MINISTRY OF HIGHER EDUCATION & SCIENTIFIC
RESEARCH DIYALA UNIVERSITY
COLLEGE OF ENGINEERING
ELECTRICAL POWER & MACHINE DEPARTMENT

INDUSTRIAL POWER ELECTRONIC LABROTORY

PRACTICAL EXPERIMENTS
IN
POWER ELECTRONIC

FOR STUDENTS OF THIRD STAGE

EXPERIMENT NO.15

EXPERIMENT NA.MOTOR STARTING & SPEED CONTROL

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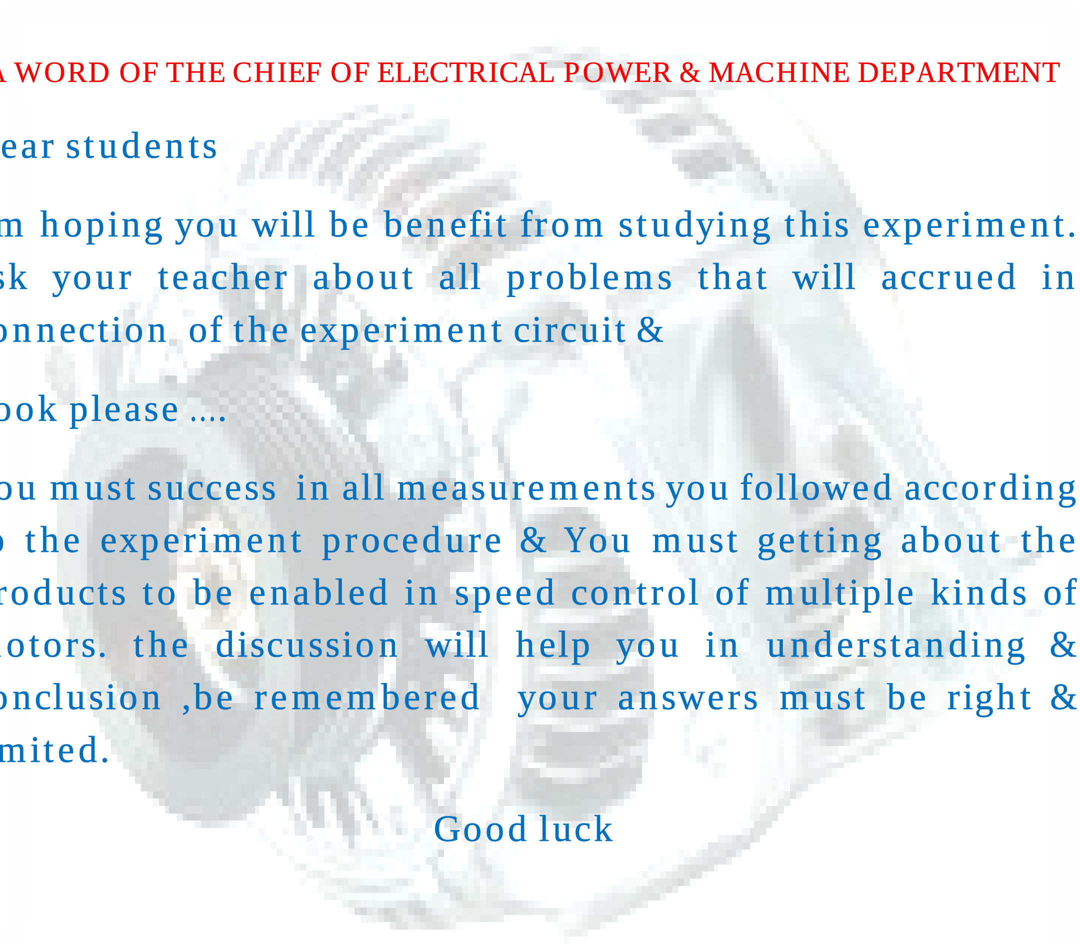
EXPERIMENT 15

MOTOR STARTING & SPEED CONTROL



A WORD OF THE CHIEF OF ELECTRICAL POWER & MACHINE DEPARTMENT

Dear students

I'm hoping you will be benefit from studying this experiment. ask your teacher about all problems that will accrued in connection of the experiment circuit &

look please ....

You must success in all measurements you followed according to the experiment procedure & You must getting about the products to be enabled in speed control of multiple kinds of motors. the discussion will help you in understanding & conclusion ,be remembered your answers must be right & limited.

Good luck

the Chief of electrical power & machine department

PH.D

NISREAN KHAMMASS SABAE

OBJECTIVE

1. Understanding the types and characteristics of motors.
2. Studying motor speed control circuits.
3. Performing TRIAC motor starting and speed control circuit.

DISCUSSION

Motors are the major sources of mechanical power in industry. Motors are classified first according to the operating voltage. The two general types are dc and ac motors. According to ac line voltage, ac motors can be classified into three types: single-phase, three-phase, and polyphase motors. Successful circuit design for electric motor control depends upon matching the performance characteristics of the motor with the load requirements of the machine or device to be driven.

Some basic questions must be answered before designing a motor control circuit, such as:

1. What horsepower is required?
2. What speed or speed control must be provided?
3. What torque is required and how does it vary with speed?
4. What are the control requirements in terms of speed variation, sequencing, and direction of rotation?

Given the answers to these questions, we must then match the customer's requirements with the proper type and size motor and electronic control.

In this discussion we will review briefly the types of motors available and their characteristics as well as the design of electronic controls.

Series-Wound DC Motor

The series-wound dc motor has the field winding in series with the armature. The dc voltage is applied across the series combination as shown in Fig. 15-1. When we say dc voltage, we aren't talking about the same filtered, regulated voltage used to operate the electronic circuitry. The dc voltage to operate motors and other heavy industrial equipment is usually a rectified ac voltage. If low ripple is required, three-phase ac voltage is rectified to provide the dc excitation.

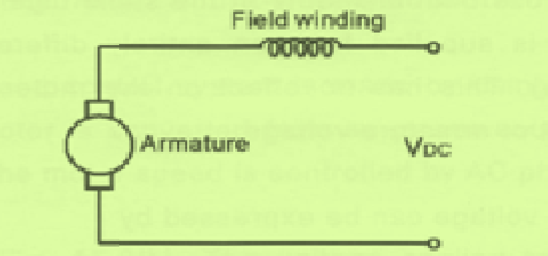


Fig. 15-1 Series-wound DC motor

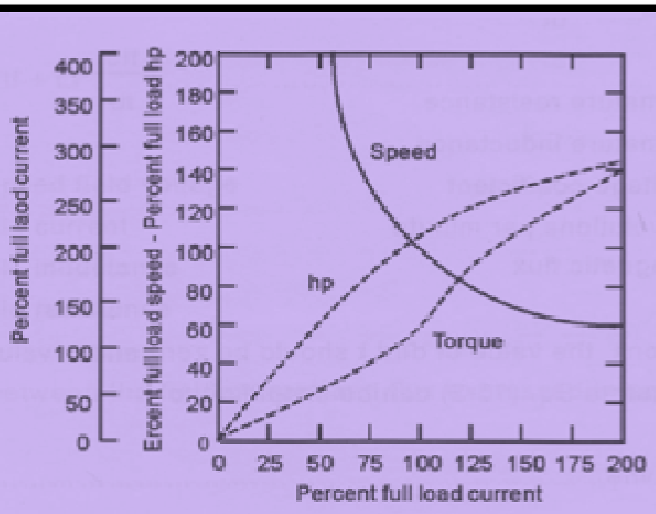
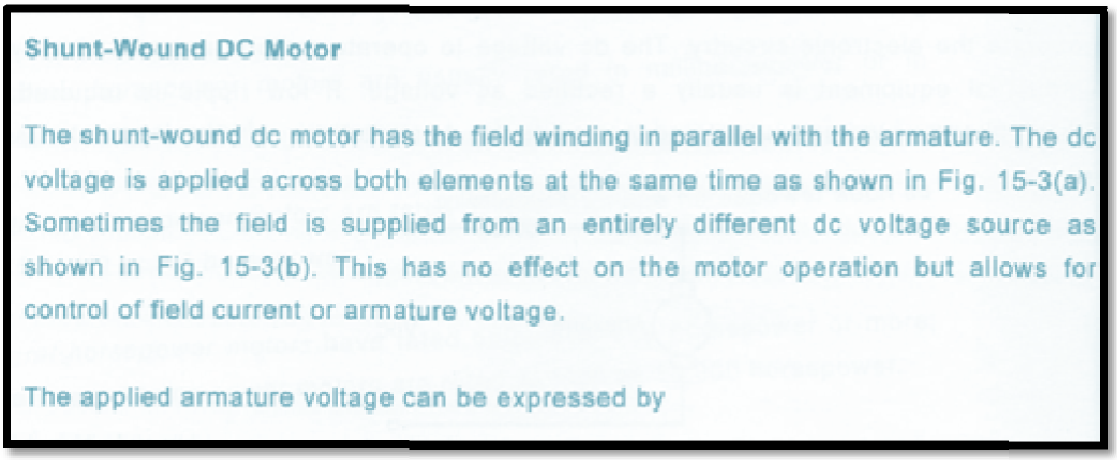


Fig. 15-2 Characteristics for a series-wound DC motor

The series-wound dc motor has the advantage of very high starting torque. Fig. 15-2 shows typical characteristic curves for a series-wound dc motor. Notice the torque is nearly 300% of full load at low speeds. As the motor speed increases, the torque and horsepower output decrease. This is not a constant speed motor. The

series-wound dc motor is ideal for applications where various torques and speeds are required, such as cranes, hoists, lifts, trolley cars, and railway cars. The ability to start slow with heavy loads, operate fast with light loads, brake quickly, and reverse makes the series-wound dc motor very popular.

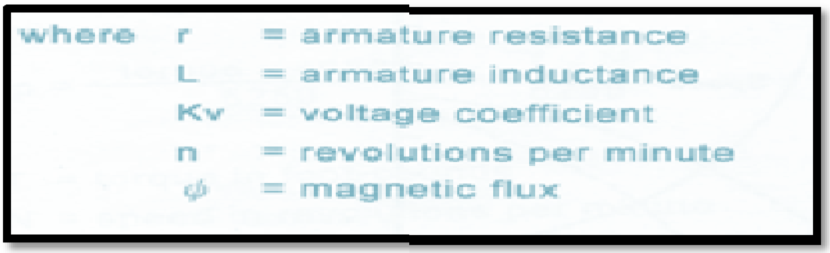


Shunt-Wound DC Motor

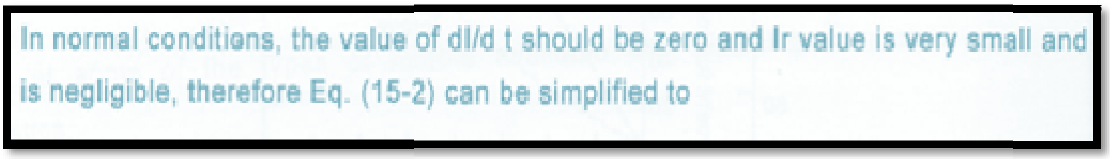
The shunt-wound dc motor has the field winding in parallel with the armature. The dc voltage is applied across both elements at the same time as shown in Fig. 15-3(a). Sometimes the field is supplied from an entirely different dc voltage source as shown in Fig. 15-3(b). This has no effect on the motor operation but allows for control of field current or armature voltage.

