POWER SAVINGS AND LOAD REDUCTIONS ON SUCKER ROD PUMPING WELLS *

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ABSTRACT

In 1985, a silicon-controlled rectifier (SCR) device was installed on a sucker rod pumping well in the North Hobbs Unit, New Mexico, to eliminate a potentially severe structural shaking on unit start-up. On the basis of limited tests on this unit that indicated possible power savings and load reductions, a joint Shell-MagneTek test program was carried out in 1988 on seven pumping wells in West Texas and near Ventura, California.

The SCR device was used to turn the motor off for one or two intervals during each pumping stroke. The motor was turned off for as much as 60 percent of the time in some of the tests. Tests were conducted on conventional and Mark II units and on NEMA "D" and ultra-high slip motors.

Using the SCR device reduced rod loads and peak gearbox torque, or power consumption, by 5 to 15 percent on most of the wells tested. If the power generated during the stroke was ignored, power reductions were 10 to 25 percent. However, we were unable to achieve the maximum rod loads/gearbox torque reduction and maximum reduction of power consumption using the same SCR cycle.

On the basis of the initial tests, a microprocessor controlled prototype unit is being designed and tested. The controller has four operating modes to a) minimize energy consumption; b) minimize rod/gear box loading; c) maximize pumping efficiency, or; d) improve overall performance by optimizing the above modes.

INTRODUCTION

A SCR type soft-starter, similar to the ESP soft-starter described by Neely, et al[1], was installed on a pumping well in the North Hobbs Unit, New Mexico in October 1985. The well was being produced with a conventional 168 inch [4.26 m] stroke unit driven by a 100 hp [74.6 kW] NEMA "D" motor, with a 2.25 inch [51.15 mm] downhole pump located at a depth of 4,250 feet [1295 m]. The soft starter was installed in a successful effort to eliminate potentially damaging structural shaking during the unit start-up.

In 1986, additional tests were performed on this unit to determine if peak loading and energy consumption could be reduced by switching off power to the motor during part of each stroke. Although problems with data collection were encountered, the North Hobbs measurements and subsequent computer simulations led to a joint Shell-MagneTek test.

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Measurements were made on five West Texas wells and later on two additional wells near Ventura, California. Tests covered conventional and Mark II units, NEMA "D" and ultra-high slip motors, and one well ("F") had a 50-50 steel and fiberglass rod string. Data on the seven wells are listed in Table 1.

TEST PROGRAM

Tests were carried out using an enhanced version of the Shell "Delta" van described by Kramer, et al.[2] The system measured the polished rod load and position, motor speed, and three-phase power 35 times per second. Measurements were displayed in real time and recorded on computer disk for later analysis that included calculating the downhole pump dynamometer card and gearbox torque. Although measurements were stored for several hundred strokes on the seven wells, only a few typical cases are discussed in this paper.

Typical analysis of one uncontrolled pump cycle (well "C") are shown in Figures 1-A and 1-B. Figure 1-A shows the measured load versus position dynamometer card at the polished rod and the calculated downhole pump card.[3] Figure 1-B shows the measured polished rod load, motor speed, and kilowatts as a function of gearbox crank angle, where zero degrees is defined as the bottom of the stroke. Motor speed varied between 1245 and 1012 rpm, or 19 percent, during the pump cycle. During about 60 degrees of crank rotation, the kilowatts went negative which means the unit generated electricity during this part of the cycle. The geometry of conventional and Mark-type pumping units result in the unit always generating electricity at least once and frequently twice during the cycle. Note that the peak kilowatts measured during the upstroke and downstroke are almost equal indicating nearly optimum counter-balance.

The SCR device was connected so that it could turn the power off and back on one or two times during each pumping unit stroke. Instrumentation allowed the on/off time increments to be adjusted as desired. When power was turned on, it was ramped up to prevent a large surge of current. In this discussion, a controlled cycle used the SCR device to turn the power off during parts of the pump cycle, and during an uncontrolled cycle, the SCR device was not in use.

