Experiment no. 4

Characteristics of separately excited Dc Motor

1 Aim

To study the variation of speed with
- Armature Voltage
- Field Current

and to obtain the performance characteristics (T-ω) of a separately excited (S.E.) DC motor.

2 Theory

One of the unique features of the DC motor which has helped to maintain its supremacy over other electric drive systems, is its ability to provide a smooth and wide range of speed control with relative ease. This is because the mmf (magneto-motive force) produced by field coil and that produced by armature coil are always at quadrature, and hence they can be controlled independently. As shown in Fig.1, field mmf (F_s) is taken along the x-axis (also known as direct or d-axis) and the armature mmf (F_a) is along the y-axis (quadrature or q-axis). The generalized torque expression can be written as:

$$T_e \propto F_s F_a sin\angle(F_s \& F_a)$$

Since this angle is 90^o, the expression becomes $T_e \propto F_s F_a$. Now, F_s and F_a are proportional to field current (I_F) and armature current (I_a) respectively. Therefore $T_e \propto I_F I_a$. Since the angle between I_F and I_a is always 90^o, the ratio ($\frac{T_e}{I_a}$) is maximum. This is another important feature of the DC machine (in other machines, additional control is required to achieve this feature). Generally, it is assumed that the magnetic circuit is linear. Therefore, Φ is proportional to I_F. Hence, the torque expression becomes T_e = K ΦI_a, where K is constant.

2.1 Speed Control

The other basic equations governing the steady-state operation of the DC motor are:

$$V_a = I_a R_a + E_b, \qquad E_b = K\phi\omega, \qquad \text{and} \qquad I_F = \frac{V_F}{R_F}$$

Alternate method of deriving the expression for torque is as follows:
Multiplying the first equation by I_a we get, $V_a I_a = I_a^2\ R_a + E_b\ I_a$
The first term in the above equation is the power input to the armature, second term is the power lost as heat in the armature resistance and the last term is the power developed in the armature. This power should be equal to the mechanical power ($T_e\ \omega$) if mechanical losses (friction and windage) are neglected.
Equating $E_b\ I_a$ = (K $\phi\ \omega$) $I_a = T_e\ \omega$
Therefore T_e = K $\phi\ I_a$
Substituting for I_a in terms of torque and flux, the relationship between T_e and ω is given by:

$$\omega = \frac{V_a}{K\phi} - \frac{T_e R_a}{(K\phi)^2}$$

If the armature terminal voltage V_a and airgap flux ϕ are held constant, the above equation can be written as:

$$\omega = \text{A} + \text{B}\ T_e,$$

where A and B are constants. This is an equation of a straight line wherein, A is the y-axis intercept and (-B) is the slope. The y-axis intercept represents the no-load speed which depends only on the terminal voltage and air gap flux. The variation of speed with torque is shown in Fig.2. Generally, the drop in speed with increase in torque is small (it is desirable that the speed of rotation is independent of load coupled to the motor shaft). A point to be noted is that in an actual machine, armature reaction helps in maintaining the speed almost constant. Therefore if V_a and ϕ are held constant, the speed of a separately excited dc motor will remain almost constant and it is independent of torque applied to the shaft. Hence in order to vary the speed of rotation over a wide range, the no-load speed (magnitude of 'A') should be varied. This can be achieved by the following methods:

- By controlling the voltage applied to the armature terminals of the machine
- By controlling the flux produced by the field winding

2.1.1 Armature Voltage control:

The schematic diagram for this control technique is shown in Fig.3(a). In this method, the field current (hence ϕ) is held constant at its rated value and V_a is varied. The speed-torque characteristics for this method are shown in Fig.3(b). These characteristics are drawn for various values of V_a and fixed value of ϕ. This method of speed control is used for speed below the rated value. In addition, the following point may be noted:

* Since ϕ is held constant, the speed of rotation changes linearly with V_a. Motor will draw a constant armature current I_a from the source if it is driving a constant torque load ($T_e = K\phi I_a$). Under this working condition, the power (P) drawn by the motor varies linearly with the speed. This mode of operation is known as **constant flux** or **constant torque mode.** The variation of the various quantities with speed is shown in Fig.3(c).