The applied armature voltage can be expressed by

$$Vdc = Ir + L\frac{dI}{dt} + Kvn\phi \ldots\ldots\ldots\ldots\ldots\ldots (15\text{-}2)$$

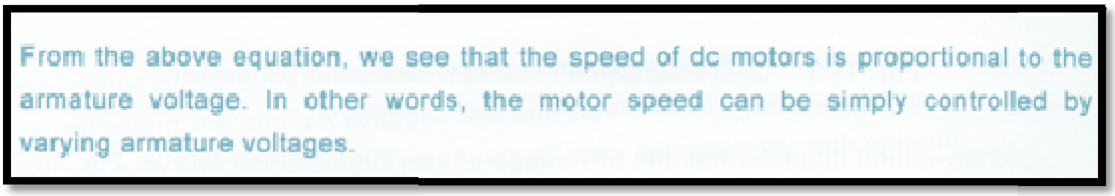


where r = armature resistance
L = armature inductance
Kv = voltage coefficient
n = revolutions per minute
ϕ = magnetic flux



In normal conditions, the value of dI/d t should be zero and Ir value is very small and is negligible, therefore Eq. (15-2) can be simplified to

$$Vdc \approx Kvn\phi \ldots\ldots\ldots\ldots\ldots\ldots (15\text{-}3)$$



From the above equation, we see that the speed of dc motors is proportional to the armature voltage. In other words, the motor speed can be simply controlled by varying armature voltages.

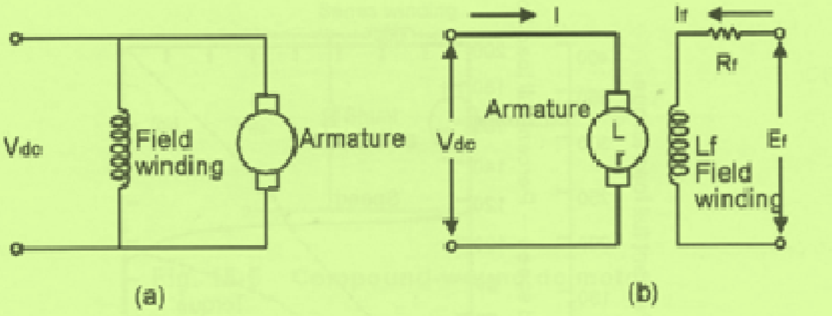


Fig. 15-3 Shunt-wound dc motor

$$E_f = R_f I_f + L_f \frac{dI_f}{dt} \qquad (15\text{-}4)$$

Ward Leonard motor speed control system is made by using this principle. The dc voltage applied to dc motor is converted from ac power source with phase control and filtering. Therefore the motor speed is controlled by AC phase control.

Refer to the circuit of Fig. 15-3(b). The voltage applied to field winding can be written as

where E_f = applied field voltage
I = field current
L_f = field inductance
R_f = field resistance

The relationship between the field current and flux expressed in equation form is:

$$\phi_f = f(I_f) \qquad (15\text{-}5)$$

From the above equation, we find that the motor speed can be controlled by adjusting the field current I_f.

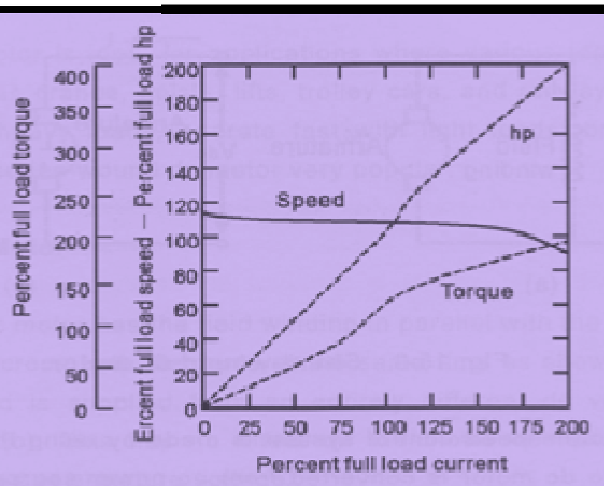


Fig. 15-4 Characteristics for a shunt-wound DC motor

Fig. 15-4 shows the typical characteristics for a shunt-wound dc motor. Unlike the series-wound dc motor, the speed of the shunt-wound dc motor remains relatively constant over the range of loads. Therefore a shunt-wound dc motor is a motor with constant speed and its power output and torque will increase as the armature current increases.

The shunt-wound dc motor has the advantage of controlling the speed by varying the field current or armature voltage. A wide range of speed control is possible - a 20-to-1 ratio between maximum and minimum speed is not uncommon. The shunt-wound dc motor is most suitable for applications requiring a wide range of operating speeds with easy reversibility and good braking. Typical applications are rolling mills, strip welders, printing presses, elevators, and machine tools. If constant speed is required for a range of loading, the dc shunt motor might also be used.

Compound-Wound DC Motor

A combination series-wound, shunt-wound motor is used to get speed-torque characteristics between those of Figs. 15-2 and 15-4. Such a motor is called a compound-wound dc motor as shown in Fig. 15-5. Referring to the speed-torque characteristics shown in Fig. 15-6, the speed variation in compound-wound dc motors is smaller than series-wound motors and torque variation is smaller than shunt-wound motors.

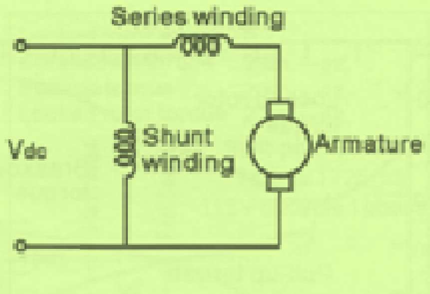


Fig. 15-5 Compound-wound dc motor

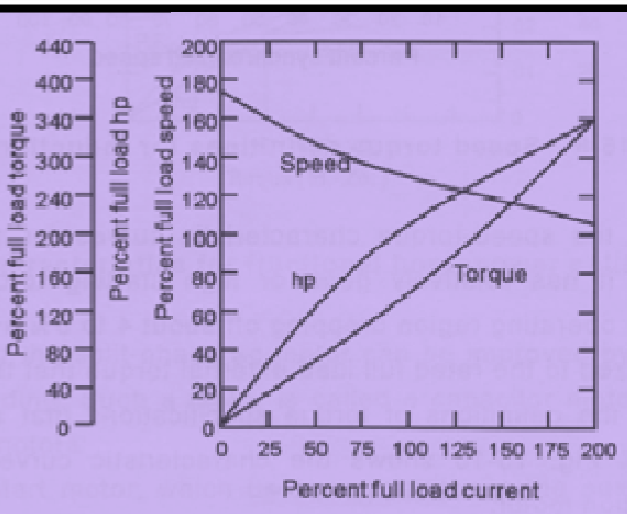


Fig. 15-6 Characteristics for a compound-wound dc motor

Split-Phase Induction Motor

The split-phase induction motor operates on single-phase ac line voltage. It is usually rated at fractional horsepower output. The split-phase motor requires an auxiliary stator winding to start the motor action when operating from single-phase line voltage. Fig. 15-7 shows the winding connections. When the motor reaches 75 to 80% of its final speed, the centrifugal switch opens and the motor operates on its main stator winding under continuous duty.

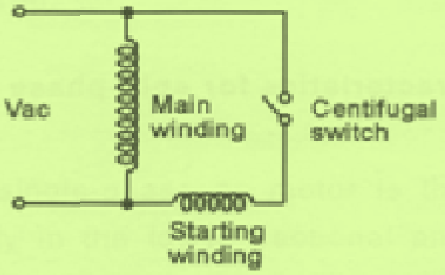


Fig. 15-7 Split-phase induction motor

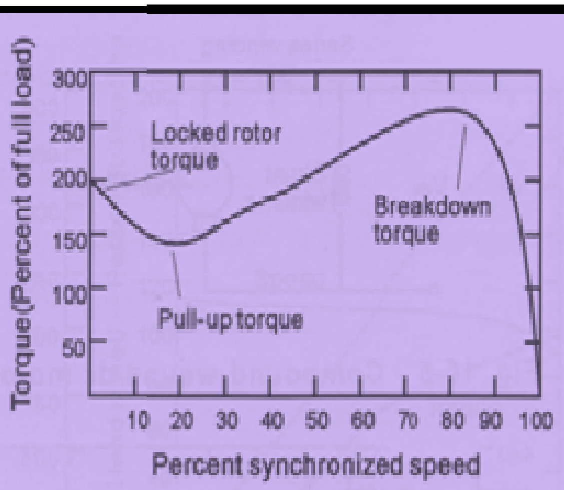


Fig. 15-8 Speed torque definitions for induction motors

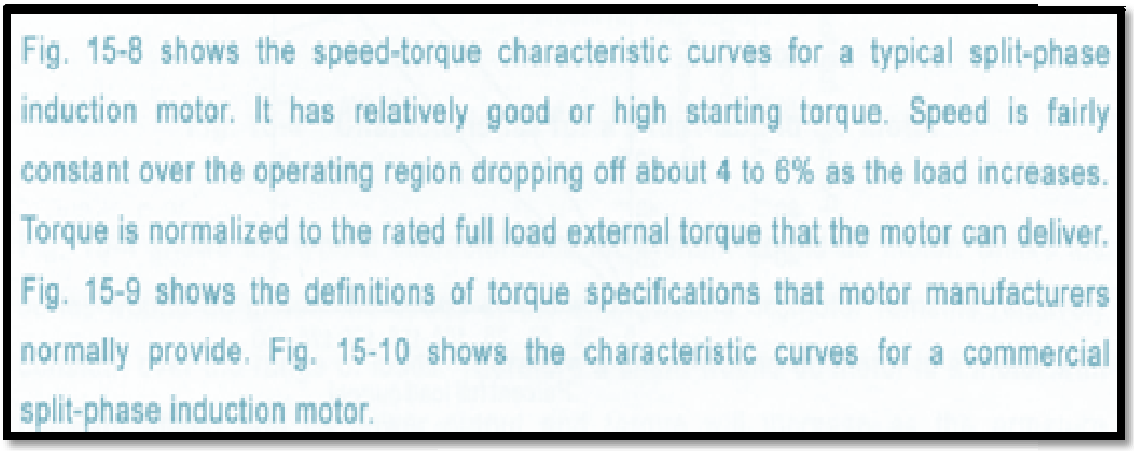


Fig. 15-8 shows the speed-torque characteristic curves for a typical split-phase induction motor. It has relatively good or high starting torque. Speed is fairly constant over the operating region dropping off about 4 to 6% as the load increases. Torque is normalized to the rated full load external torque that the motor can deliver. Fig. 15-9 shows the definitions of torque specifications that motor manufacturers normally provide. Fig. 15-10 shows the characteristic curves for a commercial split-phase induction motor.