The SCR device was connected so that the pumping unit could easily be transferred between the controlled and uncontrolled mode of operation. Since conditions on a well that pumps off can change within several minutes, the controlled and uncontrolled data for a stroke were taken within one to two minutes of each other. When the change was made, the well would stabilize within one or two strokes. Each figure is labeled with the time and date, so the time between pump cycles can be determined.

All the wells tested were capable of pumping more fluid than the well inflow capacity and were normally controlled by a pump-off controller. However, during these tests the pump-off controllers were turned off for convince in testing. The SCR device can be used with any of the types of pump-off controllers described by Neely, et al[4]. With or without pump-off control, the SCR control should be inoperative during the first five to ten strokes following a shutdown period.

DISCUSSION OF RESULTS

When power is turned off for part of the stroke, the pumping speed is affected. If power is off while the motor normally generates electricity, the unit speed increases above the speed of the uncontrolled case since the motor acts as a brake when it generates electricity.

In this discussion, comparisons of power used are based on a per barrel of downhole displacement, calculated using pumping speed and downhole stroke. Power comparisons are made for net power and total positive power; since whether an operator gets credit for the power generated depends on the field system and method of metering power. Rod load comparisons are based on measured polished rod data, and gearbox torque comparisons are based on the API method[5] which ignores inertia.

On most of the figures, the dashed lines represent the base uncontrolled case and the solid lines represent measurements taken with the SCR device turning the motor on and off during the stroke. For these comparisons, the controlled and uncontrolled cases were taken within a minute of each other so the well conditions were essentially the same for the two cases.

WELL "A"

The power and motor speed curves for a test case are shown in Figure 2. The uncontrolled case shows that the motor generated power twice during the stroke and the speed varied from 1235 rpm to 1115 rpm or about 10 percent. Immediately after these measurements were recorded, the SCR device was placed in service, resulting in the power being turned off for about 215 degrees or almost 60 percent of the stroke. The controlled case, recorded one minute after the previous set of measurements, shows the speed varying from 980 to 1565 rpm, which is a speed variation of 37 percent. The controlled stroke resulted in a 4.5 percent reduction of rod loads, a 17.5 percent reduction of peak torque, and a 8.7 percent reduction in net power. If regenerative power is ignored, the power reduction was 25.5 percent.

Another example from the same well, recorded about one hour after the previous case, is shown in Figure 3. In this controlled case, the power was shut off for the same length of time during each stroke as during the previous case; however the off increment was during a different part of the stroke. This resulted in less time required for the upstroke and more time required for the downstroke, and allowed the unit speed to slow down much more during the upstroke. In this case, the motor speed varied from 635 to 1450 rpm, which is a 56 percent speed variation. Rod loads, for this case, were 12.3 percent lower and the peak gearbox torque was 10.9 percent lower than the controlled case. In this case, the net power reduction was less than one percent; but if regenerative power was ignored, the power reduction was 17.5 percent.

These two examples show that a person may have to decide whether electrical power savings or equipment loading is more important. In the field where this test was carried out, rod and gearbox loads are relatively light and power savings would probably be more important. In deeper wells, reducing rod loads would usually be the prime consideration.

WELL "B"

Controlled and uncontrolled measurements on this well are shown on Figure 4. Although this well generates electricity twice during the cycle, one period was quite short. In the controlled case, power was turned off for 50 percent of the stroke. Turning the power 20 degrees sooner (near the top of the upstroke) would have avoided generating electricity. The motor speed variation increased from just over 20 percent to about 27 percent for the controlled case. The controlled case resulted in a 9.7 percent reduction in rod loading and 5.9 percent reduction in peak torque. Total power was reduced by 7.0 percent and positive power used was 12.3 percent lower.

