SUBMERSIBLE MOTOR CONTROL

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ABSTRACT

Submersible pumping applications are becoming more and more commonplace in the oilfields. Many oilfield personnel are quite familiar with the beam pump and its characteristics. Just as this unit has served reliably over the years, a properly installed and controlled submersible should give a respectable service life and should pay for its existence many times over. Maximizing the service life of submersible equipment entails the proper utilization and understanding of submersible motor controls. A variety of motor controls and their many features, ranging from simple load-break magnetic circuits to the more sophisticated solid-state monitoring technology, will be presented. This paper will treat not only control functions but also what benefits the user can realize by proper application and analysis of particular control areas.

Before analyzing control functions and their operating characteristics, it is important to develop a basis for understanding the relationship between the submersible pumping equipment and the motor controller. The motor controller is more than just an adequate term which would seem to suggest an energizing mechanism. In reality, the controller encompasses the full meaning of control, i.e., regulation and direction, and ultimately leads to protection of its subjective parts. In most cases the cost of the controller will be from 10% to 20% of the cost of the entire system. Therefore, effective use and proper understanding of controller functions can certainly net positive economic results.

EQUIPMENT SUBJECTIVE TO THE CONTROLLER

Submersible Pump—This entity converts rotating torque to hydraulic work. Indirectly through the submersible motor, the pump transmits information to the motor controller concerning its operation. Processable information includes terms such as pump-off condition, gassy well conditions, low flow, and excessive wear. These terms will be further explained as the description of the controller makes their understanding necessary.

Submersible Motor—The submersible electric motor is a specially designed two-pole, three-phase induction device. Specifically, this is the most expensive part of the system but it can be directly and easily controlled. One outstanding physical element which dictates the need for motor control is higher than normal levels of heat subsequently increasing the probability of premature motor failure.

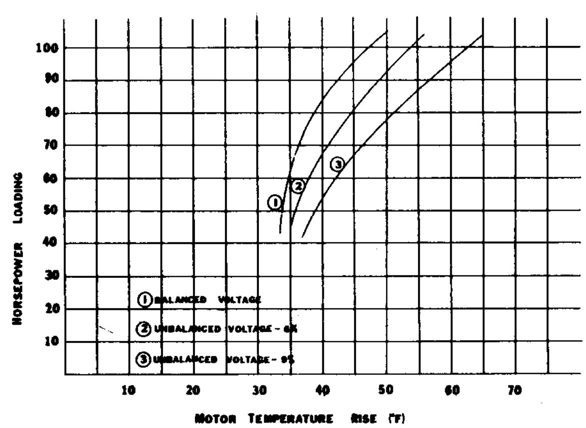
The heat experienced by the submersible motor involves two sources. One is the ambient temperature associated with the well fluid; and, two, the heat generated internally due to winding loss (electrical), core loss (magnetic), friction and windage losses (mechanical). Higher than normal levels of heat ultimately shorten the life of the equipment. High levels of heat that would adversely affect motor life can be attributed to four controllable parameters.

1. The current drawn by a submersible motor is a direct function of the horsepower loading. Therefore, when a motor operates beyond its rating, larger than normal currents are present. As the motor current increases, the heat generated in the motor increases directly as a function of the power (I^2R). This results in higher heat being present in the insulation area and ultimately decreases motor life.
2. The submersible motor is designed to be cooled by the liquid flowing along the perimeter of the motor to the intake of the pump. Any flow reduction, such as well pump-off, plugged

pump stages, etc., would then result in less heat being dissipated by the cooling medium.

3. A locked rotor condition exists when any condition stops the turning of the motor shaft. A submersible unit can demand up to eight times the nameplate-rated current at 100% nameplate voltage. As in the first case, internal temperatures rise drastically; and, as in the second case, there is no flow for dissipating this tremendous heat generation.
4. Finally, if a submersible motor is subjected to a "single phase" or severe unbalanced voltage condition, then high levels of heat will be experienced in the windings of the electric motor. The source of this heat is the circulating currents in the motor of both "positive" and "negative" sequence. "Positive" sequence currents are those that represent useful (positive) work. "Negative" sequence currents flow opposite to "positive" sequence and thereby represent net losses to the system. The "negative" sequence currents increase as voltage unbalance increases. Figure No. 1 portrays motor temperature rise as a function of horsepower loading and percentage of voltage unbalance. A single-phase condition is, of course, the most severe case for voltage unbalance.

