious that using the motor current as a basic input signal met the design criteria. To monitor the motor current does not require any connection of equipment to the pumping unit or the flow line. The motor current represents accurately the load on the entire pumping system. With the pumping system being mechanically fixed (pump size, rod string, counterweight, etc.) any change in motor current reflects corresponding change in pumping conditions.

Motor current in amperes was observed during normal pumping conditions (fluid above pump) and during pumped-off conditions. Based on the change in motor current when a well pumped-off, the motor current reflects the difference between pumping and pumped-off.

When a pumping system produces fluid, more power input is required than when that same system is not producing fluid. This power consumed is proportional to motor current.

As detail design was taking place it was necessary to compensate for line voltage variation. Power is a function of line voltage and current according to the following equation:

$$P=K\ (V)\ (1)$$

(P) represents power in watts. (V) represents line voltage. (1) represents motor current. (K) is a constant product of the power factor and the square root of three. To compensate for this fluctuation, compensating circuitry was designed into the control circuitry. Electronic circuitry was developed to sense the motor current and control the electric motor based on the change in average motor current. It was important to use average current in order to reflect changes in load throughout the pump stroke, cycle after cycle.

The following is a brief description of the circuit used in the control. Motor current was sensed using a current transformer to sense current supplied to the motor. The current signal was stepped down by a factor of 1000. The signal was rectified and converted to a DC voltage directly proportional to the AC motor current. Figure 1 shows a typical plot of motor current versus time. The average current is represented by the straight horizontal line.

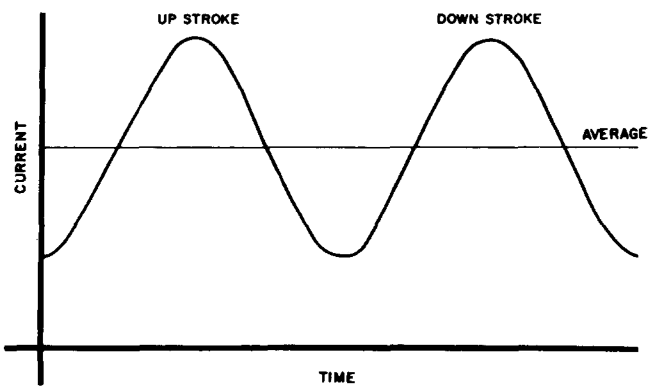

FIG. 1

Figure 2 shows a theoretical dynamometer card. The solid line represents a full pump card. Lines 2 and 3 represent progressive pump-off. Figure 3 shows the motor current and the decreasing average corresponding to degree of pump-off indicated in Fig. 2.

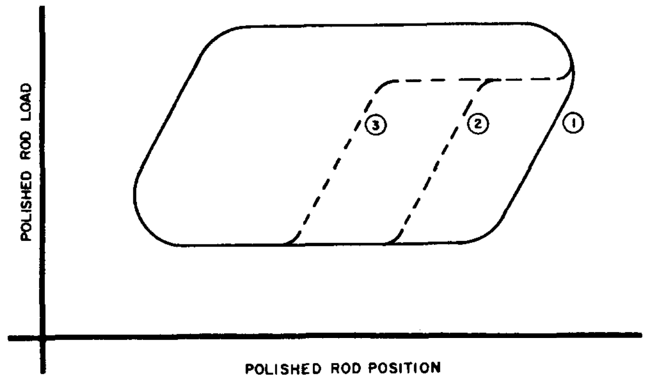

FIG. 2

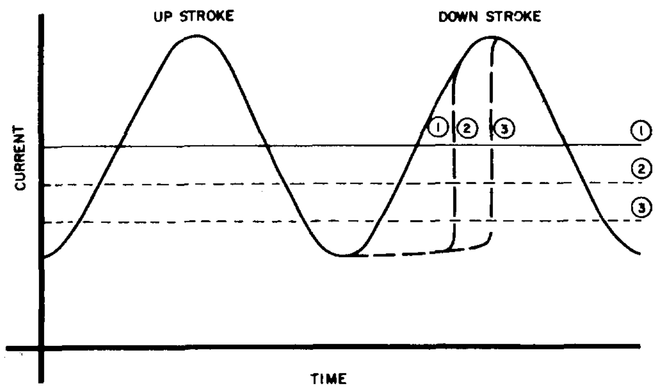

FIG. 3

This average was computed electronically and supplied to one input of a comparator. An adjustable control point is supplied to the other input of the comparator. When the well pumps-off, the total power demand decreases (reflected by decrease in downstroke motor current). Therefore, the average motor current decreases. When the average current decreases to the control point level supplied to the comparator, the comparator switches and provides a signal to control a relay which ultimately controls the pump motor.