The ultra-high slip motor on this well was run in both the high and low torque modes to determine the effect of speed variation. Switching from the high to low torque mode with uncontrolled motor speed resulted in increasing the speed variation from 20 percent to over 40 percent. The power curves for the two modes were dramatically different, but the power used remained constant. Efforts to improve loading and power usage with the SCR controller were not successful in this case. At first glance, it appeared that changing to low torque had improved results. Rod loading and peak torque were each reduced about 10 percent. Power usage dropped about 5 percent but downhole pump displacement dropped 15-20 percent, resulting in a 10 percent increase in power used per barrel of pump displacement.

WELL "C"

Figure 5 shows motor speed and kilowatts for a controlled stroke on this well, with the power off for about 150 degrees. The corresponding uncontrolled data is shown on Figure 1-B. Speed variation in the controlled stroke was 45 percent versus 19 percent for the uncontrolled stroke. Using the SCR device also reduced rod loads by 10.1 percent and the peak gearbox torque 7.5 percent. The power used during the cycle remained essentially unchanged. Again, these measurements show that allowing the motor speed to drop during the start of the upstroke minimized rod loading, but did not result in using less power.

WELL "E"

This was the only well tested that used a Mark-type pumping unit. The Mark unit has drastically different geometry, designed to give more even loading on the motor during the stroke. Figure 6 shows kW versus crank angle for a stroke of uncontrolled and controlled data. Note that the uncontrolled stroke shows two negative kW periods, but they occur just before and just after the bottom of the stroke. (The bottom of the stroke is the left end of the curve.) The power is positive at the bottom of the stroke due to phasing of the crank counterweights. Motor speed could not be measured on this unit. It should also be noted that this unit was badly out of balance, as indicated by the unequal amplitudes of peaks A and B. The controlled stroke shown resulted in a 2.4 percent reduction of rod loading and a 5.3 percent reduction in peak gearbox torque. In this case, the power used was unchanged. The power probably should have been turned off about 60 degrees earlier and turned back on a little earlier. The test was not conclusive as to the potential benefits of using SCR devices on Mark II units. Also, the badly out-of-balance condition may have effected the test results.

WELLS "F" AND "G"

Wells "F" and "G" are located near Ventura, California. Both of these wells have much higher dimensionless pumping speeds (N/N_o) than the West Texas wells. We were unable to measure the motor speed on either of these wells.

Well "F" has a 50-50 steel/fiberglass rod string. In one case, the controlled stroke showed an 11.3 percent reduction in rod stress and a 3.2 percent reduction in peak torque. Total power was reduced 3.6 percent and positive power was reduced 11.9 percent. In one case, well "G" had a 9.6 percent reduction in rod stress and 7.8 percent reduction in peak torque. In this case, total power used was increased 1.1 percent, but total positive power was reduced 8.9 percent. Results probably could have been improved on both wells if the motor speed measurements had been available to fine tune the tests. Figures 7 and 8 show comparisons directed at reducing rod stresses and improving overall performance.

SUMMARY OF TESTS

The tests show that substantial reductions in loading and electrical power usage can be achieved with on/off control on sucker rod pumping wells. However, maximum load reduction and minimum power usage will not occur simultaneously. An operator must decide which is more important in a particular case.

Most pumping wells have two intervals of negative power during each stroke. These occur at the top and bottom of the stroke for conventional units. Turning the power off for periods of negative power was beneficial in all cases. Minimum loading was obtained by turning the power off prior to reaching the bottom of the stroke, and leaving the power off until well into the upstroke. However, the longer power is off at the beginning of the upstroke, the more the unit will slow down. Bringing the unit back up to speed uses extra power. Thus, minimum power usage will occur when power is left off for the negative power periods only.

PROTOTYPE UNIT

The SCR test results were obtained by sensing beam pump position with a potentiometer and using an adjustable electronic timing device to position and modulate the on/off time increments. The solid state SCR motor starter was used to control the motor torque. The on/off times were manually adjusted to optimize operating conditions while monitoring rod stresses and systems power.

This process must be automated to be practical for field applications with varying well and pump conditions. To accomplish this goal, a microprocessor based system and control algorithms are being developed. Figure 9 outlines the basic control configuration.

