Part 2
Direct current motor

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Direct Current Motor (DC motor)

DC motor is similar to dc generator; in fact the same machine can act as motor or generator. The only difference is that in a generator the EMF is greater than terminal voltage, whereas in motor the generated voltage EMF is less than terminal voltage. Thus the power flow is reversed, that is the motor converts electrical energy into mechanical energy. That is the reverse process of generator.

DC motors are highly versatile machines. For example, dc motors are better suited fore many processes that demand a high degree of flexibility in the control of speed and torque. The dc motor can provided high starting torque as well as high decelerating torque for application requiring quick stop or reversals.

DC motors are suited in speed control with over wide range is easily to achieve compare with others electromechanical.

Counter EMF in DC motor

When voltage is applied to dc motor, current will flow into the positive brush through the commutator into the armature winding. The motor armature winding is identical to the generator armature winding. Thus the conductors on the north field poles are carry current in one direction, while all conductors on the south field poles carry the current in opposite direction. When the armature carry current it will produce a magnetic field around the conductor of it own which interact with the main field. It is cause to the force developed on all conductors and tending to turn the armature.

The armature conductors continually cut through this resultant field. So that voltages are generated in the same conductors that experience force action. When operating the motor is simultaneously acting as generator. Naturally motor action is stronger than generator action.

Although the counter EMF is opposite with the supplied voltage, but it cannot exceed to applied voltage. The counter EMF is serves to limit the current in an armature winding. The armature current will be limited to the value just sufficient to take care of the developed power needed to drive the load.

In the case of no load is connected to the shaft. The counter EMF will almost equal to the applied voltage. The power develops by the armature in this case is just the power needed to overcome the rotational losses. It's mean that the armature current I_A is controlled and limited by counter EMF therefore.

$$Ia = \frac{VL - Ea}{Ra}$$

Where:

VL	=	Line voltage across the armature winding
R_a	=	Resistance of the armature winding
E_a	=	Induced EMF or generated voltage
I_a	=	Armature current

Since, E_A is induced or generated voltage it is depend on the flux per pole and the speed of the armature rotate (n) in rpm. Therefore

$$E_a = K \phi n$$

Where:

K	=	the constant value depending on armature winding and number of pole of machine.
ϕ	=	Rotation of the armature

And,

$$K = \frac{Z \times P}{a}$$

Where:

Z	=	Total number of conductor in the armature winding
a	=	Number of parallel circuit in the armature winding between positive and negative brushes.

For wave wound armature "a" = 2

Lab wound armature "a" = P

Example

A dc motor operated at 1500 rpm when drawing 20 amps from 220 volts supply, if the armature resistance is 0.2 ohms. Calculate the no load speed assumed Ia = 0 amp (This amount to assuming the brushes and rotation loss are negligible)

Solution

When load condition Ia = 20 amps.

$$\begin{aligned} Ea &= VL - Ia\,Ra \\ &= 220 - 20\,(0.2) \\ &= 216 \text{ Volts.} \end{aligned}$$

And Ea = $k \phi n$

	216	=	$K\phi \times 1500$		
	$K\varphi$	=	$\frac{216}{1500}$		
		=	0.144		
At no load condition	Ia	=	0 Amp.		
	Ea	=	VL	=	220 Volts.
Hence	Ea	=	$k\phi n$		
	n	=	$\frac{220}{k\phi}$		
		=	$\frac{220}{0.144}$		
		=	1528 rpm.		

Mechanical power develop in dc motor (Pd)

P_d = Mechanical power develop

T = Torque exerted on the armature

$$P_d = \omega T$$

$$= \left(\frac{2\pi n}{60}\right) T$$

Where: $T = P_d / \omega$

$$= \frac{Ea \times Ia}{2\pi n / 60} \qquad = \frac{K\varphi n \times Ia}{(2\pi n) / 60}$$

Therefore: $T = K\phi I_A$

Example: from the motor that mentions before, determine

Solution: $P_d = E_A I_A$

$= 216 \bullet 20$

$= 4320$ watts.

$T = P_d / \omega$

$= 27.51\ N_M$

Classification of dc motor

There are generally three type of dc motor namely

1, Series motors

2, Shunt motors

3, Compound motor

The series motor is widely used because its excellent starting torque characteristics, but each type of dc motor has very definite operating characteristics. It is essential to know construction and requirement before a proper motor4 selection.

Starting of dc motor

At the instant of start up, the armature is not rotate, therefore the counter EMF E_A is zero because no any flux which induced to the armature winding. If we start the motor as mention before with direct across the line 220 volts supply. That armature winding tend to reach search current equivalent to 220/ 0.2 = 1100 A. This current subject to the armature to produced as mechanical shock and would blow fuse and disconnect itself from supply. It is therefore necessary to insert some resistance in series with the armature circuit to limit the current flow through the armature winding.

