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Closed Loop Speed Control of DC Motors used in Rock Drilling and Mud Pump Application

Nitai Pal, Pradip Kumar Sadhu and R. Swaroop

Abstract—**This paper deals with closed loop speed control of DC motors used in rock drilling. Drilling is the most important part of exploration geology. It is also used for exploration of crude-oil. Drillability of rock mass is the resistance of different rock materials against drilling, controlled by various technological and geological properties. Furthermore, the wear of the drilling equipment may be a severe factor of costs in exploration geology as well as in exploration of crude-oil. When drilling operation encounters various rock types of different drillability, then the necessity of speed control of drill bit comes into account. The closed loop PID control strategy is helpful to regulate the speed of drill bit as well as mud pump. When the drill bit cuts the hard rock without speed variation then maximum heat will be produced due to higher friction with the rock. This overheating of drill bit is one of the main causes of bit failure. In case of hard rock, the speed of the bit is less and torque requirement is more for sustaining the costly drill bit. On the other hand, more chemical mud pressure is required to control the temperature of drill bit. This chemical mud pressure is generated from mud pump which runs at higher speed. The speed of the drill bit must be reduced and at the same time speed of the mud pump will be increased by the proposed scheme. The operating circuit is simulated using PSIM software. The simulation results are plotted and shown feasible for real implementation. The entire TRIAC based speed controller system must be understood before applying geological expertise to the solution of expected or developing drillability problems.**

Index Terms—**PID Controller, Rock Drilling, Mud Pumps, PSIM, TRIAC**

I. Introduction

For decades drilling has been used for exploration to production of petroleum, coal, natural gasses, ore body etc. Now in natural sequences when drilling carried out, rock materials occur as differential layers of varying chemical and physical properties [1]. These properties determine the drillability of rocks. In natural rock sequence when alternation of soft rock and hard rock present the control of speed of drill bit is necessary. When drill bit encounters hard rocks the generation of frictional heat increases many times in comparison to soft rocks at very high speed. These may cause melting and damaging of drill bit. To reduce the heat in hard rock speed should be optimized. But again in soft rock high speed is necessary to reduce the operating time. The speed control is achieved by varying the armature voltage of dc series motor using TRIAC based electronic speed controller.

On the other hand, the speed control of dc series motors using thyristor switching elements is now very widely used for mud pumps applications. A variety of schemes have been evolved incorporating these elements for such purpose. Half-controlled converters and full-controlled ones are examples for such schemes. The steady-state and the transient behaviour of converter controlled dc series motors, assuming linear and nonlinear models, were the subjects for many authors [2], [3], [4] & [5]. Doradla has also used a single thyristor switch together with a bridge rectifier to regulate the speed of dc series motors [6]. In all the above mentioned control schemes phase angle method of thyristor triggering is used. The motor speed is controlled by advancing or retarding the triggering angle of the thyristor.

There was only one published attempt to use the other method of thyristor triggering, namely the integral-cycle method of triggering to control the speed of dc series motors [7]. However theoretical analysis was not given and only experimental results was presented.

In this paper the method of controlling the speed of a dc series motor using an integral-cycle controlled single TRIAC and a bridge rectifier is investigated. The suggested analysis is useful for the proper choice of the TRIAC rating and the proper design of the protective schemes.

II. Mud Pumps

Mud pumps on drilling rigs provide the means for supplying flow and pressure of the chemical mud fluid through the drill pipe, drill bit and return to the surface via the annulus of drill pipe. In this process, the mud maintains down-hole pressure, cools the drill bit and removes the cuttings from the well bore [8].

The motor(s) driving the mud pump through a chain and sprocket must have the ability for variable speed since flow from the positive displacement simplex, duplex or triplex pump is directly proportional to speed. Since down hole conditions require a variable flow rate, the ability to vary the motor speed is essential. Output mud pump pressure is determined by the hole depth, natural down hole pressures, drill bit nozzle sizes, pipe size and restrictions of the mud flow path. Under surface drilling conditions, the pressure requirements are at their minimum. As the hole progresses to deeper conditions, the pressure requirement is increased which is met by the increased motor torque [9].