The microprocessor software and circuitry operate to regulate and ramp the motor current on and off in response to the sensed parameters (i.e. beam position, rod stress, voltage, amperage, and power). The specific on/off action taken depends on the control mode chosen to best suit the specific well conditions. The following four modes are being developed to address specific field conditions.

MODE I - Power Reduction. This algorithm minimizes[6] or reduces system power while increasing the ratio of strokes per minute to kW (SPM/kW).

MODE II - Load Reduction. This algorithm reduces rod and gearbox loads while maintaining the strokes per minute within predetermined limits.

MODE III - Improved Efficiency. This algorithm operates to improve mechanical pumping efficiency by providing greater pump displacement. This is obtained by controlling the negative power flow to increase the pumping speed and downhole stroke.

MODE IV - System Optimization. This algorithm operates to provide an overall performance balance of the above three modes. The kW and rod stress are reduced while the strokes per minute are increased, maintained, or kept within acceptable limits.

CONCLUSIONS

Field measurements indicate that reductions of 5 to 10 percent, in rod loads and peak torque, can be obtained by using SCR devices to turn power on and off during the pumping stroke. A reduction in net power used of 5 to 10 percent can be achieved, and a reduction of 10 to 25 percent of the power used can be obtained if the generated power is ignored. These results are for conventional units with both NEMA "D" and ultra-high slip motors. Results on the one Mark II unit tested were less conclusive.

The SCR on/off control can be used with or without pump-off control. In either case, the on/off control should be inoperative during the first 5 to 10 strokes following a shutdown period.

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Table 1
Description of the Beam Pumped Wells Tested

Well	Pump Depth (ft / m)	Pumping Unit	Motor hp	Pump Dia. (in / mm)	N/N_e
"A"	7475 / 2,278	C-320D-300-84	30	1.25 / 31.8	0.35
"B"	4975 / 1,516	C-640D-305-144	*	2.00 / 50.8	0.22
"C"	4975 / 1,516	C-640D-304-144	*	2.00 / 50.8	0.22
"D"	7575 / 2,278	C-228D-250-74	25	1.25 / 31.8	0.33
"E"	7675 / 2,278	M-640D-365-168	75	1.50 / 38.1	0.31
"F"	8730 / 2,661	C-912-365-168	100	1.50 / 38.1	0.43
"G"	7980 / 2,432	C-912-365-168	125	1.75 / 44.5	0.44

* Ultra-High Slip Motors were used on wells "B" and "C". The rest of the wells used NEMA "D" motors.

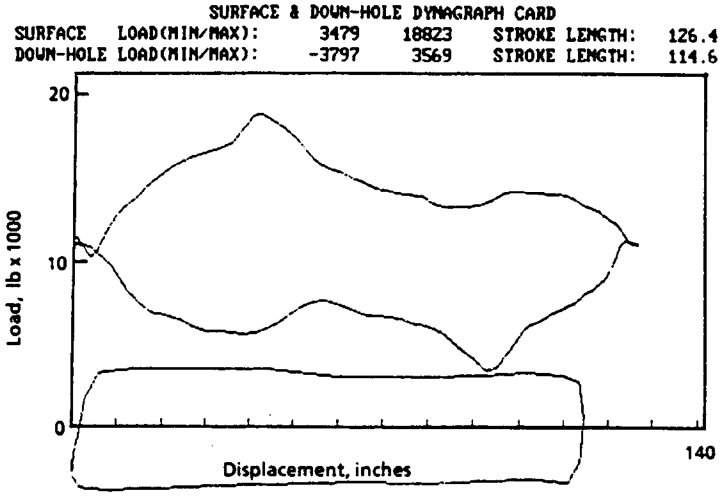


Figure 1A - Measured dynamometer card with the calculated downhole card for a typical well "C" case without the SCR device