As The motor come up to speed, this resistance is taken out in steps because E_A rise as the motor come up to full speed. This resistance arrangement is called starter. If the resistance has induced into the motor as mention above is to be limited at 100 amps. The total resistance of the starter plus the armature winding resistance of 2 ohms, the starter circuit as illustrate below.

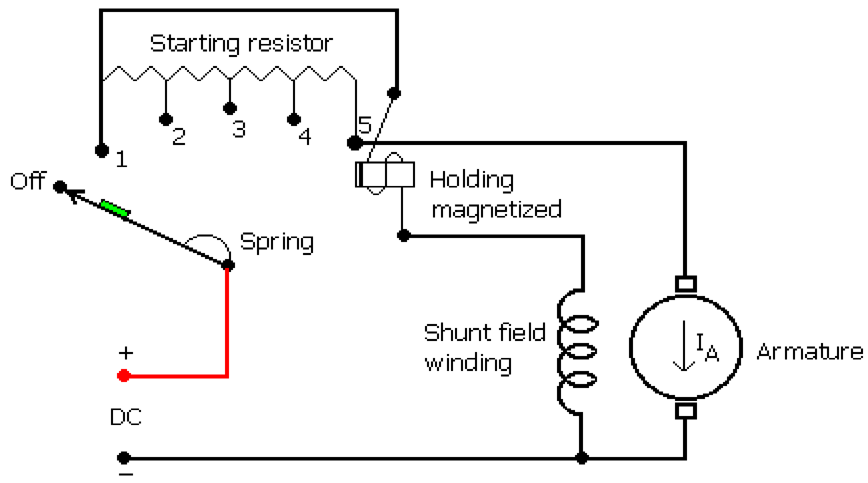


Figure 1.The starter circuit

When the main switch is turn on by starter arms is moved to contact 1 the motor is starting to rotate. The starter arm has to slowly move to the following contact until the final position. Motor is full speed condition, this whole process shout a few seconds depending on the size of motor.

The starter must be rated on horsepower, voltage and current that is used. The motor less than 1 hp. direct on line full voltage starting is allowed.

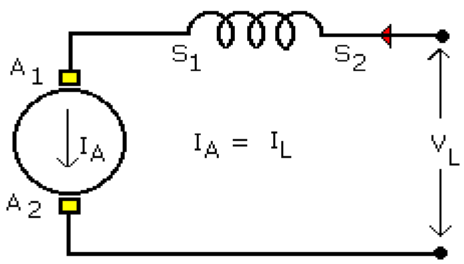
In the final position no added the external resistant connected to the armature circuit, so the current is directly apply to the armature path but the external resistant still connected to maintain the field circuit. The starter arm is continuously kept closed to the final contact by the holding coils. (Magnetized force) When there is a failure power or the field circuit is opened accidentally. The spring will return starter arm out off position, automatically shut down. The amount of current consume with starter connection becomes.

$$I_{start} = \frac{V_{source}}{R_A + R_{starter}}$$

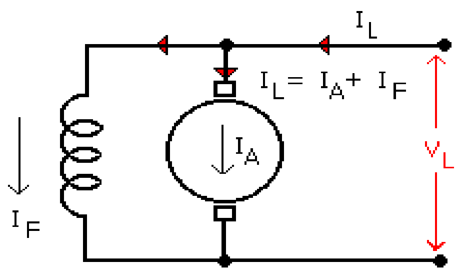
In the separately excited machine the field winding is connected to a different supply. If the field winding is connected in parallel with the armature winding we called a shunt machine. The series machines has a field winding is caries the load current, It is necessary to capable the winding to carry the load current without the excessive heat loss in its.

In case of compound motor it has both of winding conductors. This field winding may be connected so that the field aid one another, depending on flux oppose. Thus, the compound motor may have long-shunt or short shunt field winding. It is arrangement, whether the shunt field is connected before or after the series field winding.

When the motor is loaded the speed tends to slow down. This is known from practical experience. The amount which speed is slows down at full-load, as compare with no-load condition will depend on type of connection employed.