2.1.2 Field Control:

The schematic diagram for this control technique is shown in Fig.3(d). In this method, the armature voltage is held constant at its rated value and the field current is reduced. The speed of the motor changes in inverse proportion to ϕ. The $T - \omega$ characteristics for this method are shown in Fig.3(b). These characteristics are drawn for various values of ϕ and fixed value of V_a. It should be noted that the reduction in speed with torque is higher compared to that in the previous method. This method of speed control is used for speed above the rated value. In addition, the following point may be noted:

* non-linear inverse speed control of motor speed. This method also changes the value of developed torque for a given armature current. If the armature current is held constant at the rated value, the input power and therefore output power remains approximately constant (assuming that frictional and windage losses remain constant). Hence, this operating zone is known as either **constant hp (horse-power)** or **field weakening zone**. Generally the maximum speed of rotation is kept within 150% of the rated value.

2.2 Variable Voltage DC Source:

Both armature voltage and field control methods require a variable voltage dc source. If a fixed-voltage dc power supply is available, voltage applied to the armature or field circuits can be varied by connecting a variable resistance in series with these circuits. However, this results in increased losses, heat and poor efficiency Nowadays, power electronic controllers are increasingly being used to obtain variable dc (or ac) voltage supply from ac source. The advantages are smooth & flexible control, and high efficiency (one such example is elegant, light weight miniature size fan regulator. This regulator is mounted inside the switch board, while 'old' fan regulators are mounted on the switch board. Apart from larger size, the old regulators dissipate heat at low speed of operation).

Fig.4 shows the output voltage waveform of a full wave diode bridge. If the input voltage to the bridge is $V_m \sin \omega t$, then the average value of the output voltage is given by:

$$V_{av} = \frac{2V_m}{\pi}$$

From the output voltage waveform, it can be observed that the waveform is continuous and the instantaneous value is always finite and positive. Hence the average value of the output voltage depends only on the peak value of the input voltage. An autotransformer is now required to vary the output dc voltage by varying the peak input voltage.

The average value of the output voltage can also be reduced if the instantaneous value of the output voltage is made either zero or negative. This is possible by using power semiconductor devices other than diodes (e.g. thyristors). This results in the reduction of size and cost, and improvement in efficiency. However, the applied voltage to the armature is continuously pulsating. In order to reduce the pulsation in the current drawn by the motor, (developed torque depends not on the applied voltage but on armature current and flux) an inductor is connected in series with the armature. Since the current flowing through the inductor is dc, the average voltage drop across it is zero at steady state. However, the current becomes almost constant (property of an inductor- current can not change instantaneously).

2.3 Starting:

From the basic equation governing the steady state operation of dc motor, we have the following:

$$I_a = \frac{(V_a - K\phi\omega)}{R_a}, \qquad \text{and} \qquad T_e = K\phi I_a$$

The torque developed at starting is determined by the product of total flux and armature ampere-turns. This torque is utilized partly in overcoming friction, partly in accelerating the armature, and partly in accelerating the load. The value of starting torque required from a motor will then depend very largely on the load. At standstill there is no back emf, so that to circulate full load current in the armature a very small voltage is required. Neglecting the effect of armature inductance, the voltage that must be applied to the armature at starting depends only on armature resistance. Since, this resistance is very small, a large current will flow if the rated voltage is directly applied to the armature (for the given machine whose parameters are given below, this current is approximately $\frac{180}{2} = 90A$, while the full load rated current is of the order of 10.5 A!). The starting current can be limited to a safe value by the following methods:

- including external resistance only in the armature circuit so that machine develops necessary starting torque. As the motor speeds up, the back emf is generated and the current falls. Generally a large resistance is necessary to limit the starting current. If this resistance is left in the circuit, the steady state speed would be very low and in addition there would be waste of power in the resistance. It is therefore becomes necessary to cut out the whole of the resistance so that rated speed is obtained.
- applying a low voltage by using a variable dc power supply. This voltage is increased as the machine accelerates.

The developed torque and the rate at which back emf is generated depends on the air gap flux. In order to have faster acceleration rated voltage is applied to the field winding while starting.

3 Procedure:

There are three machines mounted on the stand, out of which two of them are dc machines. Note the name plate ratings of these machines and use one of them as a dc motor and the other as a separately excited dc generator. The parameters are:

- 1.5 kW dc machine: $R_a = 2.04\Omega$, $R_F = 415\Omega$, Friction & windage loss at 1500 rpm = 53 W.
- 1.1 kW dc machine: $R_a = 2.1\Omega$, $R_F = 415\Omega$, Friction & windage loss at 1500 rpm = 53 W.