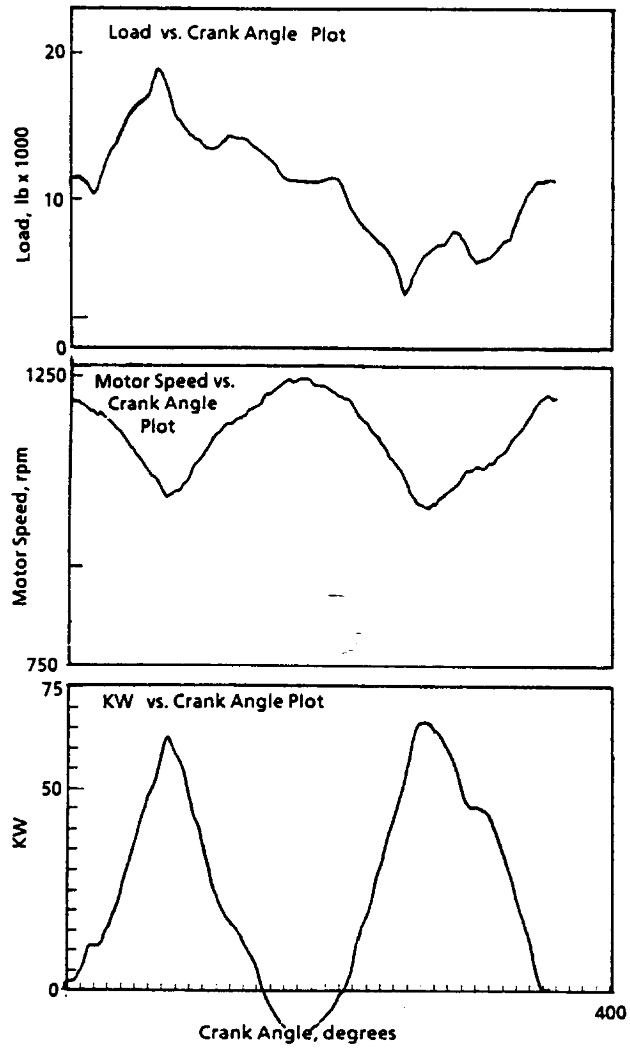


Figure 1B - Measured rod load, motor speed and kilowatts for a typical well "C" case without the SCR device