Series motor



Shunt motor

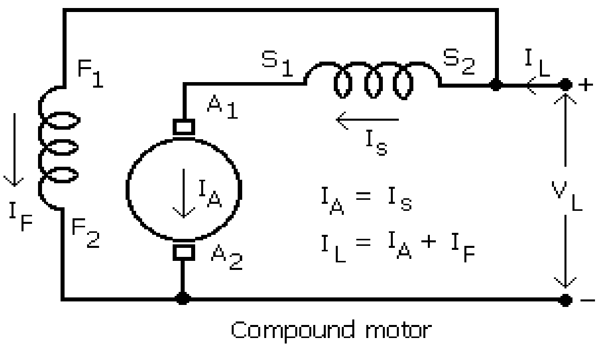


Figure2. Illustrated the current on different kinds of dc motor

The armature current on the starter position 1 is can be define as following.

$$I_1 = \frac{V_{supply}}{R_A + R_{starter}}$$

Since torque is directly proportion to the armature current and flux it is cause accelerated to the start up of the armature. During the acceleration period the counter electromotive force is increase (E_c) but the armature current tendency to decrease to some value. When the starter arm is moved to position 2 with sufficient resistance the current that flow into the armature is rise approximate to I_1 again. This operation is continued until the last contact is reach, assume that the motor is steady-state speed and current.

Example

Calculate the require resistance for a four-step starter to limit the starting current of a DC shunt motor to 150% 0f rate current. Assume that all four steps have an equal resistance value. The motor has rating as 25 Hp, 240 Volts, 860 rpm. And armature resistance is 0.08 Ohms, the overall efficiency 90%. Determine at each speed of the starter resistance must be take into the starting circuit to maintained the rate value during start up period. Assume that the field current is negligible compared to rate armature current.

Solution:

Motor starting circuit. At full load the motor input power is as computed by the following.

$$P_{in} = \frac{Hp \times 746}{\eta} = \frac{10 \times 746}{0.9} = 8{,}288 \text{ watts}$$

And the line current is

$$I_L = \frac{8{,}288}{240} = 34.53 \text{ Amps.}$$

The designed rate current is limited at 150% of nominal rating, the maximum current will be

$$I_{max} = 1.5 \times 34.53 \text{ Amps.}$$
$$= 51.79 \text{ Amps.}$$

The current-limiting resistance at startup is

$$I_{max} = \frac{V_{supply}}{R_A + 4R} = \frac{240}{0.1 + 4R} = 51.79 \text{ A}$$

$$240 = 51.79 \times (0.1 + 4R)$$

$$240 = 5.17 + 207.16R$$

$$240 - 5.17 = 207.16R$$

$$R = \frac{234.84}{207.16} = 1.13\,\Omega$$

Furthermore, at rated speed and current,

$$E_c = V - I_A R_a = k\Phi n$$
$$= 240 - (51.79 \times 0.1)$$
$$234.8 = k\Phi \times 860$$
$$k\Phi = 0.273$$

Therefore, $k\Phi = 0.273$ which is constant under stated assumptions. On the startup period, since n = 0 rpm there are four resistors connected in series with the armature winding then the total resistance and current will be.

$$I_{max} = I_R$$

Then

$$240 = I_A (0.1 + 4R)$$

The motor will accelerate and the current decay until $I_A = I_{A\ rated}$ at this point the starter is place in the contact 2 there are 3 resistors in series with the armature-winding and $I_A = I_{A\ max}$ Then

$$240 = 51.79\,(0.1 + (3 \times 1.13)) + E_c$$
$$= (51.79 \times 3.49) + E_c$$
$$= 180.6 + E_c$$
$$E_c = 59.4$$

Where : $E_c = k\Phi n$

$$59.4 = 0.273\,n$$

$$n = \frac{59.4}{0.273} \approx 218 \text{ rpm.}$$

At time t_1 the motor has produce counter EMF 59.4 volts and accelerate up to 218 rpm.

Similarly on contact 3 with 2 resistors connected in the circuit.

$$240 = 51.79\,(0.1 + (2 \times 1.13)) + E_C$$
$$= 122.22 + E_C$$
$$E_C = 117.78 \text{ volts}$$
$$n = \frac{117.78}{0.273} \approx 431.42 \text{ rpm.}$$

At time t_2 Ec = 118 volts and n = 431 rpm.

On contact 4, with a single resistor connected in the motor circuit

$$E_c = 181 \text{ volts and } n = 664 \text{ rpm. at time } t_3.$$

At contact 5, the final position the starter-arm connected without resistor no additional resistance in the motor armature circuit. Motor is directly across to the sources.

$$E_c = 235 \text{ volts and } n = 860 \text{ rpm. at time } t_4$$

When the motor has reach to a steady condition. The time interval of the revolution reach to full speed condition is depending on motor plus load inertia the variation of armature current and time will somewhat similar to the curve as giving.

Automatic starter of DC motor

The apparent disadvantages of manual starter of DC motor are.