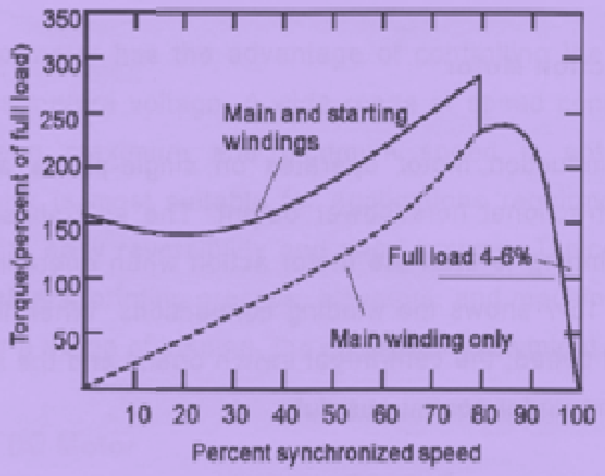


Fig. 15-9 Characteristics for split-phase induction motors

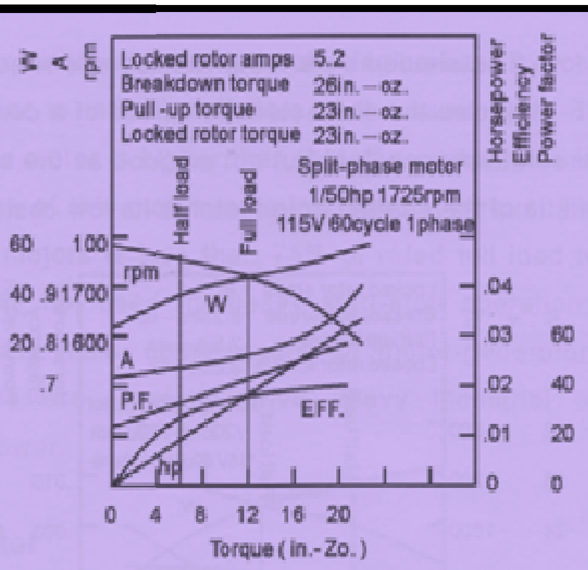


Fig. 15-10 Characteristics for fractional horsepower split-phase motor

The performance of the split-phase ac motor can be improved by using a capacitor in the auxiliary winding. Such a motor is called a capacitor motor. There are three types of capacitor motors:

(1) Capacitor-start motor, which uses a capacitor in the auxiliary winding only during starting to increase the starting torque.

(2) Permanent-split capacitor motor, which leaves the capacitor in the auxiliary winding during starting and running.

(3) Two-value capacitor motor, which uses a different capacitor in the auxiliary winding during starting than during running.

In the permanent-split capacitor and two-value capacitor motors, the starting capacitor increases the starting torque while the running capacitor increases the maximum torque and efficiency allowing the motor to run at a cooler temperature. This type motor is used in fractional and low-integral business machines, fans, blowers, desk calculators, and other applications where low starting torque and frequent operation are required.

Shaded Pole Motor

The simplest, lowest cost single-phase ac motor is the shaded pole motor. The horsepower rating is usually in the lower fractional and subfractional range. The 1/200 hp rating is common for this type motor. The starting torque, running torque, and efficiency are low. The shaded pole motor sometimes requires ventilating air to keep it cool. Fig. 15-11 shows the characteristic curves of a commercial shaded pole motor. The speed is relatively constant but not as good as the split-phase motor. The dominant characteristic of the shaded pole motor is its low cost.

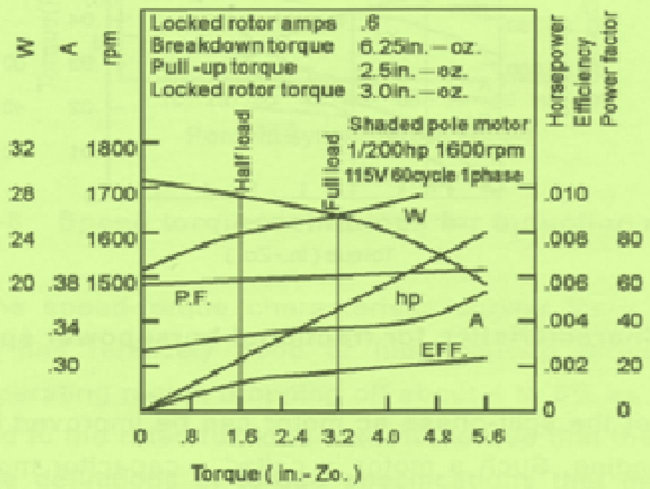


Fig. 15-11 Characteristics for shaded pole motor

Polyphase Induction Motor

Fractional horsepower ac motors are also designed to operate on two-phase or three-phase line voltages. These motors are generally very efficient with high starting and running torque. Speed is relatively constant from no load to full load.

The characteristic curves of a polyphase induction are similar to the single-phase induction motor. Industrial machine tools, air compressors, and pumps are commonly driven by three-phase induction motors.

Synchronous Motor

The synchronous motor is used in fractional as well as large integral horsepower motors. Three-phase ac voltage is used although single-phase synchronous motors are available. The speed of a synchronous motor is determined by the frequency of the line voltage. The speed remains constant regardless of the load applied.

Split-phase, capacitor-start, and shaded pole single-phase synchronous motors have characteristics similar to induction motors of the same type. The efficiency of the integral synchronous motor is higher than that of a comparable induction motor. One of the disadvantages of this motor is its low starting torque. The starting torque of many synchronous motors is less than 75% of rated full load torque. Synchronous motors are generally not used for heavy start-stop operation; they are ideal for continuous processing mills, compressors, or motor-generator sets. Three-phase synchronous motors are used to drive heavy industrial equipment requiring hundreds of horsepower.

Digital Stepper Motor

The digital stepper motor is a synchronous motor designed to operate with a pulsed input voltage rather than a continuous ac voltage. The motor is designed to move the output shaft a fixed number of degrees each time the proper pulsed voltage is applied.

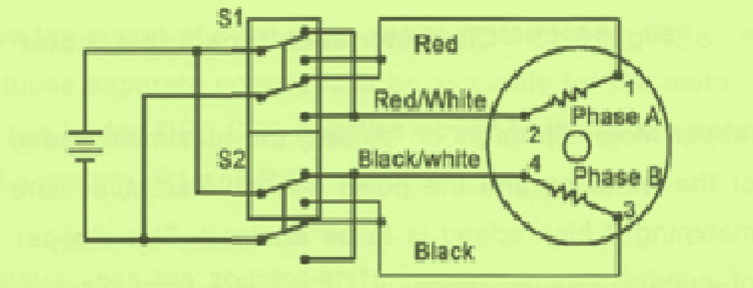


Fig. 15-12 Connections for typical stepper motor

Fig. 15-12 shows the connection diagram for a typical two-phase dc stepper motor. The sequence of pulses is demonstrated by the use of mechanical switches S1 and S2 at the input terminals. The sequence table is shown in Table 15-1. The switch control sequence is easily achieved by digital circuits in practical applications. Fig.15-13 shows the typical characteristics of dc stepper motor.

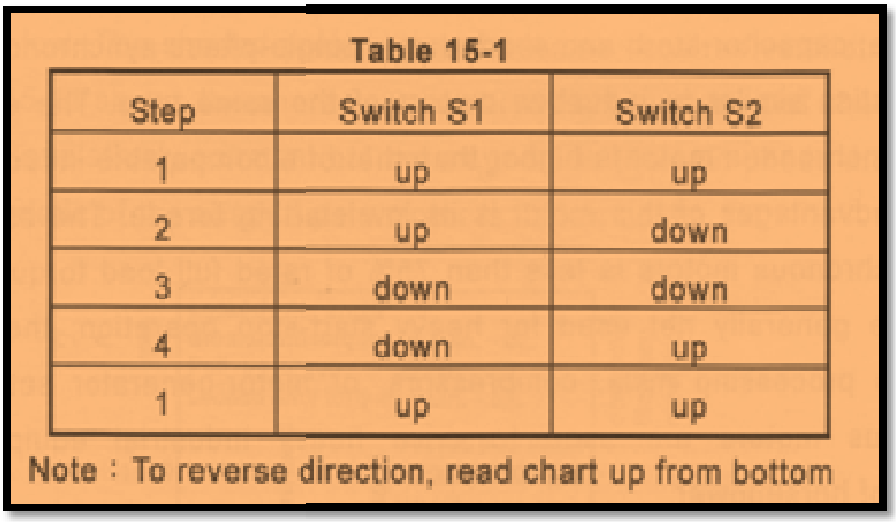


Table 15-1

Step	Switch S1	Switch S2
1	up	up
2	up	down
3	down	down
4	down	up
1	up	up

Note : To reverse direction, read chart up from bottom

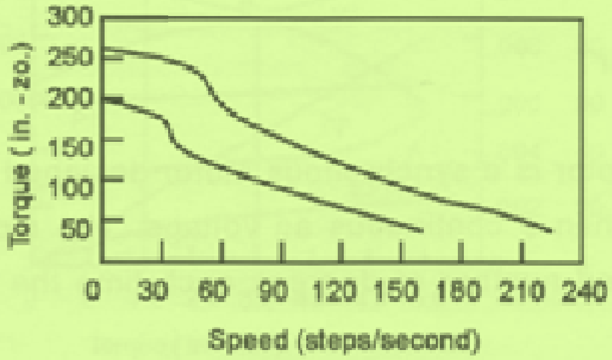
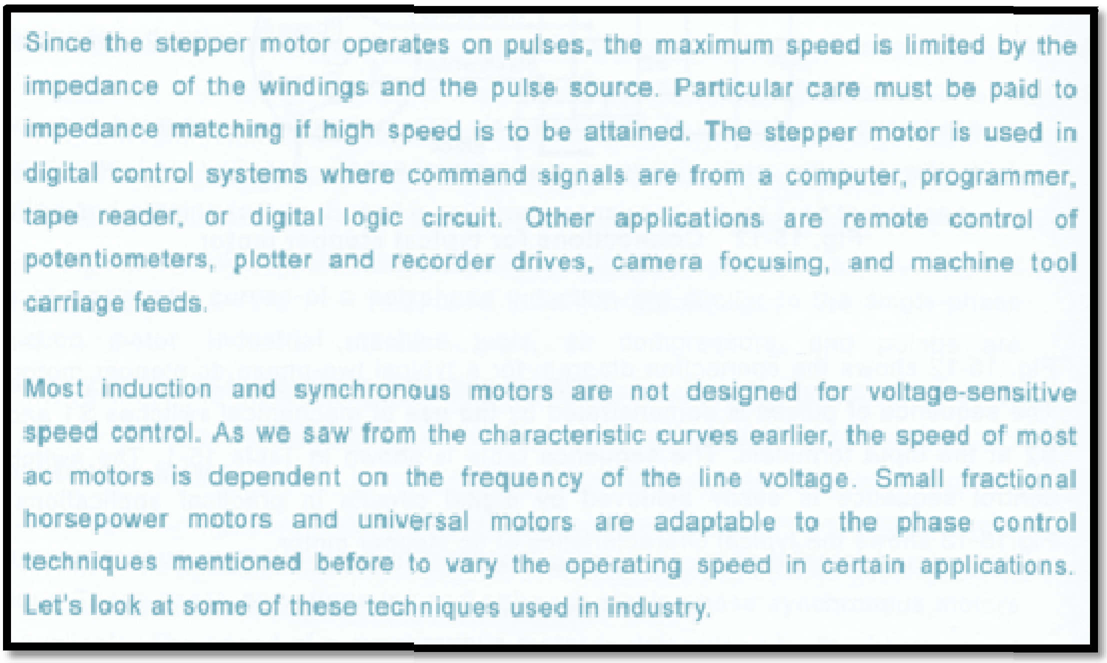


Fig. 15-13 Characteristics for stepper motor



Since the stepper motor operates on pulses, the maximum speed is limited by the impedance of the windings and the pulse source. Particular care must be paid to impedance matching if high speed is to be attained. The stepper motor is used in digital control systems where command signals are from a computer, programmer, tape reader, or digital logic circuit. Other applications are remote control of potentiometers, plotter and recorder drives, camera focusing, and machine tool carriage feeds.