The same signal that shuts down the motor starts an electronic timer which counts down-time. The down-time period allows fluid buildup in the well to take place. This down-time can be field-adjusted to suit specific well conditions. At the expiration of the down-time a signal is supplied to restart the motor. If the well begins pumping normally the average current will rise above the shutdown control point. The well will be allowed to pump until the control senses that the well has pumped-off again. At that time it will be shut down. If when the well starts there continues to be an indication of a pumped-off condition the control will shut the well down after a minimum pump time (generally set for less than three (3) minutes).

Patents relating to the design and application have been applied for and are pending.

TESTS AND EVALUATION

After electronic circuitry was developed and packaged, a thorough field test and evaluation were undertaken. The objective of the test and evaluation was to prove the theory of operation and point out any changes necessary to make the product simpler to use and more adaptable to normal field operations.

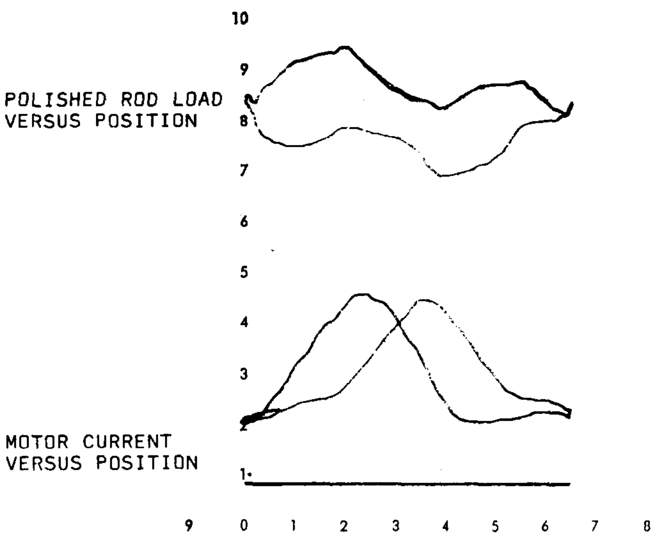

FIG. 4—POLISHED ROD LOAD AND MOTOR CURRENT VERSUS POSITION FOR NORMAL PUMPING CONDITION

Several controls were placed in operation on different types of wells to provide experience under varied pumping conditions. Performance of the pump, motor and control were monitored carefully. Records were kept to provide the necessary data to evaluate the performance of the control. Running time of the pump was accumulated on an hour meter (later to become a standard part of the product). Production of fluid (water and oil) was monitored and recorded for later comparison to running times. Recording ammeters were used to record actual current during various pumping conditions and pumped-off conditions. Dynamometer cards were drawn under various conditions to be used for analysis and comparison to motor current plots. Figure 4 shows a dynamometer card and a current plot under normal pumping conditions with fluid above the pump. The current plot is drawn by recording motor current in the vertical direction and polished rod position in the horizontal direction. Figure 5 shows the pumped-off condition of the same well as in Fig. 4. Comparison of the dynamometer card and the current plot indicate that the pumped-off condition definitely is evident in the motor current. Figure 6 shows a continuous recording from pumping normally to pumped-off. Again the current plot compares favorably to the dynamometer card.