3.1 Precaution:

* **Always start the motor by applying a low input voltage (V_a) to the armature, else the power electronic controller may get damaged due to heavy inrush current. Also, apply the rated voltage to the field winding of the motor. In case the drive has tripped, bring back the voltage control knob on the power controller feeding armature of the dc motor to 'zero position' and then press the 'green' button.**

3.2 Armature Voltage control:

A. Connect the circuit as shown in Fig.5. In this experiment the motor is loaded by loading the generator. Put off all switches of the lamp load and open the main switch 'S' connected between the load and the armature of the DC generator. Also, **open switches S_1, S_2 and S_3**. These are on machine stand.

B. Switch on the AC supply to the power electronic controller supplying power to the field winding of the motor. Using the knob on the controller, apply the rated voltage to the field winding.

C. Switch on the AC supply to the power electronic controller supplying power to the armature of the motor. Using the knob on the controller, slowly increase the voltage to the armature till the rated value. Also, apply the rated voltage to the field winding of the generator (the output terminals are at the rear side of the controller feeding the armature of the motor). Note down the meter readings, speed and direction of rotation.

E. Close switch S and load the generator in steps till it reaches full load. For each load keep the input voltage to the armature constant & note down all the meter readings and speed. **You may find that beyond a certain load, it is not possible to keep the armature input voltage constant. Do not increase the load beyond this point**. Switch off the load and open S.

F. Now apply 85% of the rated voltage to the armature and repeat the above step. Do not switch off the supply.

3.3 Field Control:

A. Using the power electronic controller apply the rated voltage to the armature of the DC motor.

B. Using the power electronic controller suppling power to the field of the DC motor, reduce the field current to 0.4 A.

C. Close S and load the generator in steps till full load. For each load keep the input voltage to the armature and field current constant, and note down all the meter readings and speed. **You may find that beyond a certain load, it is not possible to keep the armature input voltage constant. Do not increase the load beyond this point**. Switch off the load and open S.

D. Now reduce the field current to 0.38A with armature voltage unchanged at its rated value. Repeat the above step.

E. Reduce the voltage applied to the armature to zero.

3.4 Reversal of Direction of Rotation

A. Without disturbing other parts of the circuit interchange the supply terminals to the armature of motor. Apply the rated voltage to the field winding of the motor, and slowly increase the voltage to the armature till the rated value. Note down the speed and direction of rotation.

E. Reduce the voltage applied to the armature of the motor to zero and put off the supply to both the power electronic controllers.

3.5 Plotting of $T - \omega$ Characteristics:

* Using the plot of efficiency vs output power of the generator, for each output determine the input to the generator.
* Assuming 100% coupling efficiency, the above input power is the output of the motor. Knowing the speed of the motor, determine the torque. Plot T-ω characteristics.

— — — * * * * — — — —

4 Questions to be answered:

A. The condition to develop steady torque is that the relative speed between the two magnetic fields (in this case magnetic field due to field current and that due to armature current) should be zero. In other words, the two fields should be stationary w.r.t. each other. In a DC motor, the field winding is stationary whereas the armature winding is rotating. Then how is the above condition for uniform torque is satisfied?

B. Why the full field and reduced armature voltage is applied to dc motor while starting?

C. Is the speed of dc motor dependent on the direction of rotation? Justify?

D. State true or false with justification: 'Armature reaction improves the speed regulation'.

E. What may happen if the field circuit gets open circuited during motoring?

F. Which type of motor is suitable for electric traction and why?

G. Mention the limitations of a S.E. dc motor.

H. Why the maximum speed of operation of a dc motor is kept higher than the rated speed (generally 150% of that of rated speed)?

I. In a dc series motor the field winding is connected in series with the armature. Can a separately excited motor be converted to series motor by connecting the field in series? Justify your answer.

J. A 4 pole, dc series motor has an armature resistance of 0.1Ω. Its field winding is divided into 2 groups each having a resistance of 0.01Ω. When the two groups are connected in series and the motor is connected to a supply of 110V, the motor draws in a current of 50A and runs at 700 r.p.m. Find the **speed** of the machine if the field groups are connected in parallel. Assume constant load torque and neglect saturation.