Most induction and synchronous motors are not designed for voltage-sensitive speed control. As we saw from the characteristic curves earlier, the speed of most ac motors is dependent on the frequency of the line voltage. Small fractional horsepower motors and universal motors are adaptable to the phase control techniques mentioned before to vary the operating speed in certain applications. Let's look at some of these techniques used in industry.

Control of Universal Motor

As mentioned above, the speed of the universal motor will vary considerably with external loading. To maintain the speed of a universal motor constant over the entire load range, it is necessary to control speed with feedback system.

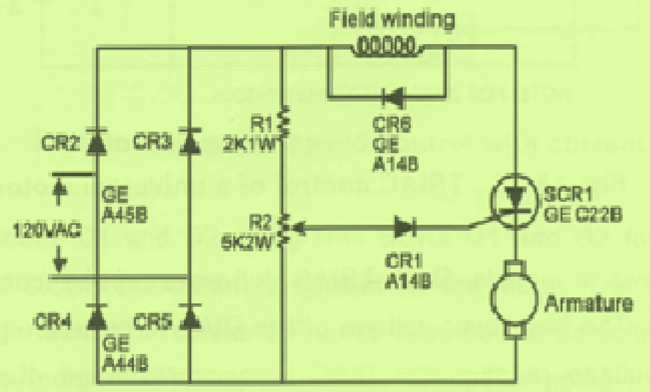
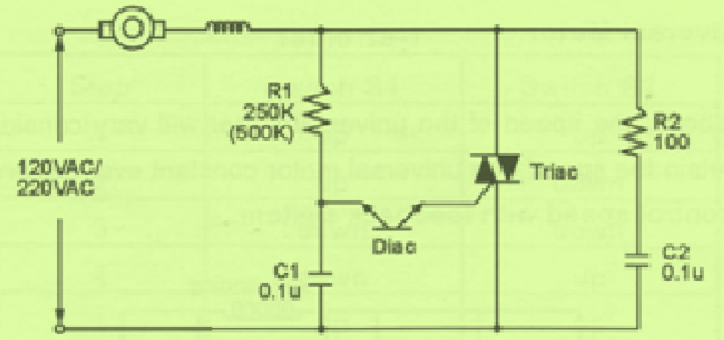


Fig. 15-14 Full-wave universal series motor speed control

Fig. 15-14 shows the circuit of a full-wave series motor speed control with feedback, which requires those separate connections be available for the motor armature and field. The full-wave bridge CR2-CR5 supplies power to the series networks of motor field, SCR1 and armature, R1 and R2.

Basically this circuit uses the counter-emf of armature as a feedback signal. When the motor starts running, the SCR1 triggers as soon as the reference voltage across the arm of R2 exceeds the forward drop of CR1 and the gate to cathode drop of SCR1. The motor then builds up speed, and as the counter-emf increases, the speed of the motor adjusts to the setting of R2. This circuit is limited by the fact that SCR1 can not be fired consistently later than 90°.



NOTE: FOR 220/240V,50/60Hz R1=500K

Fig. 15-15 TRIAC control of a universal motor

Fig. 15-15 shows a simple DIAC-TRIAC full-wave speed control circuit for a universal motor. The breakover voltage of the DIAC is between 18 and 35V. When the capacitor voltage reaches the DIAC breakover voltage, the DIAC conducts, delivering a pulse of current to the gate of the TRIAC. The TRIAC conducts, applying voltage to the motor armature. At the end of each half-cycle the TRIAC cuts off due to the anode current falling below the holding current level. Since the universal motor is an inductive load, anode current will actually flow until the fields are completely collapsed. The current flow through the motor armature and the voltage across the armature-field combination are shown in Fig. 15-16.

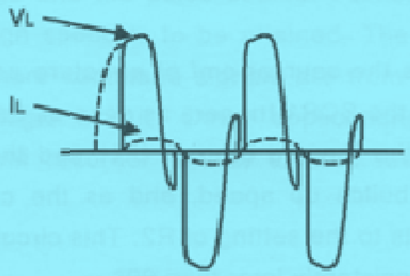


Fig. 15-16 Load voltage and current waveforms in the circuit of Fig. 15-15

The snubber circuit, C2-R2 suppression network, is used to protect TRIAC against the damage of excessive dv/dt in inductive loads.

One of the characteristics of the universal motor is that the speed decreases as the external load is increased. The circuit of Fig. 15-17 uses current feedback to maintain the speed of a universal motor constant over the entire load range.

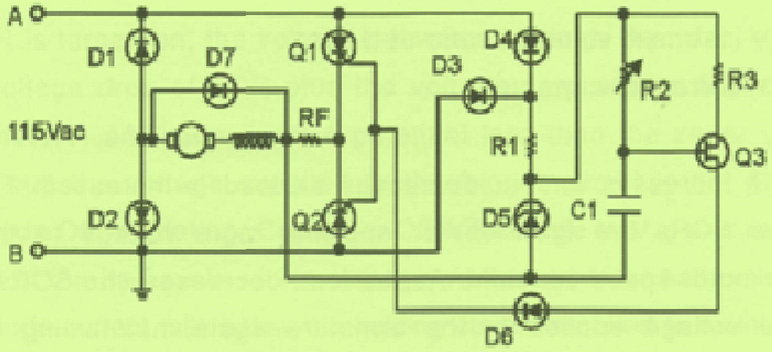


Fig. 15-17 High torque motor speed control with current feedback

In Fig. 15-17, diodes D1 and D2 along with SCRs Q1 and Q2 form the full-wave bridge rectifier to supply the armature current for the motor. The armature current also flows through feedback resistor RF. Let's assume the ac voltage is applied at terminal A at the moment that the sinusoidal voltage is going through zero with positive slope. SCRs Q1 and Q2 are both off. Diodes D1, D2, D3 and D4 form a full-wave bridge rectifier to supply the dc voltage for the triggering circuit. Resistor R1 and zener diode D5 form the voltage regulator. Resistors R2 and R3, capacitor C1 and UJT Q3 make up the basic UJT relaxation oscillator. Capacitor C1 charges through D4, R1, R2, D2, and the motor armature circuit. When the capacitor C1 charges to the UJT firing voltage, UJT Q3 conducts. Current flows through D6 to trigger SCR Q1. When Q1 conducts, the voltage supplied to the trigger circuit is not high enough to keep zener diode D5 regulating. Capacitor C1 will charge to the value of the voltage drop across R_F and remain fixed for the remainder of the half-cycle of line voltage. At the end of the half-cycle, SCR Q1 will turn off when its anode current falls below the holding current required to maintain conduction. The ac voltage at terminal B will now go positive with respect to terminal A. Current flow through D3, R1, and R2 will charge C1 toward the UJT firing voltage; but since C1 is already charged to the voltage across R_F it reaches the UJT trigger voltage sooner. The firing angle of SCR Q2 will be advanced by the initial charge on C1. The equation relating these variables is:

$$t\alpha = R2\,C1\,\ln \frac{Vz}{Vz - \eta Vz + I_f R_F} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(15\text{-}8)$$

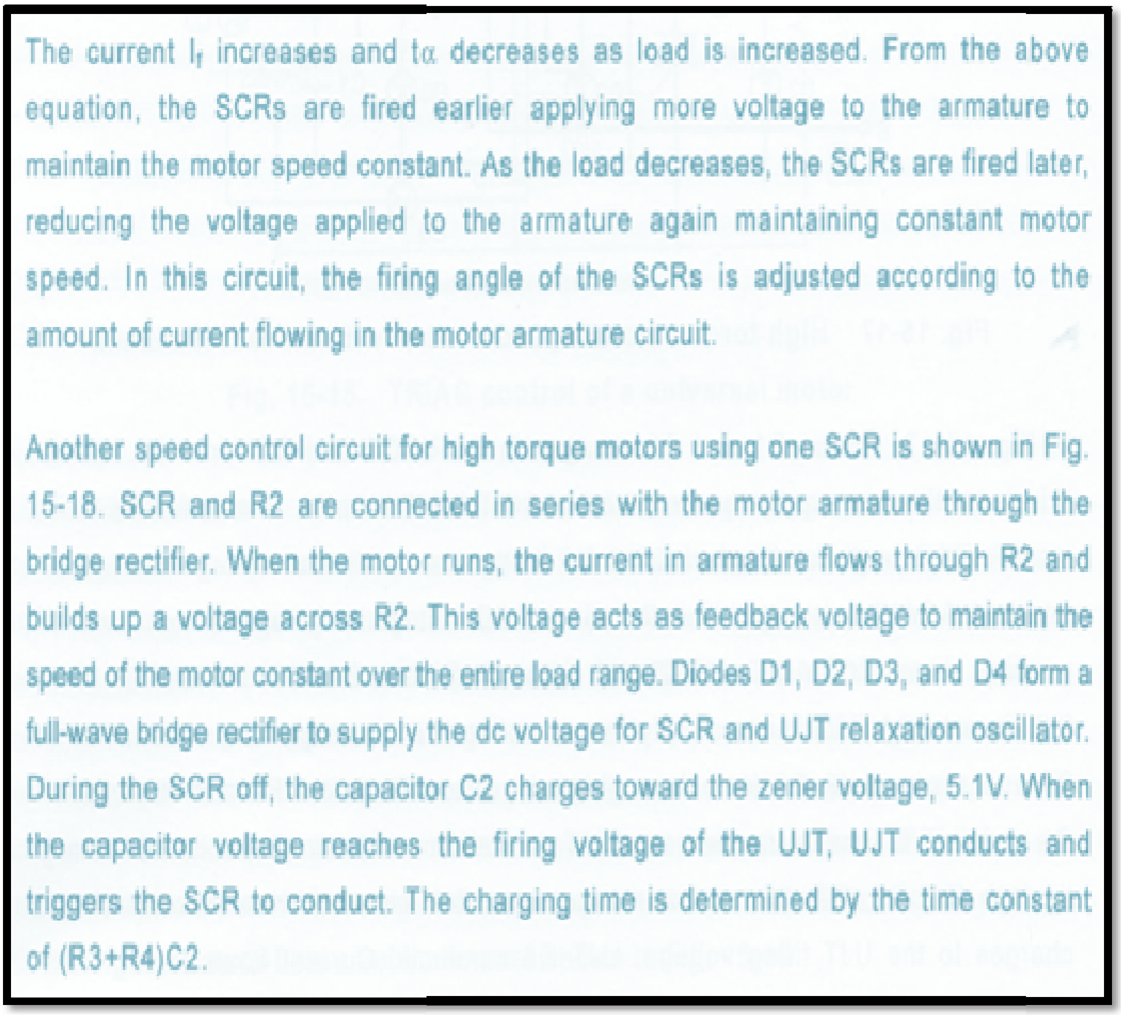
where

$t\alpha$ = time of firing the SCR

Vz = zener regulating voltage

η = instrinsic stand-off ratio of UJT

I_f = current in armature



The current I_f increases and $t\alpha$ decreases as load is increased. From the above equation, the SCRs are fired earlier applying more voltage to the armature to maintain the motor speed constant. As the load decreases, the SCRs are fired later, reducing the voltage applied to the armature again maintaining constant motor speed. In this circuit, the firing angle of the SCRs is adjusted according to the amount of current flowing in the motor armature circuit.

