Open loop and Closed loop speed control of Separately excited DC Motor

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Abstract: The open loop control of DC motor by varying Armature voltage, Flux control and Resistance control is verified. Closed loop motoring using two quadrant chopper is also verified. The results are verified using code and GNU plot.

Keywords: Armature voltage, Flux control, Resistance control, Two quadrant chopper, GNU plot

INTRODUCTION

DC motor requires different speeds for different application so it’s necessary to control the speed of a motor. Speed of motor can be controlled using two loop configurations such as open loop speed control in which the input parameter is varied to get the speed needed for the application and closed loop control in which a PI controller with a two quadrant chopper is used which automatically adjusts the speed to the reference input speed. The open loop control of a D.C motor is mainly divided into (1) Armature control methods because the changes directly affect armature circuit. It is again sub-divided into (a) Armature voltage control and (b) Armature resistance control (2) Field control methods [1]. The closed loop control of D.C motor is done using chopper circuit.

The objectives of our project is to control the speed of a separately excited D.C motor using different loop configurations such as open loop and closed loop using a two quadrant chopper.

OPEN LOOP SPEED CONTROL

Speed control means intentional change of the drive speed to a value required for performing the specific work process. Speed control is a different concept from speed regulation where there is natural change in speed due change in load on the shaft. Speed
control is either done manually by the operator or by means of some automatic control device maintaining the integrity of the specifications. One of the important features of dc motor is that its speed can be controlled with relative ease.

The speed (N) of 3 types of dc motor – Series, Shunt and Compound can be varied by changing

- Terminal voltage of the armature (V)
- External resistance in armature circuit and
- Flux per pole (φ).

The first two cases involve change that affects armature circuit and the third one involves change in magnetic field. Therefore speed control of dc motor is classified as

- Armature control methods and
- Field control methods.

Equation (1) is got by applying KVL to Fig 1

\[ E_a = K_a \phi \omega_m = V_t - I_a R_a \]  

Where,

\( E_a \) = Back E.M.F

\( \phi \) = Flux induced

\( \omega_m \) = Speed of D.C motor
\( V_t \) = Applied armature voltage

\( I_a \) = Armature current

\( R_a \) = Armature resistance

\( T = K_a \phi I_a \) \hspace{1cm} (2)

Equation (2) represents the torque developed in a motor

\( T \) = Torque developed

From the above equations,

\[ \omega_m = \frac{V_t - I_aR_a}{K_a\phi} \] \hspace{1cm} (3)

\[ \omega_m = \frac{V_t}{K_a\phi} - \frac{R_a}{(K_a\phi)^2} T \] \hspace{1cm} (4)

**Armature Control of DC Motor**

Speed adjustment of separately excited D.C motor by armature control may be done by any one of the methods that follows,

- **Armature resistance control method**: This is the most common method employed. Here the controlling resistance is connected directly in series with the supply to the motor. The power loss in the control resistance of dc series motor can be neglected because this control method is utilized for a large portion of time for reducing the speed under light load condition. This method of speed control is most economical for constant torque. This method of speed control is employed for dc series motor driving cranes, hoists, trains etc.

- **Shunted armature control**: The combination of a rheostat shunting the armature and a rheostat in series with the armature is involved in this method of speed control. The voltage applied to the armature is varies by varying series rheostat. The exciting current can be varied by varying the armature shunting resistance .This method of speed control is not economical due to considerable power losses in speed controlling resistances. Here speed control is obtained over wide range but below normal speed. [2]
• **Armature terminal voltage control:** The speed control of dc series motor can be accomplished by supplying the power to the motor from a separate variable voltage supply. This method involves high cost so it rarely used.

![Speed vs Armature Voltage for Different Torque Values](image)

*Fig.2 Variations of speed with respect to armature voltage for different torque values*

**Field control of a DC motor**

The speed of DC motor can be controlled by this method by any one of the following ways

- **Field diverter method:** This method uses a diverter. Here the field flux can be reduced by shunting a portion of motor current around the series field. Lesser the diverter resistance less is the field current, less flux therefore more speed. This method gives speed above normal and the method is used in electric drives in which speed should rise sharply as soon as load is decreased.