- Bulkiness of the starter.
- Lack of remote operation.
- Possibility of improper operation.
- Non-uniform acceleration.

An automatic starter has covered all these disadvantages in order to providing other reliable control feature such as over and under voltage protection, over speed protection.

To illustrate these matters let refer to a simple automatic starter connected to a dc shunt motor as illustrate as following

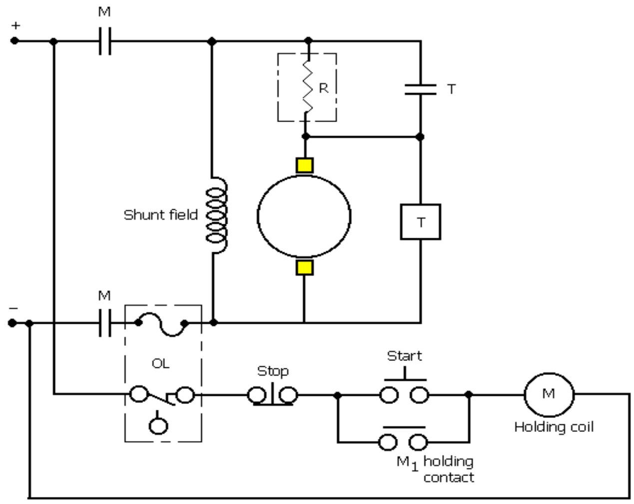


Figure3. Illustrated an automatic starter connected to a dc shunt motor

This starter circuit is called a "counter-EMF starter". The starting resistance is added to cut out the current in a single step; the contact M is a magnetic contact. The magnetic is an electrical switch which has a holding coil placed on an iron armature core. When the current flows through the holding coils, the coils become magnetize. This attracts to move iron armature that carries a set of contacts, which has an electrically insulated from each other. Thereby closing the circuit the holding coil energized, contact M are closes and complete the circuit by pressing the start button and disconnect the circuit after pressing the stop button, which together the start and stop button may be remotely located from the motor.

When the magnet is energized contacts M and M_1 close, contact M_1 is called " maintaining or holding contact" it function is keeps magnetic contact energized after the start button is released the motor continue operates until the stop button is pressing.

It is cause to the motor connected to power supplied with the starter resistor R connect in series with the armature winding because at the standstill the counter EMF is zero, the starter resistor is provided for limited the starting load current. The contact T is called "accelerating contact"

When the motor is speed up the counter EMF is increase as the voltage across the armature (E_c). Whenever E_c reach about 80% of supply voltage contact A closes and associated short out the starter resistor R. The contact T is controlled by a definite time presetting called timer-delay relay, because the counter EMF is relate to the acceleration of the motor. So now the motor is directly cross to the supply voltage. To obtain smoother accelerate and high performance.

In the starting circuit overload protection has provided by the thermal overload relay, there are two types basically both are operate by the heat generate in the heating element which is connect in series with the motor cause the amount of motor current flow through its. One type is bimetallic strip and the other is melting a strip of solder. Both types act to open the motor circuit when the over current is produced.

To stop the motor under normal operation, the stop button is presses thereby open the control circuit. This is cause by the stop button is disconnect the holding coil, the holding coil is de-energized cause the contact M are disconnect, thereby motor is separated from the sources.

Speed characteristic of DC motors.

When the mechanical load is removing from the motor, the motor speed will increase. The amount by which it increases depends on the type of motor. The speed of shunt motor increase about 8%, for a compound motor it rise approximately 15 to 20%. And for the series motor it would rise rapidly and it is for this reason the series motors must always drive a load. To make clear and understand why this happens let consider the relation as following.

$$n = \frac{V - I_A R_A}{k\varphi}$$

In shun motor the flux is only slight affected by the armature current, while the I_A R_A drop rarely exceed 5% of line voltage. Therefore the maximum change in speed must be the same order as I_A for a shunt motor. Shunt motor is fairly constant machine as indicated by a curve as following.

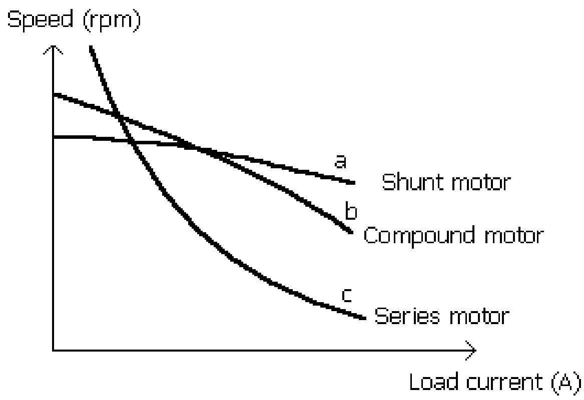


Figure 4. Illustrated shunt motor current characteristic

For a compound motor, when the load is removed there are two factors affected the speed and flux. Unlike the shunt motor, the effect of series field is removed under no-load condition, thereby weakening the overall of field flux. The result is larger increase in speed, since the speed is inversely proportional to the flux as indicated as the above formula. This is representing by curve b. We can now see why the series motor will run at danger high speed when the load is removed. There would not be any flux because the flux is depend upon load current The curve c illustrated a load current behavior of the series motor. For this reason the series motor is not used in instance where the load can be disconnected by accidentally such as belt-coupling drive should never be used with series motor drive.