Another speed control circuit for high torque motors using one SCR is shown in Fig. 15-18. SCR and R2 are connected in series with the motor armature through the bridge rectifier. When the motor runs, the current in armature flows through R2 and builds up a voltage across R2. This voltage acts as feedback voltage to maintain the speed of the motor constant over the entire load range. Diodes D1, D2, D3, and D4 form a full-wave bridge rectifier to supply the dc voltage for SCR and UJT relaxation oscillator. During the SCR off, the capacitor C2 charges toward the zener voltage, 5.1V. When the capacitor voltage reaches the firing voltage of the UJT, UJT conducts and triggers the SCR to conduct. The charging time is determined by the time constant of (R3+R4)C2.

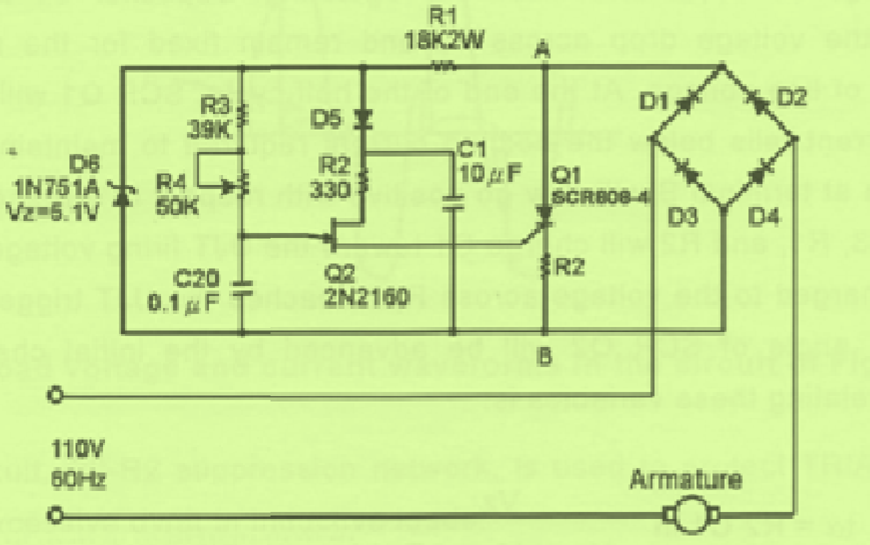


Fig. 15-18 High torque motor speed control circuit

When Q1 SCR is turned on, the voltage between terminals A and B, V_{AB}, is equal to the forward voltage drop of SCR plus the voltage drop across R2 (caused by the current in armature) and reduces to a potential less than the zener voltage of D6. The result is that the voltage supplied to the trigger circuit is not high enough to keep zener diode D6 regulating. Capacitor C2 will charge to V_{AB} and remain fixed for the remainder of the half cycle of line voltage. At the end of the half-cycle, SCR will turn off when its anode current falls below the holding current required to maintain conduction. Current flow through R3 and R4 will charge C2 toward the UJT firing voltage; but since C2 is already charged to the voltage V_{AB}, it reaches the UJT trigger voltage sooner. The firing angle of SCR will be advanced by the initial charge on C2. As the load increases and the armature current increases, the SCR is fired sooner, increasing the voltage applied to the armature again maintaining constant motor speed.

In this circuit, the firing angle of the SCR is adjusted according to the amount of current flowing in the motor armature circuit. The selection of feedback resistor R2 depends on the ratings of motor operating current and UJT current.

DC Shunt-Wound Motor Control

The workhorse of the industry as far as adjustable speed motors is concerned is the dc shunt-wound motor. Speed is conveniently controlled by varying the armature voltage or field current. This can be seen by examining the equations for the shunt motor. The total voltage in the armature circuit is

$$V_A = V_{emf} + I_A R_A \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (15\text{-}9)$$

where I_A = armature current
R_A = the resistance of the armature windings
V_{emf} = the counterelectromotive force generated by the motor

The counter-emf generated by the motor is

$$V_{emf} = K_1 N \phi \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (15\text{-}10)$$

Where N = the motor speed in r/min
ϕ = the strength of the field
K_1 = a conversion constant

Voltage is applied to the field windings to establish the value of ϕ before the motor is started. When the armature voltage is applied, the motor speed increases but so does the cunter-emf. The counter-emf will increase until the armature current is just sufficient to overcome the inertia and losses in the motor. As the external load is applied, the armature current will increase to provide the torque necessary to match the load according to the equation

$$T_2 = K\phi I_A \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (15\text{-}11)$$

The counter-emf must decrease to maintain the balance in Eq. (15-9). The motor speed decreases proportionately. Eqs. (15-9) and (15-11) can be solved simultaneously for speed.

$$N = \frac{VA - IARA}{K1\ \phi} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (15\text{-}12)$$

The motor speed can be controlled by varying V_A or ϕ. The usual technique is to vary armature voltage V_A for speed control up to the rated speed and to vary the field ϕ to control speed above the rated speed of the motor. Fig. 15-19 shows the ranges for armature control and weak field control.

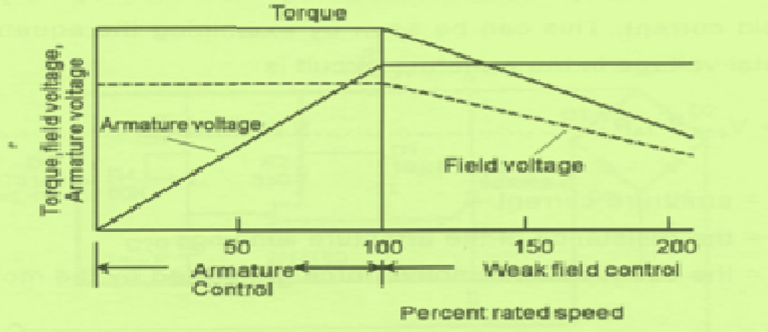


Fig. 15-19 DC shunt motor control

The basic elements of most electronic dc motor controls are a reference signal to set the desired speed, a control device to vary the armature or field voltage, and a feedback mechanism to compare the motor speed with the reference setting. The simplest, most economical design is the SCR control of Fig. 15-20. The counter-emf generated by the motor or the armature current serves as the feedback mechanism. The SCR trigger timing is dependent on the difference between the reference setting and the feedback signal. If a stable speed control is not required in some applications, the feedback mechanism is not necessary.

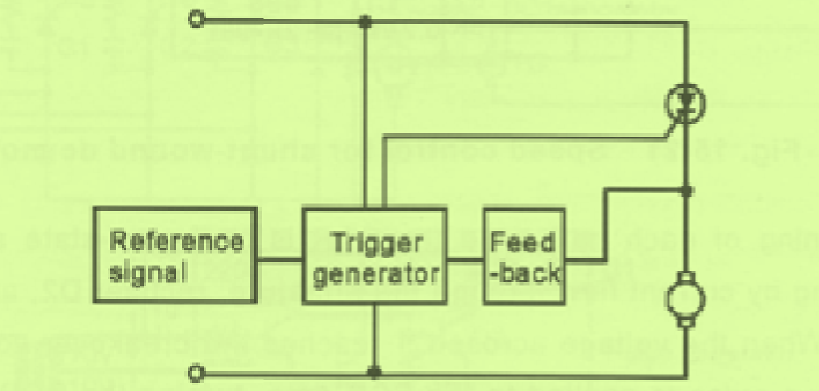


Fig. 15-20 Blocks of basic SCR motor controller

The single-phase SCR control does not offer the smooth, precise control required for some applications but it is quite common for the control of fractional horsepower motors. Large motors use three-phase rectified control to achieve smooth, precise speed control under heavy loading. The basic principles of single-phase control can be extended to polyphase controls.

Fig. 15-21 shows a simple solid-state speed control for shunt-wound DC motors. This circuit uses a bridge rectifier to provide full-wave rectification of the AC supply. The field winding is permanently connected across the dc output of the bridge rectifier. Armature voltage is supplied through the SCR and is controlled turning the SCR on at each half cycle.

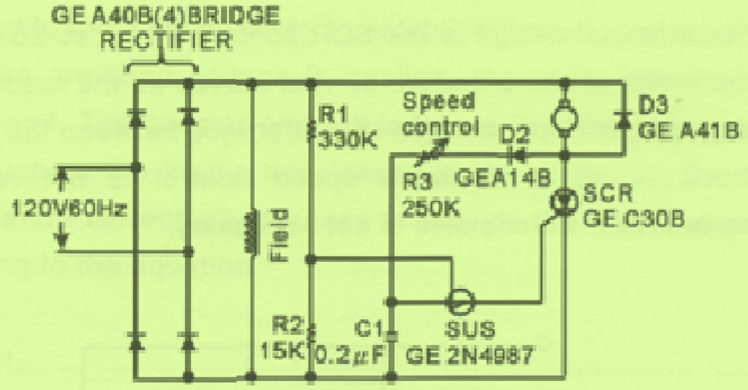


Fig. 15-21 Speed control for shunt-wound dc motor

At the beginning of each half cycle the SCR is in the off-state and capacitor C1 starts charging by current flow through the armature, rectifier D2, and the adjustable resistor R3. When the voltage across C1 reaches the breakover voltage of the SUS trigger diode, a pulse is applied to the SCR gate, turning the SCR on and applying power to the armature for the remainder of that half cycle. The time required for C1 to reach the breakover voltage of the SUS governs the phase angle at which the SCR is turned on and this is controlled by the magnitude of R3 and the voltage across the SCR.

Since the voltage across the SCR is the bridge rectifier minus the counter-emf across the armature, the charging of C1 is partially dependent upon this counter-emf, hence upon the speed of the motor. If the motor runs at a slower speed, the counter-emf will be lower and the voltage applied to the charging circuit will be higher. This decreases the time required to trigger the SUS and SCR, hence increases the power supplied to the armature and thereby compensates for the loading on the motor.