— — — * * * * — — — —

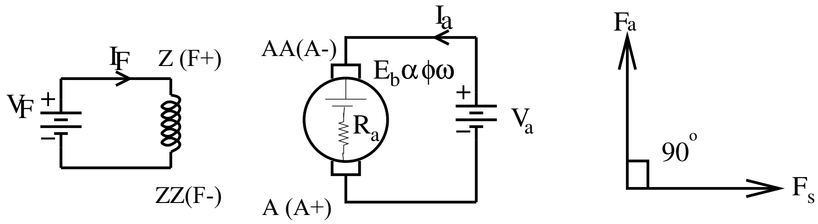

Fig.1 Separately Exicited DC Motor

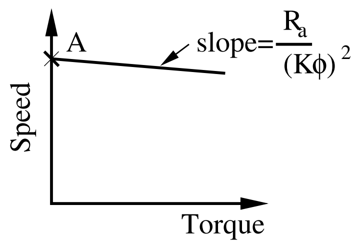

Fig.2 T−ω characteristics of Separately Excited DC Motor

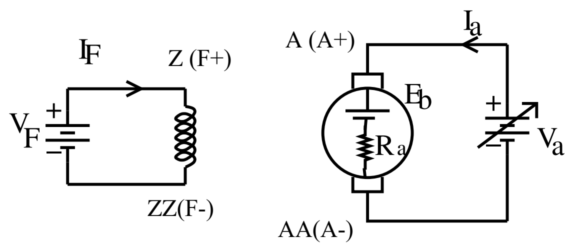

Fig.3 (a) Schematic diagram for armature voltage control

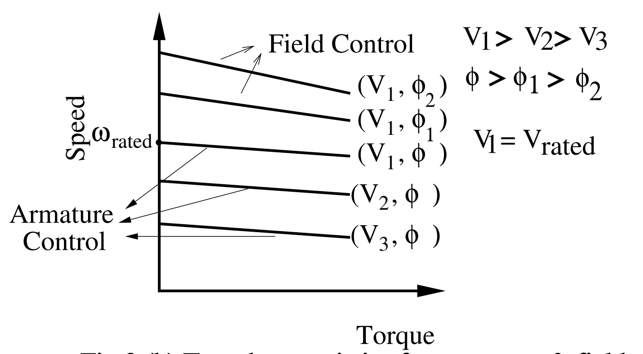

Fig.3 (b) T−ω characteristics for armature & field control

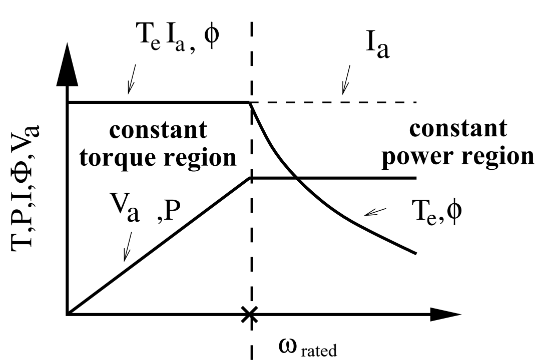