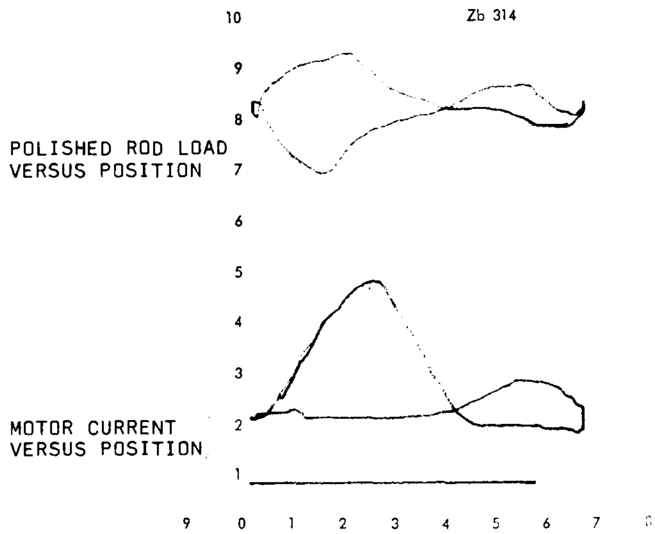

FIG. 5—POLISHED ROD LOAD AND MOTOR CURRENT VERSUS POSITION FOR A PUMPED-OFF CONDITION

Production records show that normal expected production was maintained or exceeded in every test. Running time records showed that pump efficiency was high due to operating the pump only when there was enough fluid to fill the pump. Running time records also indicated sharp decreases in total unit running time, thereby reducing power consumption and cost.

Mechanical fatigue was minimized due to turning off the mechanical pumping system when the well pumped-off.

Line voltage fluctuation and temperature fluctuation both occurred during field tests. The same condition in lab tests supported results obtained during field tests.

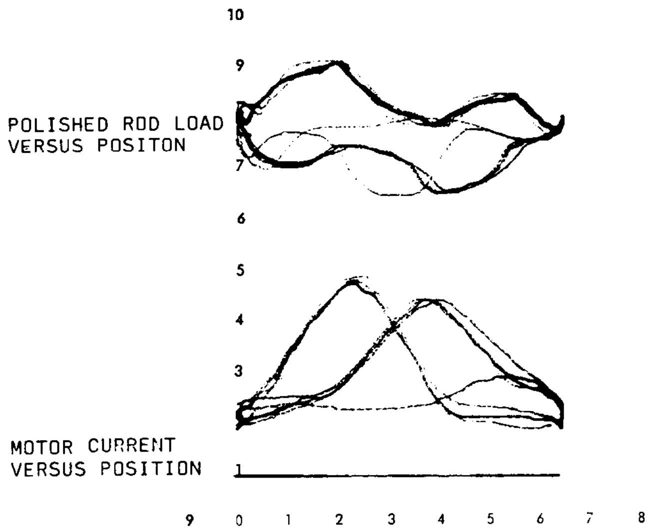

FIG. 6—POLISHED ROD LOAD AND MOTOR CURRENT VERSUS POSITION SHOWING NORMAL PUMPING, PUMPING-OFF AND PUMPED-OFF CONDITION

Field and lab tests showed performance consistent through wide ranges of voltage and temperature fluctuation.

PRACTICAL APPLICATION

After testing and evaluating the actual control device it was necessary to explore the area of practical application in day-to-day use. It was found that the control could be used on pumping wells that produce consistently as well as on those, that produce inconsistently.

By monitoring the running time of the pumping unit under pump-off control a lot of practical conclusions can be reached at field level. The key to successful use of the product is to monitor running time and production carefully. If there is variation in running time without a corresponding variation in production, the pump should be checked. A malfunction within the pumping system can cause these conditions to exist.

Water floods, steam floods and other pressure drive systems can be monitored using this control. As additional fluid is available within the well bore (assuming adequate pump capacity) the control will allow the pump to pump the well until pumped-off. If production is declining the control will allow the well to be pumped only as long as necessary to pump-off.

The control can be used to reduce wear and tear on equipment. Rod parts, fluid pound, gas locking, inefficient pumping, etc., can cause damage to the mechanical and electrical components of the pumping system. If the well is allowed to pump only when it is pumping normally and with reasonable efficiency, operating costs will be minimized and production will be maximized. Operating costs affected by use of this control include pulling costs, power costs and production lost due to down-time or missing part of the flood in cases of water flooding, steam flooding, etc. Maximum production will be obtained by pumping the well until it pumps-off every time it comes on.