Energy stored in armature inductance will result in the current flow through diode D3 for a short time at the beginning of each half cycle. During this time, the counter-emf of the armature can not appear, hence the voltage across the SCR is equal to the output voltage of the bridge rectifier. The time required for this current to die out and for the counter-emf to appear across the armature is determined by both speed and armature current. At lower speeds and at higher armature currents the diode D3 will remain conducting for a longer period of time at the beginning of each half cycle. This action also causes faster charging of capacitor C1, hence provides compensation that is sensitive to both armature current and to motor speed.

Three-phase Rectified DC Motor Control

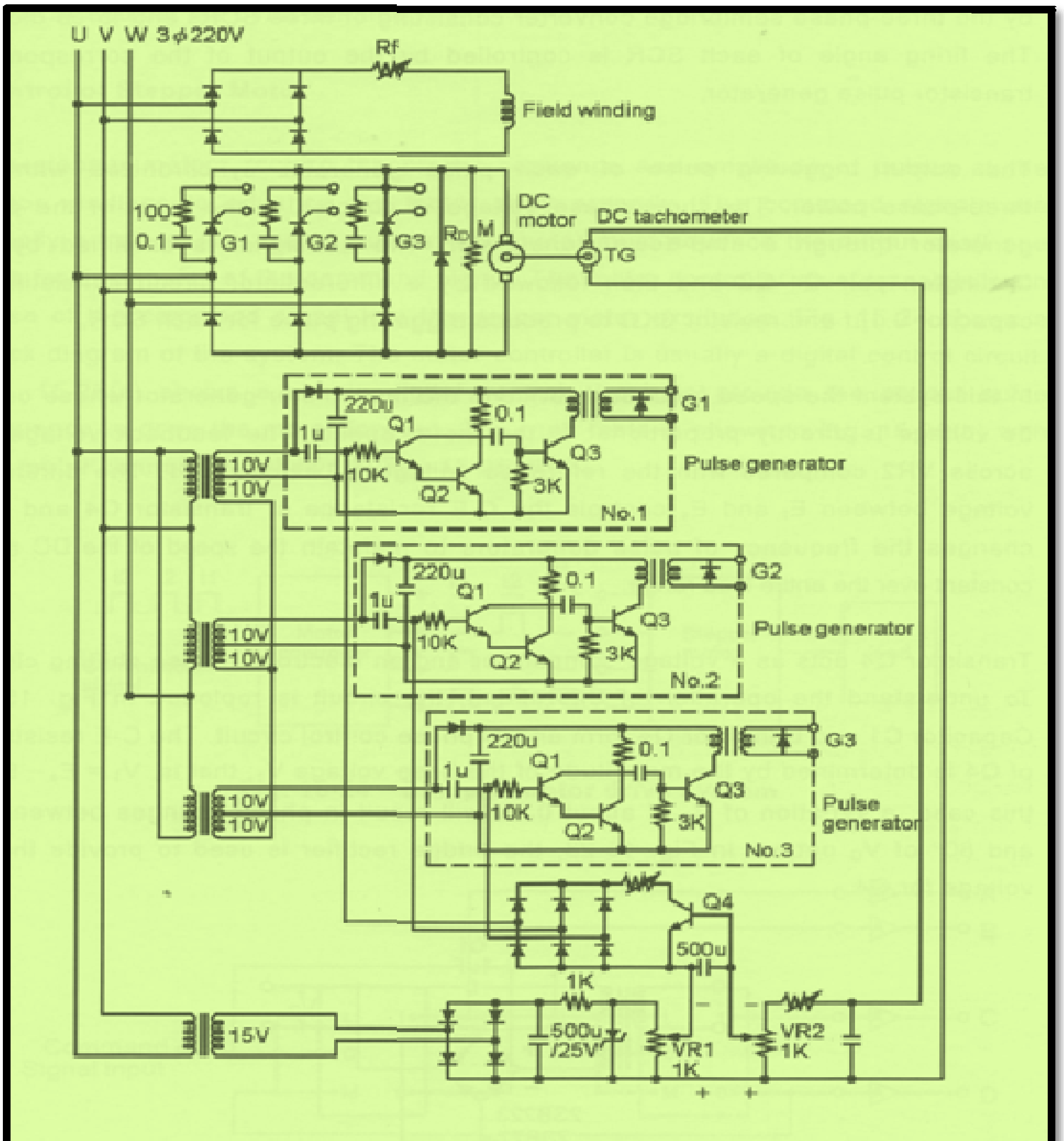


Fig. 15-22 DC motor speed control with three-phase voltage

For the DC motor rating of several kilowatts or more, it is desirable to use a three-phase converter with Ward Leonard speed control circuit. Fig. 15-22 shows a DC motor speed control system with three-phase power supply. The field winding voltage is provided by the bridge rectifier output. The armature voltage is provided by the three-phase semibridge converter consisting of three SCRs and three diodes. The firing angle of each SCR is controlled by the output of the corresponding transistor pulse generator.

The output triggering pulse of each pulse generator synchronizes with the three-phase power. The three-phase voltage is coupled to the input of the pulse generator through a step-down transformer. The ac signal is amplified by the Darlington pair Q1-Q2 and then followed by a differentiator circuit consisting of capacitor 0.1μf and resistor 3KΩ to produce triggering pulse for each SCR.

In this system the speed feedback device is the tachometer generator whose output dc voltage is directly proportional to the motor speed. The feedback voltage, E_f, across VR2 compares with the reference voltage E_s across VR1. The difference voltage between E_f and E_s controls the C-E resistance of transistor Q4 and then changes the frequency of pulse generators to maintain the speed of the DC motor constant over the entire load range.

Transistor Q4 acts as a voltage comparator and an electronic phase shifting circuit. To understand the operation of this circuit, the circuit is replotted in Fig. 15-23. Capacitor C1 and transistor Q4 form an RC phase control circuit. The C-E resistance of Q4 is determined by the magnitude of the base voltage V_1; that is, $V_1 = E_s - E_f$. In this case, a variation of V_1 of about 0.2V will result in phase changes between 70 and 80° of V_G output. In Fig. 15-23, the bridge rectifier is used to provide the dc voltage for Q4.

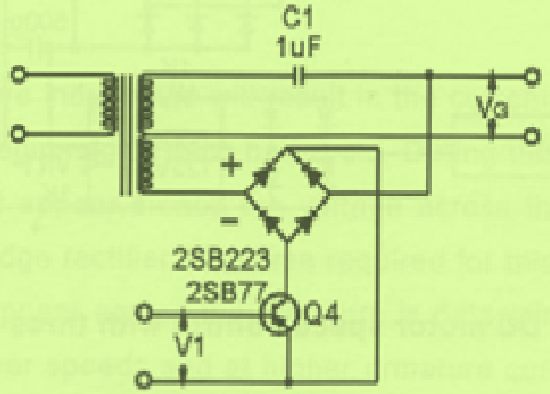
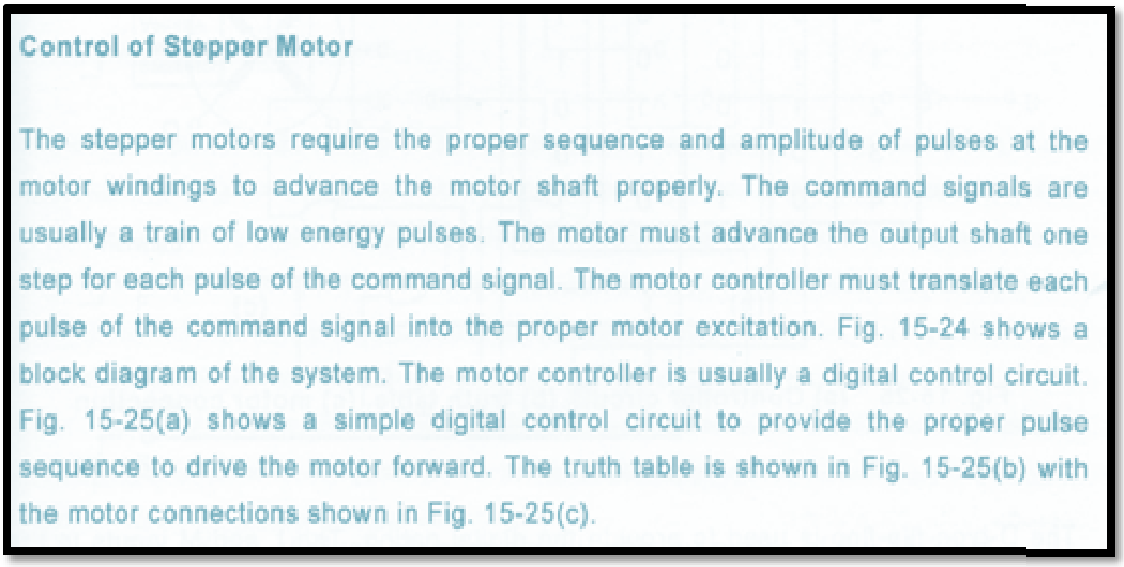


Fig. 15-23 Basic electronic phase control circuit

In Fig. 15-22, the snubber circuit connected in parallel with each SCR is to protect the SCR against the dv/dt damage.



Control of Stepper Motor

The stepper motors require the proper sequence and amplitude of pulses at the motor windings to advance the motor shaft properly. The command signals are usually a train of low energy pulses. The motor must advance the output shaft one step for each pulse of the command signal. The motor controller must translate each pulse of the command signal into the proper motor excitation. Fig. 15-24 shows a block diagram of the system. The motor controller is usually a digital control circuit. Fig. 15-25(a) shows a simple digital control circuit to provide the proper pulse sequence to drive the motor forward. The truth table is shown in Fig. 15-25(b) with the motor connections shown in Fig. 15-25(c).