- **Tapped Field control:** This is another method of increasing the speed by reducing the flux and it is done by lowering number of turns of field winding through which current flows. In this method a number of tapping from field winding are brought outside. This method is employed in electric traction.
Fig. 3 Variation of speed with respect to torque with different armature voltage values

Fig. 4 Variation of speed with respect to field current with varying resistance

Fig. 5 Variation of speed with respect to torque with different field current values
Armature Resistance control

In this method, the terminal voltage \( V \) and the field current \( I_f \) (hence flux) are kept constant at rated values. The speed is controlled by changing resistance in armature circuit and hence armature circuit resistance is used for this purpose \([3]\).
CLOSED LOOP SPEED CONTROL

The basic principle of a DC variable speed drive is that the speed of a separately excited DC motor is directly proportional to the voltage applied to the armature of DC motor. Armature voltage control method is used to vary the speed of separately excited DC motor below and up to the base speed. Rated speed is compared with the desired set point speed through a comparator and an error signal is generated. This error signal is fed to a two quadrant chopper which uses a switching device like MOSFET. Fixed frequency operation i.e. Pulse width modulation technique PWM technique is used as the power loss in the switching devices is very low. When switch is off there is practically no current and
when it is on, there is almost no voltage drop across the switch, power loss being the product of voltage and current, in thus both cases close to zero. It also works well with digital control. Now Chopper provides variable voltage across the armature of separately excited DC motor due to which speed of the motor changes.

A transistor chopper controlled separately excited motor drive has transistor $T_r$ which is operated periodically with period ‘$T$’ and remains on for a duration $t_{on}$. Present day choppers operate at a frequency which is high enough to ensure continuous conduction. During on-period of the transistor, $0 \leq t \leq t_{on}$ the motor terminal voltage is $V$. The operation is described by,

$$R_a i_a + L_a \frac{di_a}{dt} + E = V, \quad 0 \leq \tau \leq \tau_{ov}$$

(5)

$L_a =$Armature inductance

![Fig.10 Switching pulses](image)

In this interval, armature current increases from $i_{a1}$ to $i_{a2}$. Since motor is connected to the source during this interval, it is called duty interval. At $t = t_{on}$ transistor $T_r$ is turned off. Motor current freewheels through diode $D$ and motor terminals voltage is zero during interval $t_{on} \leq t \leq T$. Motor operation during this interval, known as freewheeling interval, is described by,

$$R_a i_a + L_a \frac{di_a}{dt} + E = 0, \quad \tau_{ov} \leq \tau \leq T$$

(6)

Motor current decreases from $i_{a1}$ to $i_{a2}$ during this interval and duty ratio is given by

$$d = \frac{t_{on}}{T}$$

(7)

and

$$L_a = \frac{dV-E}{R_a}$$

(8)
CONCLUSION & FUTURE SCOPE

The speed of a separately excited D.C motor can be controlled using two types of loop configurations such as open loop speed control and closed loop speed control techniques. The open loop speed control characteristics has been verified using C code and a 2-D plotting software called GNU plot. It is clear from the plots obtained that the speed of motor increases with increase in armature voltage and speed decreases with increase in field voltage. The armature voltage. Speed control comes into picture when speed of motor is less than base speed and field control is applicable when speed is greater than base speed.

APPENDIX

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Motor Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>01.</td>
<td>Rated Power (P)</td>
<td>15 hp</td>
</tr>
<tr>
<td>02.</td>
<td>Rated Voltage (V)</td>
<td>230V</td>
</tr>
<tr>
<td>03.</td>
<td>Armature resistance (Ra)</td>
<td>0.5 Ω</td>
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<tr>
<td>04.</td>
<td>Armature inductance (La)</td>
<td>0.05H</td>
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<tr>
<td>05.</td>
<td>Coefficient of Viscous friction (B)</td>
<td>0.02Nm/rad/sec</td>
</tr>
<tr>
<td>06.</td>
<td>Moment of inertia (J)</td>
<td>2kg-m²</td>
</tr>
</tbody>
</table>
Table 1: Separately excited DC Motor specification

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REFERENCES