In similar the torque-load characteristic for the shunt, compound and series motor can be compare the figure as illustrated below shows for the 3 different type of dc motors. In series motor, the developed torque depends on the load current and fluxes; because the flux in turned depend on the current under this condition.

$$T = k\varphi \ I_A$$

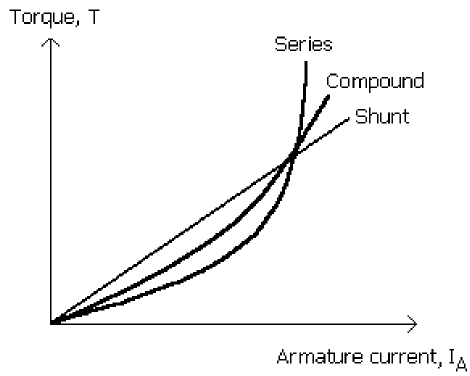


Figure 5. Illustrated DC motor speed characteristic

If magnetic saturation is considered, the graph will become a straight line at heavy load, since the flux will not change with increase loading. Figure 5 it is evident that for a given current below full-load value, the shunt motor develops the largess torque. For currents exceeding rated current, the series motor develops the largess toque. It is for this reason that in applications requiring large starting current. Such as for hoist, electric trains, and so on, the series motor is the most suitable machine.

Example

A 240-Volt shunt motor has an armature current of 0.25 ohms. Under load, the armature current is 20 A. Suppose that the flux is suddenly decrease by 2.5%, what would be the immediate effect on the develop torque?

Solution. When the current is 20 A

$$T = k\varphi I_A = K\varphi \times 20$$

and

$$\begin{aligned} E_c &= V_L - I_A R_A \\ &= 240 - (20 \times 0.25) \\ &= 235 \text{ volts} \end{aligned}$$

If ϕ is suddenly decreased by 2.5%, E_c is also decrease, since $E_c = K \phi n$ and the speed cannot change instantaneously, thus

$$\begin{aligned} E_c &= 235 - (235 \times \frac{2.5}{100}) = 235 \times 0.975 \\ &= 235 - 5.87 \\ &= 229.13 \text{ volts.} \end{aligned}$$

The new armature current is

$$I_A' = \frac{V_L - E_c}{R_A} = \frac{240 - 229}{0.25} = 44 \text{ Amps}$$

The new value of develop torque is

$$
\begin{aligned}
T &= k\,(1 - 0.025\,\varphi)\,I_A \\
&= K\,(0.975\,\varphi)\,44 \\
&= 40.7\,K\varphi
\end{aligned}
$$

This is corresponding to an increase in torque as

$$\frac{T'}{T} = \frac{40.7\,K\varphi}{20\,K\varphi} = 2.035 \text{ times}$$

Thus slight decrease of flux almost doubles the torque. This increased torque causes the armature to accelerate to higher speed. At that point the counter EMF limits the armature current just enough to carry the load at this new speed.

Speed regulation.

The motor classification on the basis of speed change with load is particularly important in the selection of motor. If the speed of motor is relatively constant over it normal range, the phenomenon of motor as having good speed regulation. Speed regulation is usually expresses ass a percentage as found as following.

$$
\begin{aligned}
\text{Speed regulation} &= \frac{\text{no - load speed} - \text{Full - load speed}}{\text{full} - \text{load speed}} \times 100 \quad \% \\
&= \frac{N_{nl} - N_{fl}}{N_{fl}} \times 100 \quad \%
\end{aligned}
$$

Where:

n_{fl} = Full-load speed

n_{nl} = No-load speed (Both express in r/min, rpm.)

<u>Note.</u> Speed changes cause by loading condition, there are no resulted by speed adjustment made by manually or by personnel.

Speed control of DC motor

In order to change in speed of dc motor there are three quantities that may be considered as parameter:

- The armature resistance I_A.
- Flux ϕ density.
- And terminal voltage V.