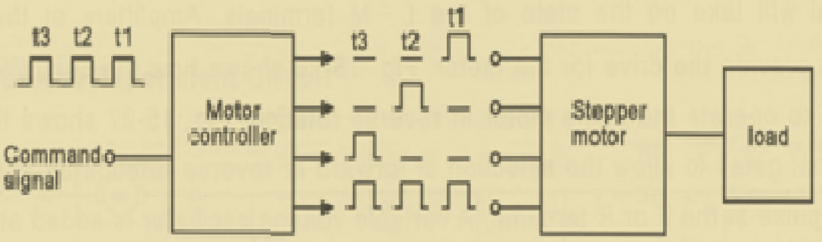
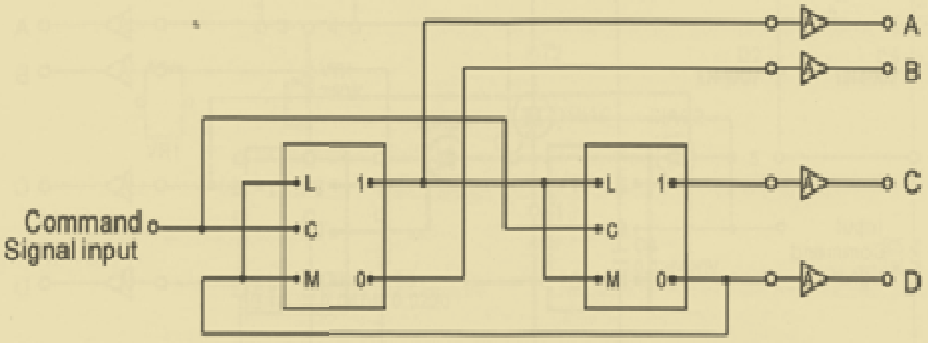
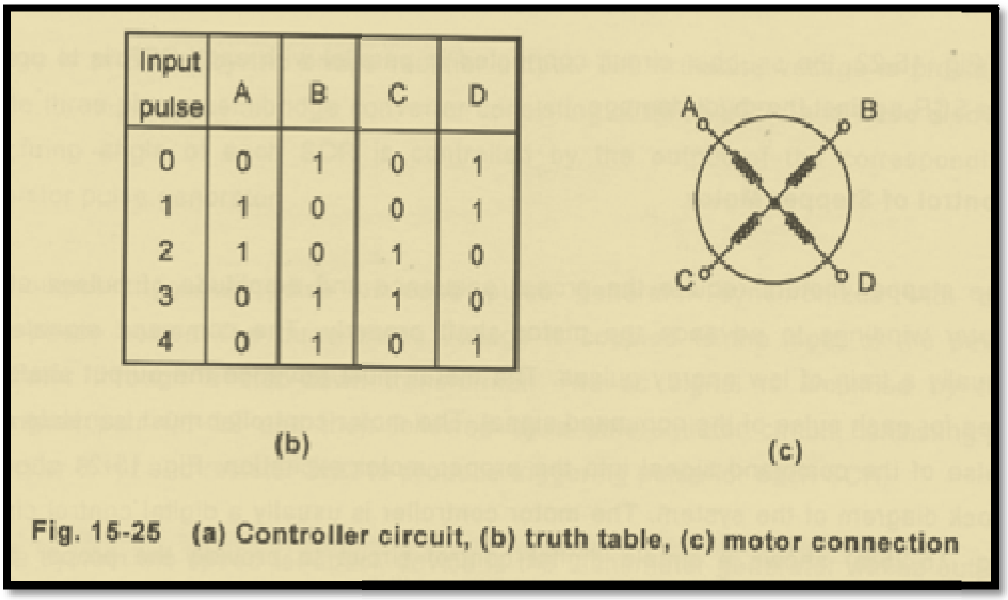


Fig. 15-24 Stepper motor drive system



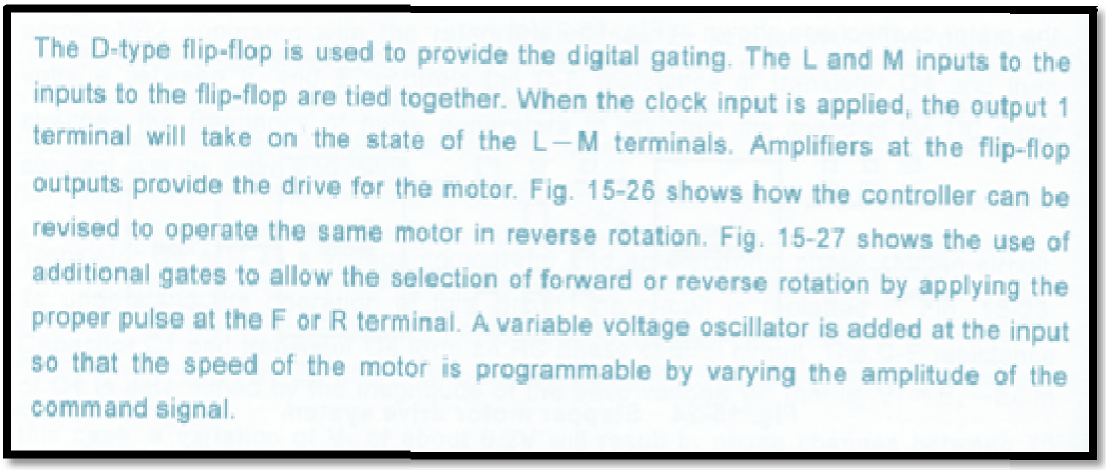
(a)



Input pulse	A	B	C	D
0	0	1	0	1
1	1	0	0	1
2	1	0	1	0
3	0	1	1	0
4	0	1	0	1

(b)

Fig. 15-25 (a) Controller circuit, (b) truth table, (c) motor connection



The D-type flip-flop is used to provide the digital gating. The L and M inputs to the inputs to the flip-flop are tied together. When the clock input is applied, the output 1 terminal will take on the state of the L—M terminals. Amplifiers at the flip-flop outputs provide the drive for the motor. Fig. 15-26 shows how the controller can be revised to operate the same motor in reverse rotation. Fig. 15-27 shows the use of additional gates to allow the selection of forward or reverse rotation by applying the proper pulse at the F or R terminal. A variable voltage oscillator is added at the input so that the speed of the motor is programmable by varying the amplitude of the command signal.

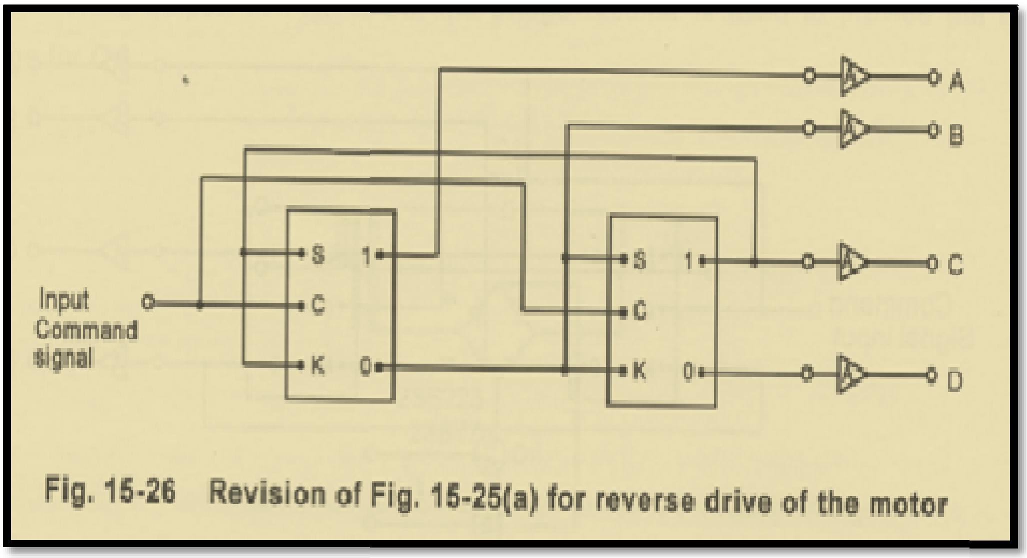


Fig. 15-26 Revision of Fig. 15-25(a) for reverse drive of the motor

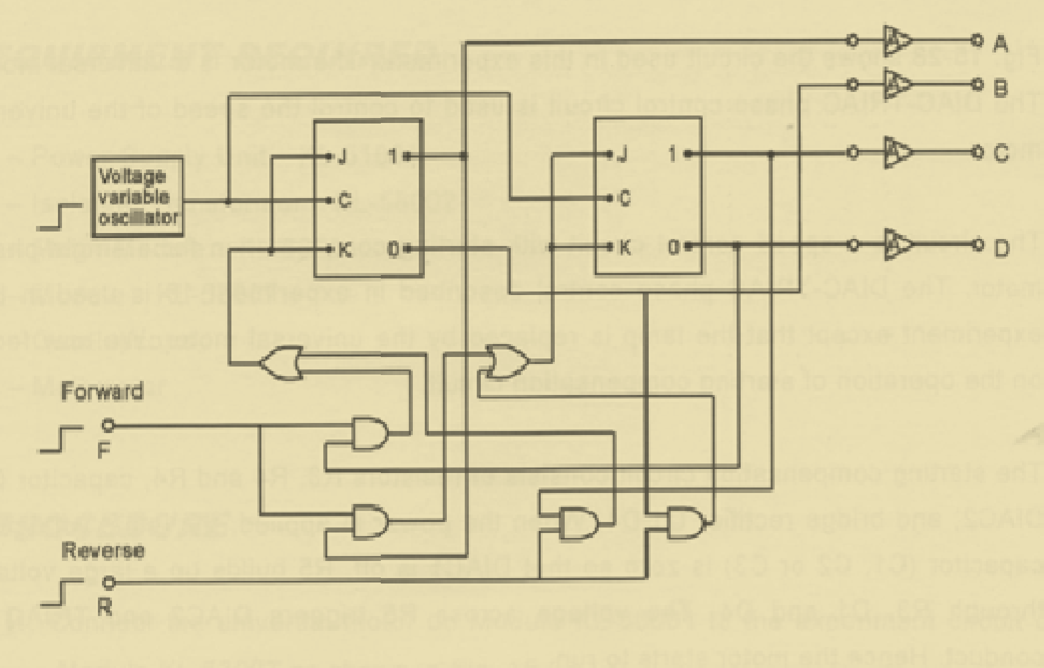


Fig. 15-27 Adjustable speed controller for motor of Fig.15-25(c)