Of course, there are other parameters that shorten motor life, such as, leaks in seal areas, severe corrosion pits which contaminate the interior of the motor, and excessive well temperatures which elevate system operating temperatures resulting in irreparable damage to motor insulating materials. Excessive bearing wear, water around connections, and rotor rub can then easily consume the remaining life of a motor. These types of problems cannot be handled by motor controller functions. This is not to imply that there is no solution; it is just that those solutions are not in the scope of this paper.



WATER @ 1 Ft/Sec. USED AS COOLING.

FIGURE 1—HEAT RISE EFFECTS OF UNBALANCED VOLTAGE, 100 H.P., 544 SERIES

The percentage of parameters that cannot be controlled are quite small in comparison to those that can be controlled. Our company records indicate that less than 15% of the failures can be attributed to parameters that cannot be controlled. All of the units examined in this sampling were under the auspices of a motor controller; therefore, it is obvious that 85% of the failures occurred under controllable conditions. One must remember that equipment does wear out and that controlled equipment has an increased useful life. Some equipment, however, is not controlled properly and herein lies the basis for this paper as detailed below.

SUBMERSIBLE MOTOR CONTROL

Control and Protection of the System

The motor control enclosure located in the proximity of the wellhead handles a variety of functions tailored to the user's needs and in harmony with the production of that particular well. Connected to the controller and banded to the tubing string in the annulus is the power transmission (communication) link between the electric motor and controller, specifically the power cable. The motor contactor, which is the heart of the controller, can be thought of as primarily a digital device; it is either "on" or "off." The monitoring equipment associated with the controller measures preset tolerance levels of specific parameters that are direct functions of both the electric motor and pump, functions that are necessary for their proper operation. A well-regulated system can be attained by monitoring the following characteristics: motor current, voltage/current unbalance, phase reversal, phase failure, short-circuit protection, and external overrides (float and pressure switches).

These control functions are not difficult to employ and achieve desirable results. An area that is more difficult to deal with is that of transient protection. Transients occur so quickly that it is beyond the ability of the motor controller to sense and respond to these phenomena before actual damage has occurred. It is, however, a parameter that should definitely be considered in many areas. Lightening arrestors and surge capacitors can be installed on the line and load side of the motor controller. Transient spikes that might damage the monitoring equipment (located in the low-voltage section of the controller) can generally be suppressed by components such as varistors.

Monitoring equipment activates, or is in itself, the necessary device to de-energize the contactor and shut the unit off, automatically restart the unit after some time interval, permanently disable an automatic start should there be a fault in the downhole system, and/or energize the contactor when certain external conditions (float and pressure levels) are achieved. With regard to the previous mention of the protection characteristics of monitoring equipment, it is important to understand what the characteristic means, when it should be monitored, why it should be utilized, and what the user can hope to gain from its application. It will then be obvious how each of these characteristics, excluding certain types of external overrides, relate to the main problem of heat and its controllable parameters.

Protection

Motor Current—Without a doubt this is the single element that should be continuously monitored in every installation. In monitoring the current, a permanent record can be obtained by using a recording ammeter for analysis purposes. When recording the current for documentation, it is an accepted practice to monitor only one of the three phases. However, in the monitoring of motor current for protection purposes, other types of devices include inspection of all three phases. In the case of overload protection, electro-mechanical relays as well as solid-state devices are continuously checking for current levels that are higher than preset tolerances. Generally, on start-up, an electric motor (as mentioned earlier) will have an inrush current as high as eight times rated current. To allow the monitoring devices to detect this momentary level of over-current and react would result in "nuisance tripping." Delay timing functions are then given a dual purpose assignment with regard to overload protection. On start-up they allow the system a period of time to stabilize, and this stabilization period is also useful in keeping momentary low levels of overload (20% to 30%) from interrupting service.

The most severe overload is, of course, a locked rotor condition. Extreme levels of heat can be achieved in seconds and if left in this state would soon result in a motor burn. An important approximation that helps relate the levels of heat with motor current is: heat generated in the windings is proportional to the current squared.

Under-load current considerations are just as important as overload; however, on electro-mechanical systems, it is a practice to monitor only one-phase current. On certain solid-state equipment, all three phases are continuously monitored just as for overload conditions. The detection of an under-load condition occurs when the submersible has pumped off, which limits the flow of fluid by the motor causing "heat stacking" in the motor. Low currents can also be present under conditions of unbalanced voltage and loss of phase.