The armature resistance method by adding resistor in series with the armature effectively increases the armature circuit resistance. Let considered the equation as follow.

$$n = \frac{V - (I_A R_A)}{k\varphi}$$

There is indicates the results in reduction of steady-state speed, since it is proportional to the counter EMF, except for no-load condition. This method is the field current is kept constant. Figure. Illustrate the characteristic of different value of armature circuit resistance. As apparent, this method of speed control is relatively simple and inexpensive. Anyway it has some disadvantage such as.

1. Adding resistance in the armature circuit the speed of the motor, compare to that without any resistance adding, however it is always lower

2. This method of speed control is ineffective at no load condition due voltage drop cause by I_A and R is less.

3. Adding resistance means increase in I^2 R losses, therefore waste power due to heat generated. As a rule of Thumb, the percentage reduction in speed is equals to the percentage of input power that is consumed in the added resistor.

4. The constant-speed characteristic of the motor is loss. In generals the speed control of this method is limited about 50 % of nominal rated speed.

Example. A 200 volts shunt motor run at 1000 rpm when the armature current is 60 A, the armature circuit resistance is 0.2 ohms. Find the required resistance to be added in series with the armature to reduce the speed to 800 rpm when the armature current 40 A.

Solution

$$\begin{aligned} E_c &= V - (I_A R_A) \\ &= 200 - (60 \times 0.2) \\ &= 188 \text{ volts.} \end{aligned}$$

Since the field current has remained constant, the counter EMF is proportional to the speed. Therefore the counter EMF at 800 rpm is.

$$\begin{aligned} E_c' &= k \varphi n = 188 \times \frac{800}{1000} \\ &= 150.4 \text{ volts} \end{aligned}$$

Therefore, the voltage drop in the armature circuit is equal to the voltage drop at the resistor plus voltage drop by the armature resistance; they are computing as follow.

$$\begin{aligned} V_L &= V_R + V_{R_A} - E_c \\ V_R + V_{R_A} &= 200 - 150.4 = 49.6 \text{ volts.} \end{aligned}$$

The total armature circuit resistance is obtaining by.

$$R + R_A = \frac{49.6 \text{ volts}}{40 \text{ Amps.}} = 1.24 \text{ Ohms.}$$

Therefore, the additional resistance required in the armature circuit for reduced the speed from 1000-rpm into 800-rpm compute by.

$$R = 1.24 - 0.2 = 1.04 \text{ Ohms.}$$

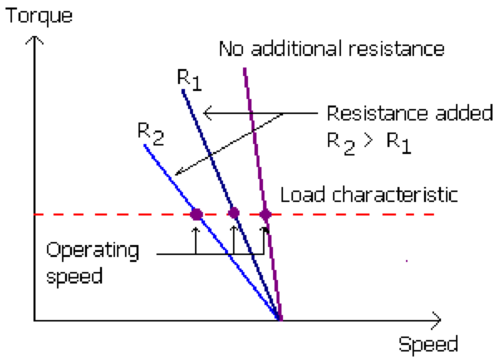


Figure 6. Illustrated shunt motor armature resistant characteristic

The second method of speed control is by changing the fluxϕ. The additional resistor is employ to connect in series with the field winding. Normally used a variable resistor and it is generally called "field rheostat" Therefore the field current is directly proportional to the field rheostat. The speed of motor is increase by reduction in flux (increase resistance value). This method has some disadvantage. One is it can only increase speed at the motor normally run at a light load. Another disadvantage is speed is increase without corresponding reduction in shaft load. The motor will overload condition. However at a light loads or under no-load condition the speed can be above nominal rating speed reach about 200%. And the field current control as shown in figure7 bellow.

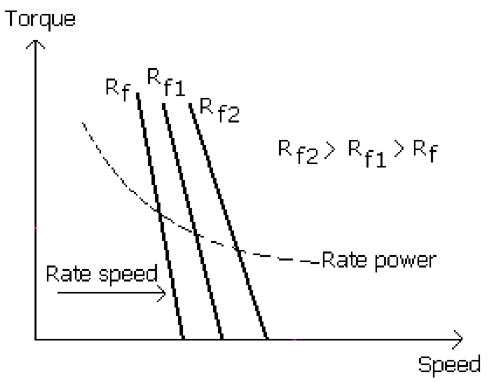


Figure 7 Illustrated DC motor field resistant characteristic

The third method of speed control is by changing the terminal voltage V of the motor. This is normally the most frequent application of control, at least for shunt motor, where the field winding is separately excited as represent by the figure 8 as bellow.