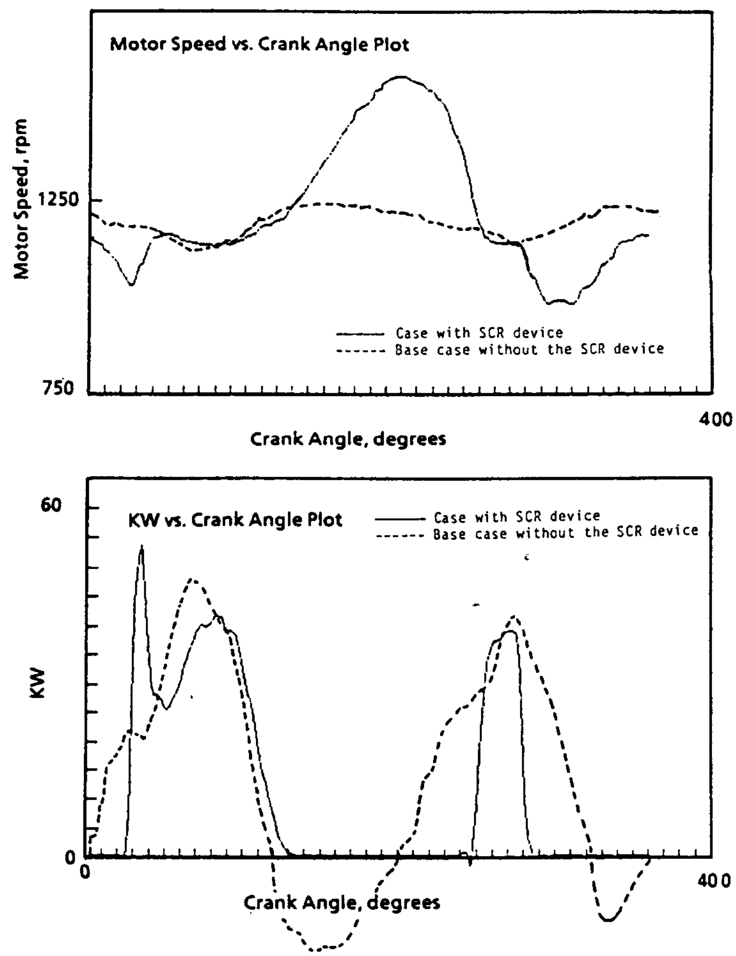


Figure 2 - Measured kilowatts and motor speed as a function of the gearbox crank angle for Test Well "A"

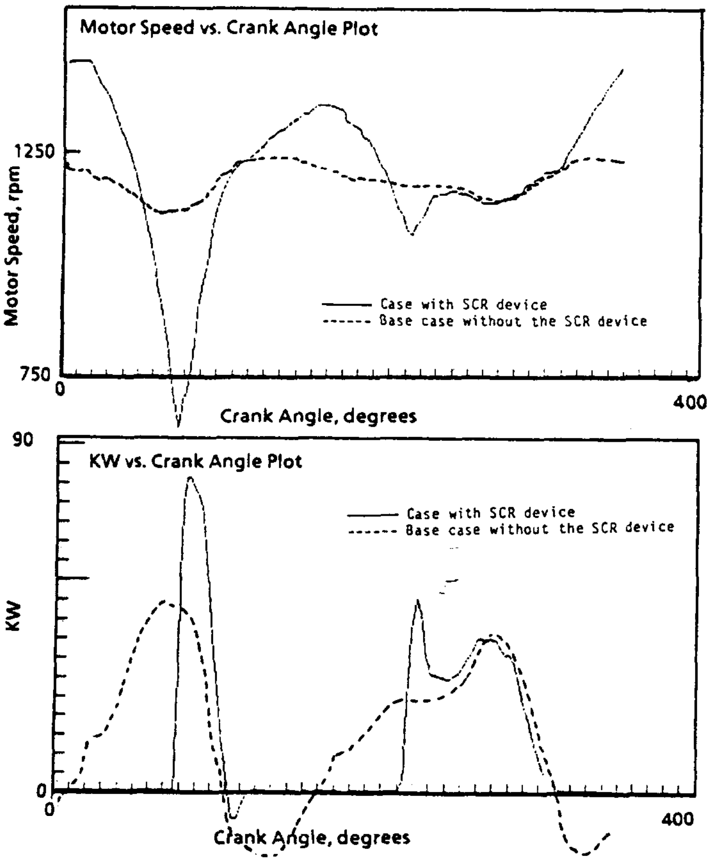


Figure 3 - Measured kilowatts and motor speed as a function of gearbox crank angle for Test Well "A"