Figure Nos. 2 through 7 are examples of ammeter charts. Figure No. 2 depicts normal conditions; Figure Nos. 3 through 7, the most common problems that may be encountered in submersible pumping applications.

Figure No. 3 is indicative of overload conditions that could be caused by increases in fluid-specific gravity, sand production, emulsions, or mechanical problems. Figure No. 4 is the erratic loading of the pump due to gassy well conditions. Remember, pump horsepower loading is directly related to motor horsepower demand, which alters the needs of the current required. Figure No. 5 is a more severe case of Figure No. 4. As the free gas to liquid ratio (GLR) increases, the probability of "gas locking" increases. The breakover point for gas locking of a submersible pump is 15% of free gas by volume. At the wellhead the gas-oil ratio (GOR) can be much higher than 15% with no gas-locking problems. This is due to the fact that much of the gas is in solution and can be pumped with no problem. Figure No. 6 is indicative of a pump that is too large for the well. As can be seen, the pump quickly reduces the fluid level, then loses its load (due to insufficient fluid at the pump intake), and shuts down due to undercurrent (under-load). Figure No. 7 is the undercurrent (under-load) situation. This particular type of curve is caused by fluid lacking density or volume to maintain a minimum load on the motor.[1]

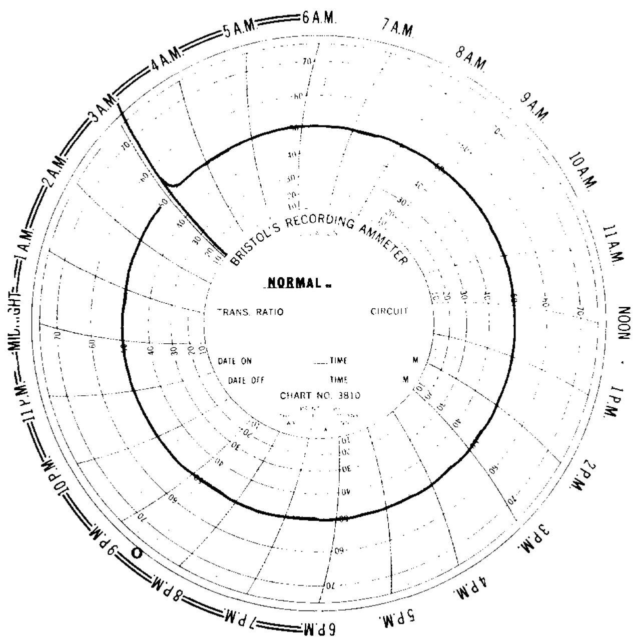


FIGURE 2 -NORMAL

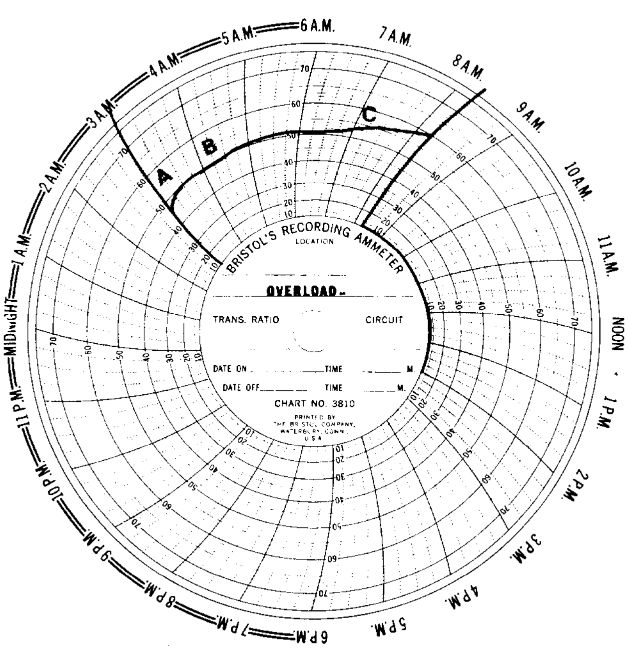


FIGURE 3—OVERLOAD

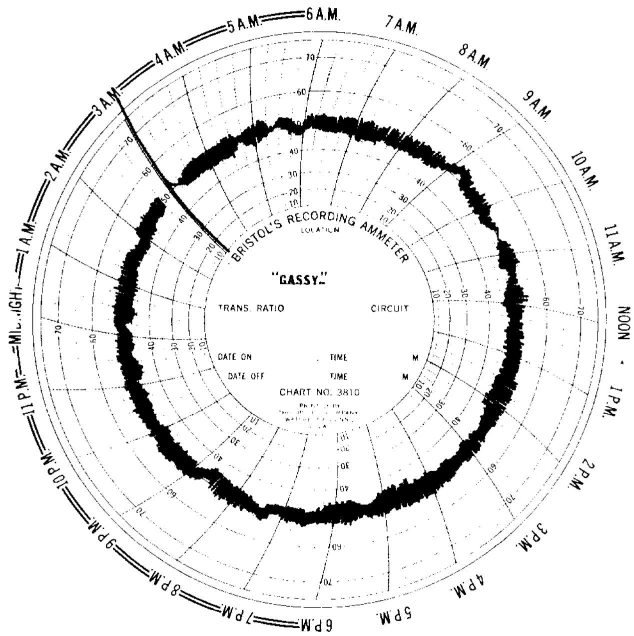


FIGURE 4 GASSY

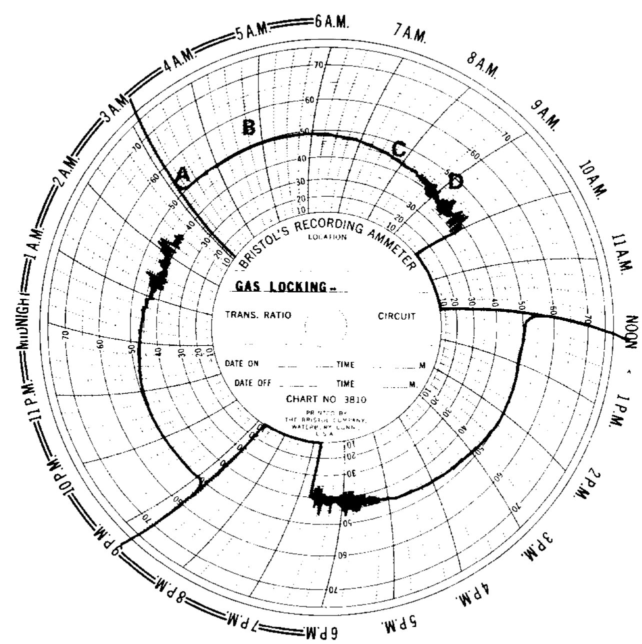


FIGURE 5 "GAS"

The next three characteristics of motor control (voltage/current unbalance, phase reversal, and phase failure) are usually found in one electro-mechanical device and can be incorporated in some