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Since flow is proportional to motor speed and pressure is proportional to motor current, the voltmeter and ammeter recording the activity of a shunt type motor accurately depicts the flow and pressure conditions of a mud pump. Through proper calibration, the voltmeter can display flow in gallons / minute while the ammeter displays mud pump pressure in pounds / square inch for a given liner size. In the event a series type motor is used, flow and pressure signals can be obtained from the speed calculator card and from the field current. Accuracy of this information to correlate flow and pressure to speed and current is not as precise as with a shunt type motor but will provide a general indication of conditions. Mud pump applications typically require a continuous rating on the part of the motor.

III. DC Series Motor for Drill Rig and Mud Pump

When supplied power from a DC generator, the series type DC motor was avoided in drilling applications because of the possibility of over speed conditions when its mechanical load was suddenly decreased or lost.ˉ However, with the introduction of the TRIAC based regulator, the ability to control the over speed condition of the series motor was solved.

The basic equation for speed (N) of a series type DC motor is:

$$N = \frac{V_a - I_a R_a}{K_1 I_a} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where, N = motor speed in RPM
K_1 = a proportional motor constant
V_a = motor armature voltage
I_a = motor armature current = I_f = motor field current

This equation states that the motor speed is directly proportional to the ratio of voltage to current. With a fixed value of armature voltage, decrease in field (or armature) current will cause a corresponding increase in motor speed and vice-versa.

The TRIAC based electronic regulator has the ability to respond very rapidly when called upon in certain situations. For example, when a heavily loaded mud pump being driven by a series DC motor has its drive chain break, the series motor could over speed to destruction. With electronic detection of decreasing motor current when the chain breaks, the regulator can either be turned off completely or "phased back" to remove or reduce the armature voltage to prevent this runaway condition.

IV. The Series Motor Has Several Operating Characteristics in Drilling Applications:

1) No separate field supply is needed with a series type DC motor for normal operation. However, when regenerative or dynamic braking a series motor, some manufacturers provide a separate high current field supply to create this mode of operation for the drawworks motor. With the mud pump and rotary table, braking with the field supply is not required.
2) When reversing is not required, such as with the mud pump motors, only two conductors are required to the motor.
3) To prevent over speed and to regulate speed under normal operating conditions, an electronic "speed calculator" card is required in conjunction with the TRIAC based electronic regulator.
4) The DC series motor produces greater torque than the shunt motor at the upper end of the torque-current curve. This is a result of the mechanical construction of the field coils which take up less space than the multiple small shunt coil wires to get the same electrical flux / torque. A comparison between the shunt and series motor torque-current curves is shown in Fig. 1.
5) The correlation of speed to voltage of a series motor is not as accurate as with a shunt type motor. This is because speed is a function of both field current and voltage. Consequently, a load change (torque/pressure in a mud pump) will result in a change in current. Since field current and armature current are the same in a series motor, this then results also in a speed change.

$$T = K_2 \times I_a \times I_f = K_2 \times I_a \times I_a = K_2 \times I_a^2 \text{ --------------------(2)}$$

where, T = torque
K_2 = motor design constant
I_a = motor armature current = I_f = motor field current

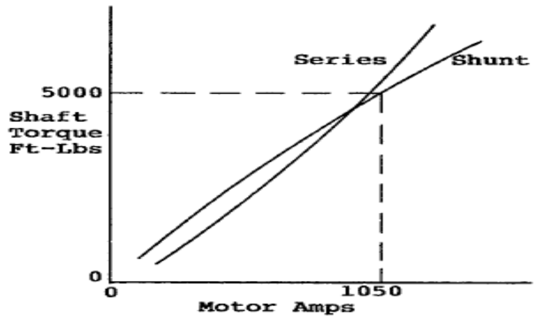

Fig. 1. Torque current curves of shunt and series type dc motors

V. Suggested TRIAC Based Motor Control Scheme for Drill Bit and Mud Pump

The TRIACs of today are well suited to the requirements of switching inductive loads. TRIAC control circuits must be particularly well tuned to be both economical and applicable to inductive loads. The TRIAC based motor control scheme for drill bit suggested for our study is shown in Fig. 2 and the same scheme for mud pump is shown in Fig. 3. The closed loop PID control strategy is helpful to regulate the speed of drill bit as well as mud pump. When the drill bit cuts the hard rock without speed variation then maximum heat will be produced due to higher friction with the rock. This overheating of drill bit is one of the main causes of bit failure. In case of hard rock, the speed of the bit is less and torque requirement is more for sustaining the costly drill bit.