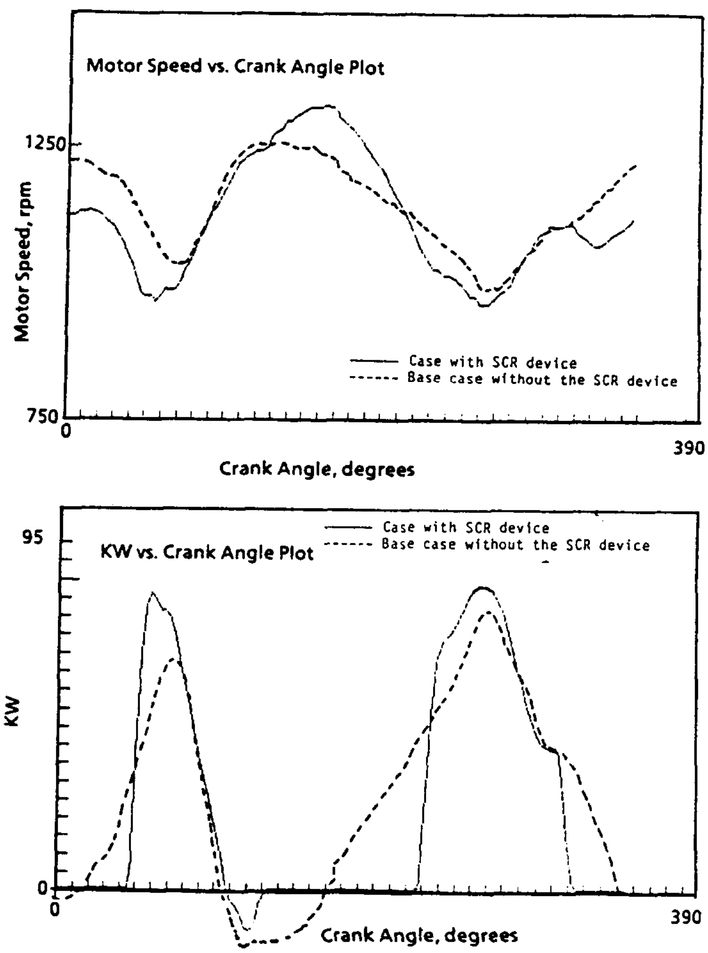
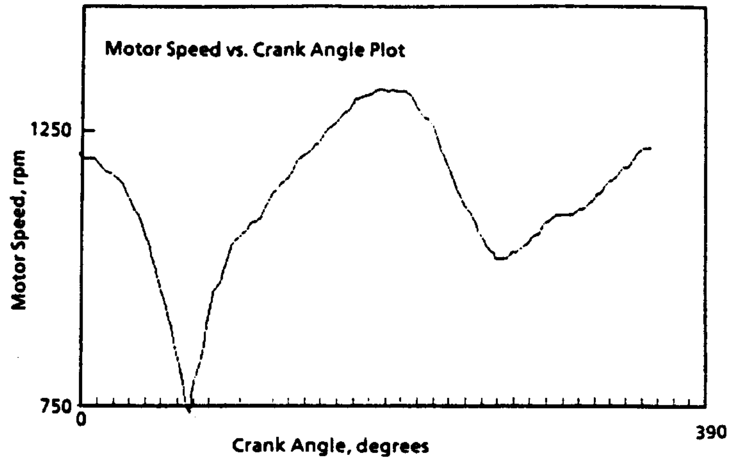


Figure 4 - Measured kilowatts and motor speed as a function of the gearbox crank angle for Test Well "B"



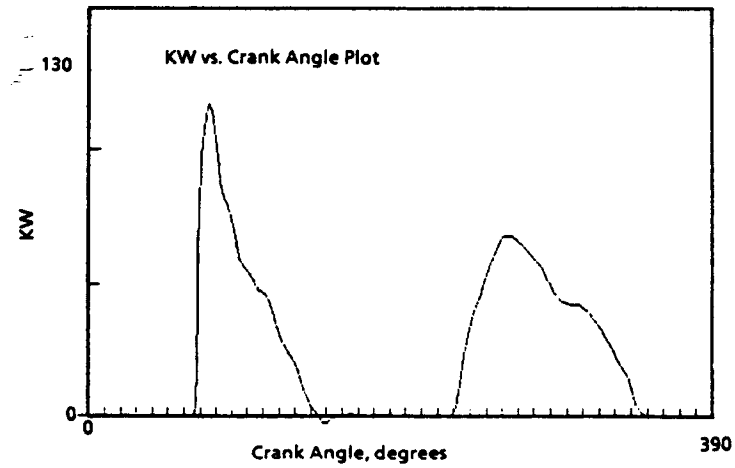


Figure 5 - Measured kilowatts and motor speed as a function of the gearbox crank angle for Test Well "C"