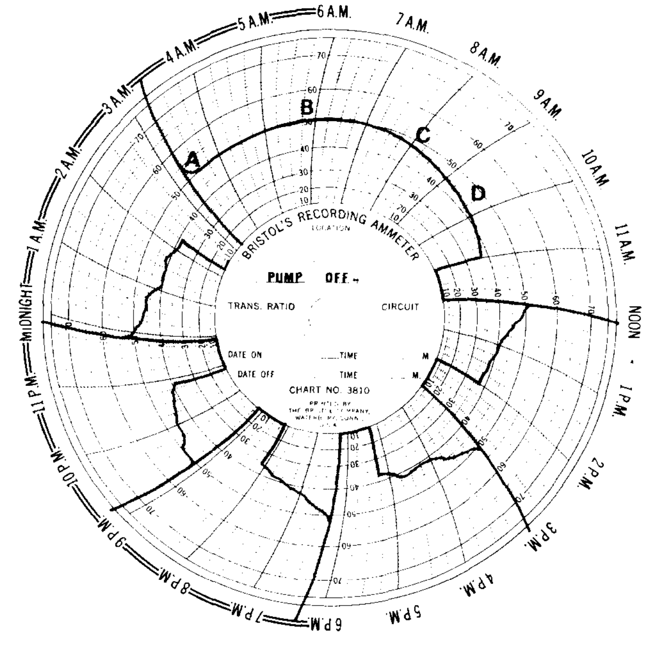


FIGURE 6 PUMP OFF

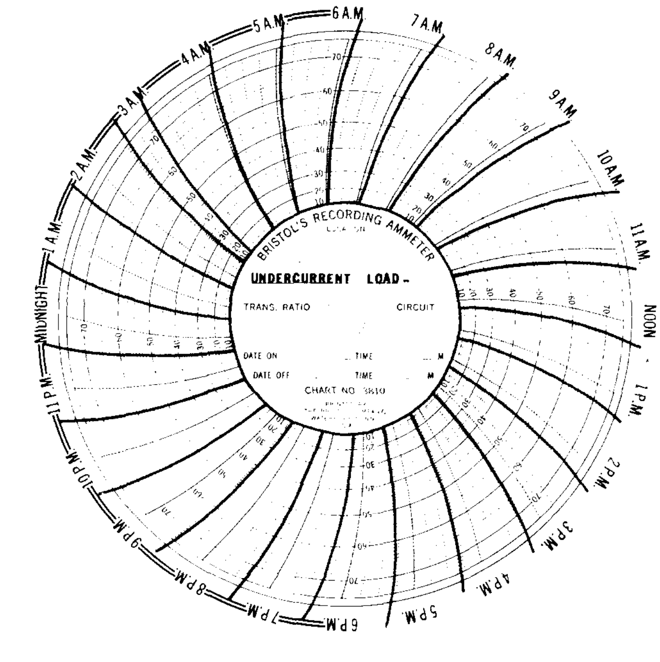


FIGURE 7 UC LOAD

solid-state devices. Voltage/current unbalance, as previously mentioned, causes increased motor heating from high phase currents. Phase reversal is predominant on the source side of the controller when power companies discontinue service for repairs. If this occurs, previously defined ABC systems become ACB which results in reverse rotation of the submersible motor. Even though the submersible pump may be producing fluid, it is definitely not producing according to established curves. Horsepower requirements will be the same or increase; however, flow of the fluid past the motor will decrease and will cause poor heat transfer. Eventually this situation would cause the operator to replace the unit before its full life could be realized. Phase failure as mentioned earlier directly leads to higher levels of heat. The cure for these three conditions is handled by a specially designed relay, which inspects phase angle relationships. This relay is an electro-mechanical device and is either current or voltage oriented. The result of this device (electro-mechanical or solid-state) is, if the condition is detected, immediate de-energization of the main contactor.

Short-circuit protection is not handled by intricate relay detection circuits, but by simple load break devices, fuses and circuit breakers. If there is a major fault on the line, it is not the function of overload relays or overload circuitry in solid-state controllers to take the unit out of service. Any time load fuses are blown or circuit breakers tripped, it is a good indication that careful checks in the power system as well as the load to be energized should be made before attempting to start the motor. Fuses and circuit breakers are relied upon for short-circuit protection because their power interrupting ratings are better suited for the large current flows associated with short-circuit conditions.

Flow, Float, and Pressure Controls

This section of circuitry in the motor controller is significant to the system when used to sense submergence (pressure) of the motor. This information could detect ensuing "pump-off" conditions which would be manifested as an under-load condition on the motor. Other float and pressure sensors are located in tanks (float) or in flow lines (flow) for user needs. All of the above sensing units are wired across normally open or normally closed contacts, usually in series with a control coil and a higher-rated contact used for energizing (de-energizing) the main contactor coil. Timing functions are coordinated with these alarm contacts to minimize contact bounce, transient conditions, and nuisance tripping.

CONCLUSIONS

It should be obvious that the main function of the controller is to protect the submersible motor from harmful levels of heat. An observant reader will already be aware that the detection methods employed are all indirect, relying on functions of heat equations. To date, there is no dependable, direct heat-monitoring system for a submersible motor. In considering motor protection and control for submersible installations, the following is a summary of points to be considered.

1. Motor protection involves de-energizing the motor when preset alarm points occur (high or low current, single phase, phase reversal, etc.).
2. Single phase or unbalanced voltage conditions cause excess motor heating.
3. Protection of the motor insulating materials from transient spikes is not a function of the motor controller. Additional elements external to the motor switchgear are needed to suppress transients.
4. Delay timers and automatic restart timers are necessary to prevent "relay race," to optimize fluid production, and to eliminate shaft breakage problems if the unit were allowed to be started too soon after de-energization.

Whether the user is increasing the life of his equipment or the production of his well, proper submersible motor control will without a doubt be an effective cost reduction tool.

REFERENCE

1. Riling, G.: *Submersible Pump Handbook*, Borg-Warner, (1975) 200-226.