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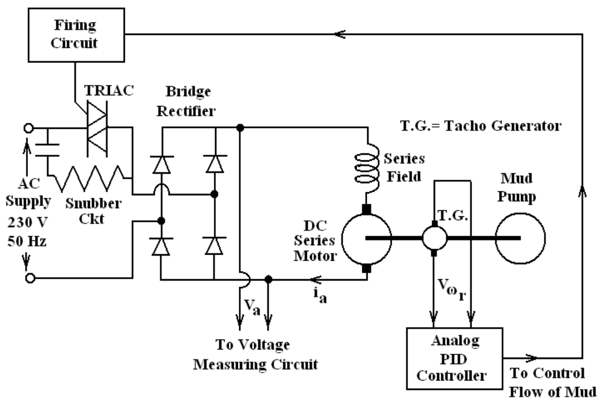

Fig. 2. Suggested TRIAC based motor control scheme for drill bit

On the other hand, more chemical mud pressure is required to control the temperature of drill bit. This chemical mud pressure is generated from mud pump which runs at higher speed. The speed of the drill bit must be reduced and at the same time speed of the mud pump will be increased by the proposed scheme. Both the schemes consist of a single TRIAC connected in series with the bridge rectifier across ac supply lines. The motor current is rectified using a bridge rectifier. The bridge provides also a relaxation path for the motor current during the extinction period of the TRIAC. The motor is controlled by applying a conduction period of a complete number of supply cycles followed by an extinction period of another number of supply cycles to the motor terminal. The necessary firing circuit for such method of TRIAC triggering was developed.

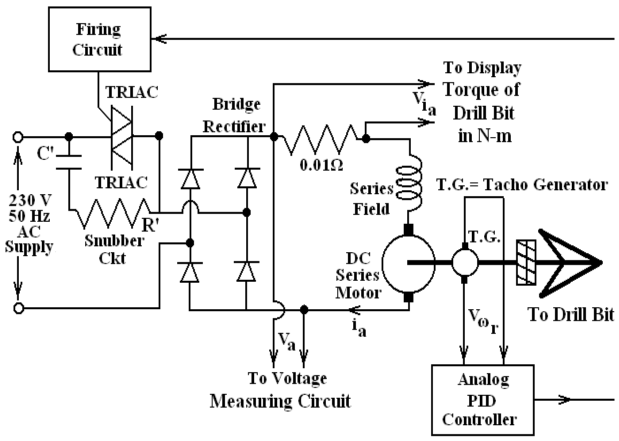

Fig. 3. Suggested TRIAC based motor control scheme for mud pump

The TRIAC based suggested motor control scheme can be simulated with the help of PSIM (Power SIM) software under the following assumptions:

1) The TRIAC and diodes are assumed to be ideal switches.
2) Skin effect in armature conductors and field winding is neglected, so that the total motor series resistance can be assumed constant.
3) Eddy current losses in armature conductors and in field winding are also neglected.
4) The relation between the motor current and the induced e.m.f is described by the magnetization curve.
5) Armature reaction and brush voltage drop are ignored.
6) The mechanical losses for both motor and load generator are non linear functions of motor speed.
7) The iron losses for both motor and load generator are also nonlinear functions of magnetic flux and speed.
8) The motor se1f inductance varies with the variation of the motor armature current.
9) The source inductance is neglected.

VI. CONCLUSIONS

The performance characteristics of a dc series motor having an integral-cycle controlled single TRIAC connected in series with one of its ac supply lines is studied. The motor current is unified using a rectifier bridge. It shows that the average speed of a dc series motor can be controlled using the suggested scheme presented in this paper. However speed ripple, vibration and noise may probably make this form of control unsuitable for large motors. Speed ripple has to be reduced to improve motor dynamics. This will be investigated in a future study. The suggested methods for the reduction of the speed ripple are summarized. A microprocessor aided measuring circuit can be used to measure the motor performances. The speed control of dc series drill motor requires a critical choice of TRIAC triggering circuit to control the speed of drill bit and mud pump to control the flow of mud.

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