The successful application of this control depends on its specific application to each well. The control adjustments are simple and do not require sophisticated equipment or personnel. Through proper adjustment the control can be applied to many kinds of wells. Gassy wells require an adjustment different from that of wells producing no gas. High-volume producers require adjustment different from that for low-volume producers. Each characteristic of each well must be considered for best results.

Training sessions are a necessary part of practical application of this type of product. Field personnel as well as upper management personnel must be properly schooled in its use and proper application. The manufacturer conducts sessions to provide this training and also provides literature outlining the adjustment procedures and the use of the product in varied applications.

AUTOMATION ADAPTATION

One of the major points in using pump-off controls is the ability to monitor and control the pumping unit from a remote location.

A set of contacts is provided so that the running time of the pumping unit can be monitored. If the contacts are closed, the pumping unit is running; or if they are open the pumping unit is not running. The expected percent of running time of the pumping unit can be set into a monitoring computer. The period of time can be as short as one pumping cycle or as long as 24 hours or longer. Since the shorter the time interval considered, the greater the possible variations in running time, a good compromise is 24 hours elapsed time. This is a long period of time to get a fair average of the pumping unit running time per hour. Yet is it short enough to allow field personnel to correct a problem with a minimum delay. The computer can be programmed to give an alarm when the running time of the pumping unit falls outside of the expected limits.

In addition to monitoring the pumping unit running time, the computer can monitor the pump-off control for indications of a well malfunction. A set of contacts is provided that indicates when the pump-off control senses a malfunction. If a malfunction of the pumping system occurs, the computer can be programmed to give an alarm immediately. Corrective action can be taken and the well can be put back on line quickly.

The pumping unit can be started or stopped from a remote location by sending a 15-volt pulse to the appropriate inputs of the pump-off control. These signal inputs are completely isolated from the pump-off control electronics circuits by means of optical isolators. These isolators prevent any ground loops from interfering with the normal operation of the pump-off control.

For special computer applications, an extra card location is provided for interface electronics.

ECONOMIC ANALYSIS

The only reason for using a pump-off control is the economic advantage that it gives. There are many factors involved in the economy achieved. Some factors are directly related while others are more intangible.

The directly related factors are power reduction and optimum pumping of the well. The amount of power saved is dependent on pump capacity, formation productivity, motor size and present pumping method (24 hours per day, time clock, etc.). These factors will be different for each well. However, they can be calculated fairly accurately for most wells.

The intangible factors are more difficult to evaluate. However, they definitely exist and should be considered. These factors are reduced rod parts, lower pumping unit maintenance, lower pump maintenance, less tubing wear, and scheduled well service. In addition, the operator can be aware of any of the above problems within 24 hours. Quick attention to problems will be instrumental in increasing overall production of the wells.

As stated before, these factors are more difficult to evaluate, but it should be noted that if the pump-off control saves only one pulling job, it will pay for itself. From the standpoint of power reduction, it has been shown on some wells that the pump-off control would pay out in less than six months.

When all factors are considered, using the pump-off control is the most economical way to pump a well.

CONCLUSIONS

Several conclusions were reached during the course of the development of this control device. One of the first conclusions was that a better method to control pumps was needed. This conclusion was reached after reviewing previous pump control methods. Basic design criteria were reviewed carefully and test units proved that the actual control device met these criteria. Through extensive field and lab testing it was concluded that a better pump-off control had been developed. The motor current averaging technique had been proven to be superior to other load or production monitoring devices both in accuracy of detecting pump-off and in simplicity.

Certain pump and equipment malfunctions were found to be detectable with the control device after it was in the testing stage. Rod parts, sticking pumps, gas locks, single phasing motors and other conditions causing abnormally high or low motor load can be sensed. Pumps can be turned off automatically when these conditions prevail.

It was concluded that automation requirements could be met by supplying terminals for the various outputs of the control device.

After proving the theory of control in the field, studies were made to determine the practical application of the theory. It was concluded that the theory and the product can be applied to most electrical pumps operating under conditions of pump-off.

The final conclusion of any undertaking must be in relation to the economics of application of the theory and the actual product. Numerous economic analyses have been made by the designer and the users. Conclusions reached by those analyses indicate that application of the product and theory offers economic value that returns the user's investment very quickly with minimum maintenance costs over long-term use. The control is currently being manufactured and marketed successfully.

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