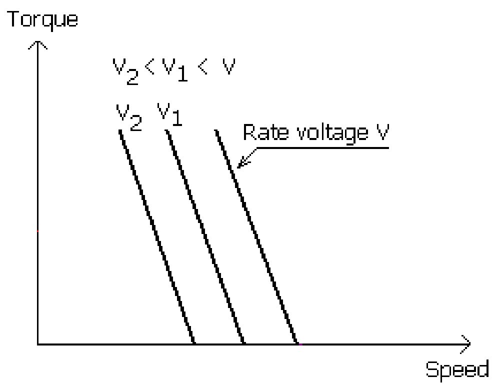


Figure 8 Illustrated DC motor terminal voltages characteristic

The voltage control method lowers the speed in a similar as the armature resistance control method; but it does not drawback. Due to the no-load and full-load speed can be reduced all the way down to zero. And there is not much power wasted. There are various ways to obtain a variable DC voltage. Some modern ways are using solid-state device.

Finally if the speed control above and below nominal speed are desired, a combination of two methods. For example, field control combined with armature voltage control would achieve this mode of control.

Solid-state controllers

The Dc speed is function of the armature and field voltages. Control and adjustment of armature voltage cause results in a constant-torque drive, while constant horsepower is obtained by field-voltage control. Therefore all DC drives essentially consist of a controlled voltage supply and a feedback network, which controls the dc voltage as a function of speed.

Recently a solid-state or computer control is used for this purpose. In this section to introduce some of concepts without going too much detail of electronic controls to electrical machines requires a sound knowledge of both electronic and machines.

Power switching principles

A wide range of speed control for dc motor can be achieved by controlling the field and armature current by adding resistance in the corresponding circuits. The easily of control is at the expense of reduced efficiency. Commercial electronic controller for dc motor is used ac line alleviating the need for a separately dc source. This controller consists of solid-state circuit and electronic components such as thyristors (SCR), diode, and choppers are essence.

They control the average current supplied to the motor. The combination of control system and motor is usually referred to as the drive system.

Figure9. Show a simple switching circuit in principle. The switch is opened and closed at specified intervals; in fact this be done by electronically. If voltmeter were connected across the load resistor R the average voltage read by a dc voltmeter would be.

$$V_R = \frac{t_1}{t_2} E \quad \text{volts.}$$

Generally, the ratio t_1 / t_2 is called "duty cycle" of the waveform and by controlling it; the amount of power consumed by R is controlled. For example as below the on time is 2ms, while off time is 3ms. Therefore the average current in the circuit is.

$$I_R = \frac{E}{R} \times \frac{t_{on}}{t_{off} + t_{on}} = \frac{12}{2} \times \frac{2}{2+3} = 2.4 \text{ Amps.}$$

For the specific switching rate of one cycle equal to 5 ms, therefore 200 of on-off operation of the switch per one second are required. It can be appreciated that a these switch rates or greater, electronic switching techniques must be resorted to for this either power transistors or SCRs are usually used to handle the required power. There are numerous varieties of circuits that accomplish. The method of speed control by controlling the duty cycle will be illustrated in the following.

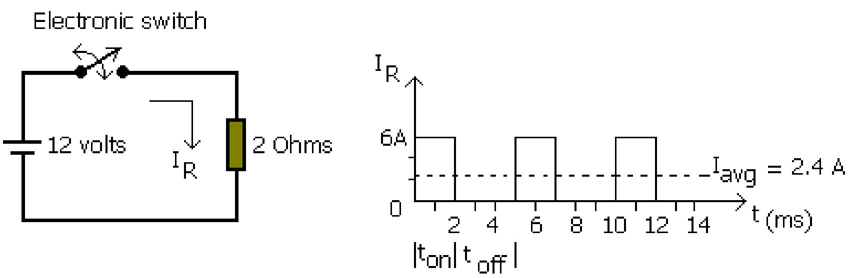


Figure 9 Show a simple switching circuit in principle

Example. A Dc motor is supplied from 120 volts dc switch source as showing. The duty cycle is 50% and the input power is 3 kW at 600 rpm. The armature circuit resistance is 0.05 ohms. Determine

a. The delivered shaft horsepower.

b. The new speed and output horsepower if the duty cycle is increased to 0.6

Solution,

a. If the duty cycle is o.5 the average motor voltage is $V_m = 0.5 \times 120 = 60$ volts

And the average input current is $I_{dc} = 3000 / 120 = 25$ Amps.