Fig.3 (c) Variation of various quantities with speed

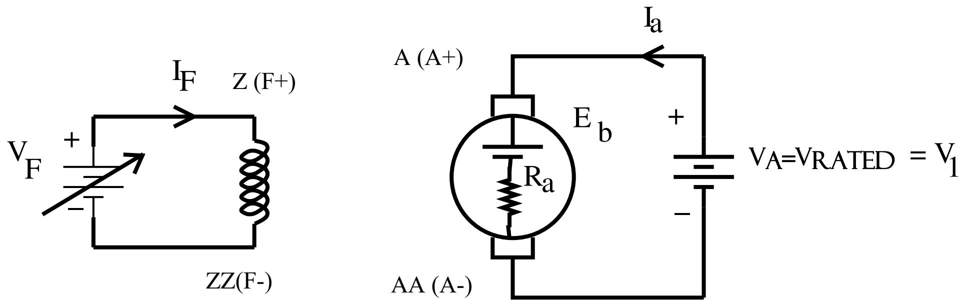

Fig. 3(d) Schematic diagram for field control

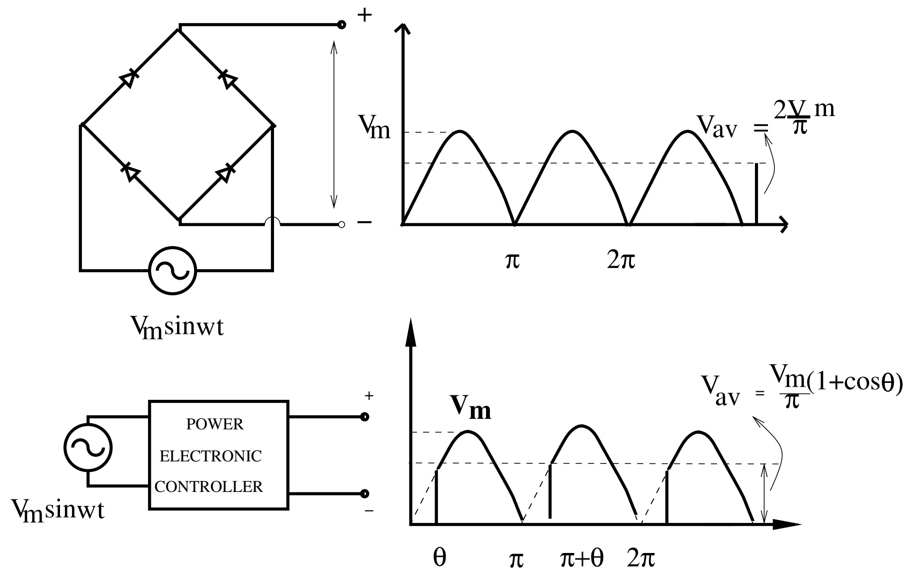

Fig.4 Output voltage waveform of Power Electronic controller

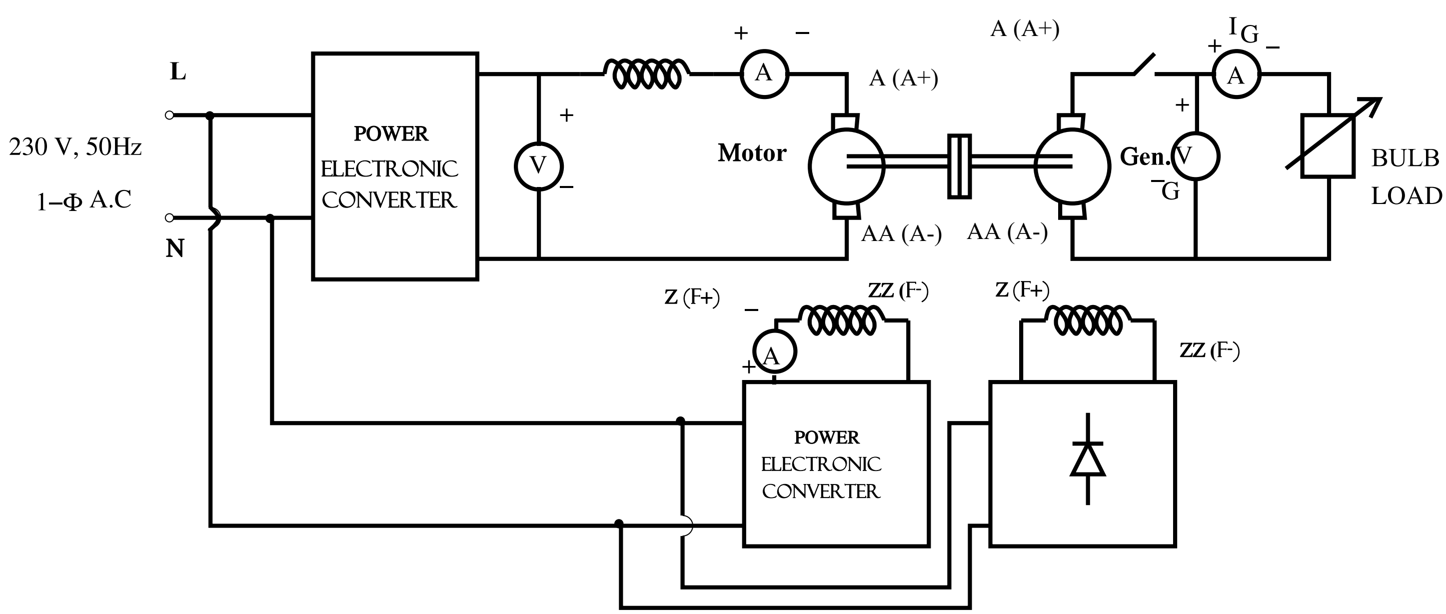

Fig.5 Circuit diagram for speed control of Separately Excited DC Motor

Efficiency Vs Output power of D.C Generator

Date :