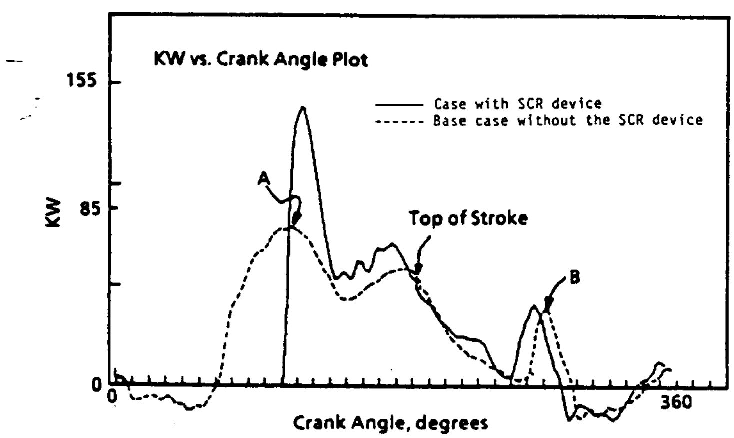


Figure 6 - Kilowatts as a function of the gearbox crank angle for Test Well "E" with a Mark-type pumping unit

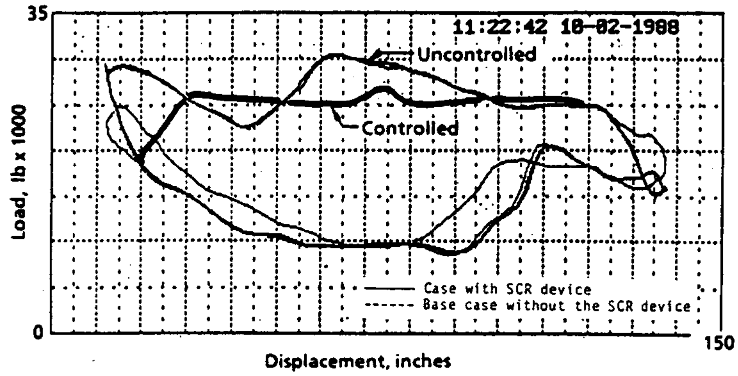


Figure 7 - Measured surface dynamometer cards for the Test Well "F"

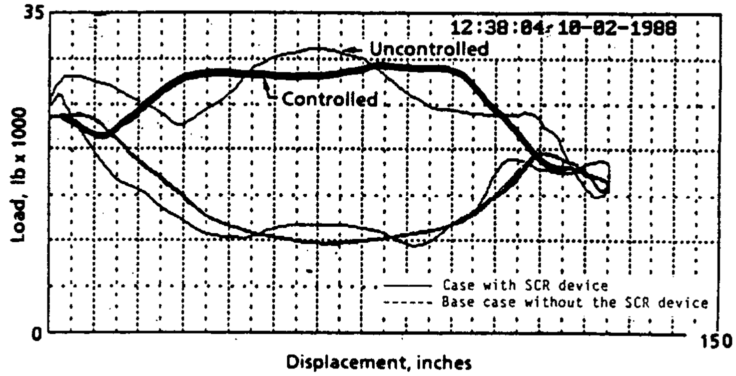


Figure 8 - Measured surface dynamometer cards for the Test Well"G"

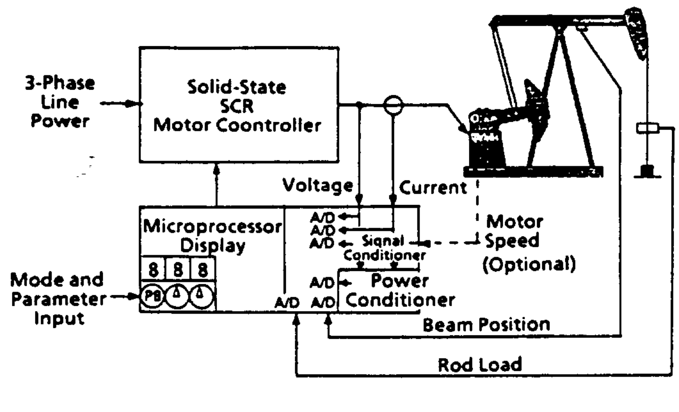


Figure 9 - Basic configuration for a microprocessor-based system for controlling the on/off time increments during a pump stroke