Since the average power is the same on either side of the switch, the average motor current is

$$120 \times I_{dc} = 60 \times I_A$$

$$I_A = 2 \times I_{dc}$$

$$= 50 \text{ Amps.}$$

The average counter EMF is

$$E_c = 60 - (50 \times 0.05) \text{ volts}$$

$$= 57.5 = K\phi n$$

Hence; $E_c = K\phi n$

$$K\phi = 57.5 / 600$$

$$= 0.0958$$

Therefore, the average output power is

$$W = 57.5 \times 50$$

$$= 2{,}875 \text{ watts.} = 3.85 \text{ Hp,}$$

b. When the duty cycle is adjusted to 0.6 the average motor voltage becomes $0.6 \times 120 = 72$ volts. With the load remaining the same, the torque will remain constant, since $T = K\phi I_{A,}$ The field current being constant. Thus I_A remains the same.

Hence;

$$E_C = 72 - (0.05 \times 50) = 69.5 \text{ volts}$$

And the new speed

$$n' = \frac{69.5 \times 600}{57.5} = 725 \text{ rpm}$$

The output power

$$P_o = E_C\ I_A = 69.5 \times 50 = 3475 \text{ watts}$$

$$= 4.66 \text{ Hp.}$$

As example above the controlling of dc motor speed by controlling of duty cycle is rather than changing of armature resistance or field resistance. Control by electronic means results in insignificant added losses their force. High system efficiencies can be maintained at all speeds. Considering that at a duty cycle of 1.0 that is, when full voltage is applied, the speed becomes 1200 rpm. The speed of the motor can be controlled over a wide range. Of course additional control is available by changing the field current as well as.

When a high inductive circuit is interrupted abruptly, the inductance temps to keep the current flowing. It can do so only when a path provided. Therefore a diode is added in the circuit as shown, normally referred to as a freewheeling diode.

Diodes

A silicon diode is two terminal devices consisted of a thin layer of silicon, doped so as to provide a P-type layer and N-type layer. A diode allows unidirectional flow of current. That is conducts well in only one direction. The figure shows the circuit symbol and static characteristic of diode. Current flows through the diode when the voltage at the anode (P-type materials) is positive with respect to the cathode (N-type materials). The allow configuration of the symbol shows the direction of conventional current flow and the diode is then open circuited.

Thyristors (Silicon- controlled rectifiers)

A silicon-control rectifier (SCR) is a three-terminal device made from four layers of alternating P-and N-type materials. Normally, the device blocks current flow in both directions, using one of P-N junction's forms by these layers. Common N1 layer performs most of the blocking duty, so that the block capacity is symmetrical. A second layer N_2 forms the cathode and the other P_1 layer forms the anode. The gate is connected to the P_2 layer. A positive pulse of current from the gate to cathode floods junction J_2 (which is responsible for forward blocking) with carries so that it looses its blocking capability and start to conduct in the forward direction. Once start the gate signal can be removed, as this process is self-generating and forward blocking cannot be recovered without turning off the current flow. Normally with gate current applied, the thyristor will perform essential the same as a diode.

Gate pulses are of a few microseconds' duration and insignificant power compared to that controlled. Conduction ceases when the positive voltage is removed from the node, after control by the gate is reestablished.

AC rectification

In the section on power switch principles, it was shown that dc motors could be energized from dc source using electronic switching methods. As the result current or voltage waveform indicates, the ripple in the armature current will generally by high. Thus some additional filtering in the circuit is necessary to keep the motor losses to acceptable levels, although the armature inductance may provide some of this filtering.

To have some measure of ripple present, the form factor is used. It is measure of departure from pure dc and is defined as the root-mean-square (rms) value divided by its average value of the current. For half-wave rectifier current the form factor is 1.57; for full-wave it is 1.11 pure dc has a factor of 1.0 or unity.

The form factor is an important consideration with motors designed to operate form rectified ac power supplies. The increase in motor heating for a constant out is approximately proportional to the square of the form factor. For example a motor operating from half-wave rectified dc will have about 2.5 times the heat rise of the same motor operating on pure dc voltage source.

To accommodation the increase heating effect, a larger motor is generally required for such applications. However, with motor ratings increase, larger amounts of power are needed, which are available only from ac sources. Alternating current is then converted into direct current using rectifiers, thyristors, or a combination of such devices.

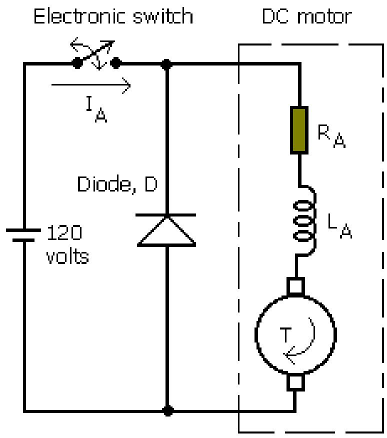


Figure 10 Show a simple electronic switching circuit in principle