Description of Experiment Circuit

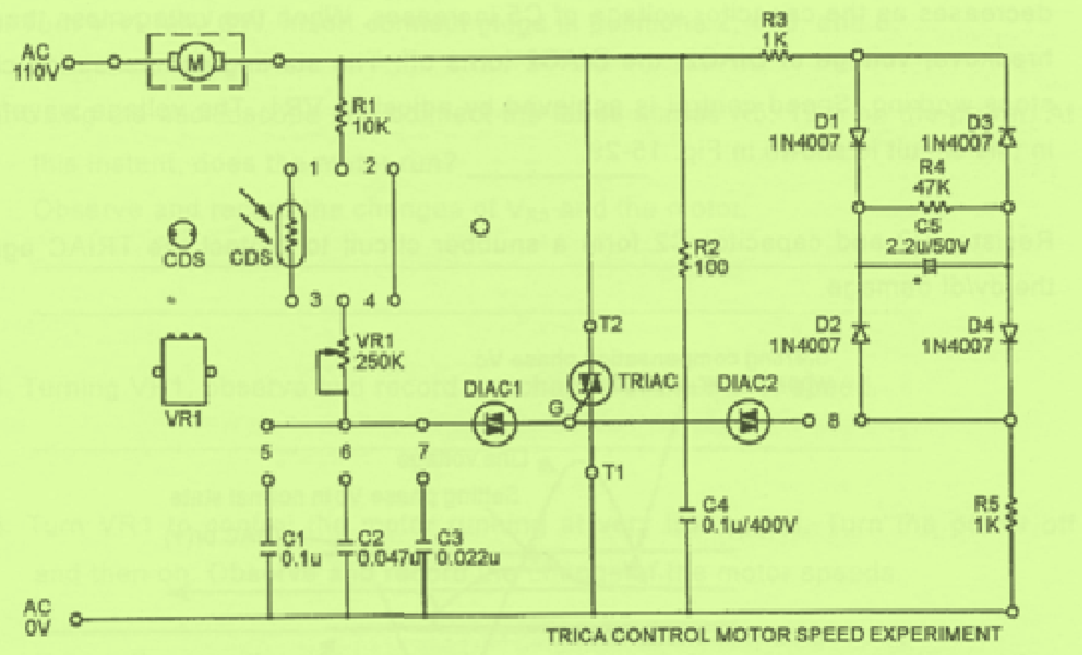


Fig. 15-28 Experiment circuit

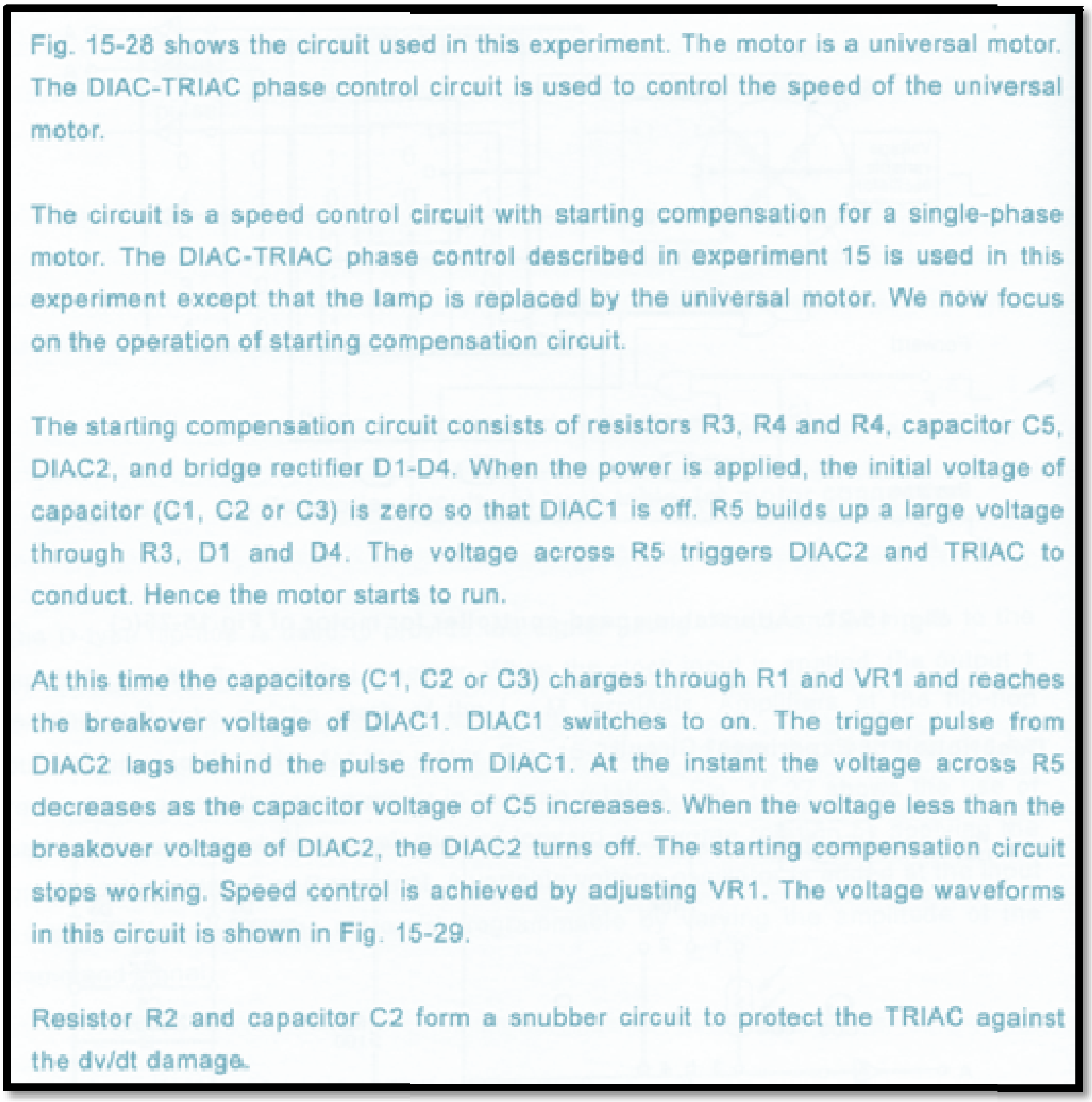


Fig. 15-28 shows the circuit used in this experiment. The motor is a universal motor. The DIAC-TRIAC phase control circuit is used to control the speed of the universal motor.

The circuit is a speed control circuit with starting compensation for a single-phase motor. The DIAC-TRIAC phase control described in experiment 15 is used in this experiment except that the lamp is replaced by the universal motor. We now focus on the operation of starting compensation circuit.

The starting compensation circuit consists of resistors R3, R4 and R4, capacitor C5, DIAC2, and bridge rectifier D1-D4. When the power is applied, the initial voltage of capacitor (C1, C2 or C3) is zero so that DIAC1 is off. R5 builds up a large voltage through R3, D1 and D4. The voltage across R5 triggers DIAC2 and TRIAC to conduct. Hence the motor starts to run.

At this time the capacitors (C1, C2 or C3) charges through R1 and VR1 and reaches the breakover voltage of DIAC1. DIAC1 switches to on. The trigger pulse from DIAC2 lags behind the pulse from DIAC1. At the instant the voltage across R5 decreases as the capacitor voltage of C5 increases. When the voltage less than the breakover voltage of DIAC2, the DIAC2 turns off. The starting compensation circuit stops working. Speed control is achieved by adjusting VR1. The voltage waveforms in this circuit is shown in Fig. 15-29.

Resistor R2 and capacitor C2 form a snubber circuit to protect the TRIAC against the dv/dt damage.

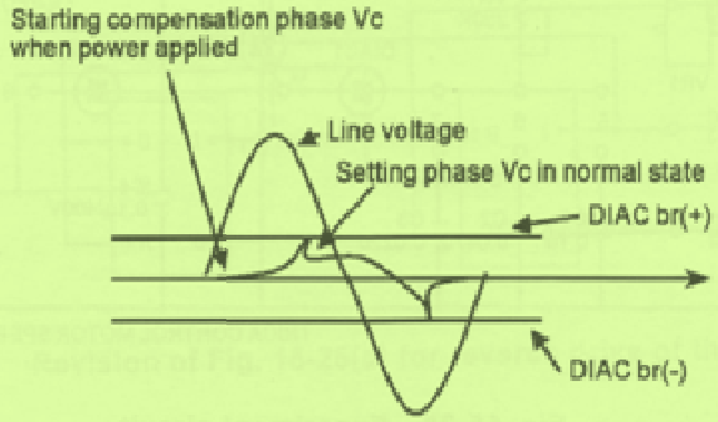


Fig. 15-29 Voltage waveforms in the circuit of Fig. 15-28

EQUIPMENT REQUIRED

1 – Power Supply Unit KL-51001
1 – Isolation Transformer KL-58002
1 – Motor Module KL-58001
1 – Module KL-53007
1 – Oscilloscope
1 – Multimeter

PROCEDURE

1. Connect the universal motor on Module KL-58001 to the experiment circuit on Module KL-53007 as shown in Fig. 15-28.

2. Connect 110VAC supply from Power Supply Unit KL-51001、KL-58002 to KL-53007 module.

3. Turn VR1 fully CW. Insert connect plugs in positions 2, 4, 5, and 8.

4. Using the oscilloscope and connect the leads across R5. Turn on the power. At this instant, does the motor run? ____________
   Observe and record the changes of V_{R5} and the motor.

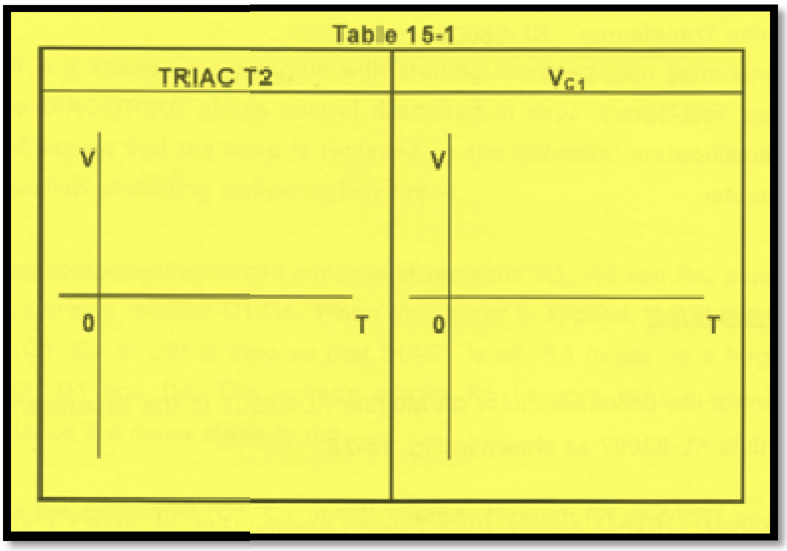
5. Turning VR1, observe and record the change of the motor speed.

6. Turn VR1 to control the motor running at very low speed. Turn the power off and then on. Observe and record the change of the motor speeds.

   Using the oscilloscope, observe and record the change of the voltage waveform of TRIAC T2.

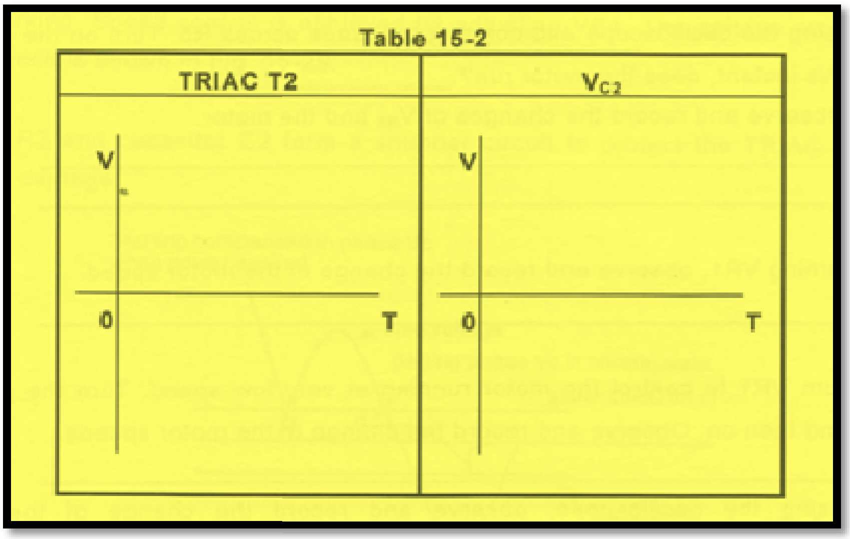
7. Set VR1 to its midposition. Using the oscilloscope, measure and record the voltage waveforms at SCR T2 and across C1 in Table 15-1.

Table 15-1



8. Turn off the power. Remove the connect plug from position 5 and insert it in position 6. Turn VR1 fully CW. Repeat steps 4 through 7. Record the results in Table 15-2.

Table 15-2



9. Turn off the power. Remove the connect plug from position 6 and insert it in position 7. Turn VR1 fully CW. Repeat steps 4 through 7. Record the results in Table 15-3.

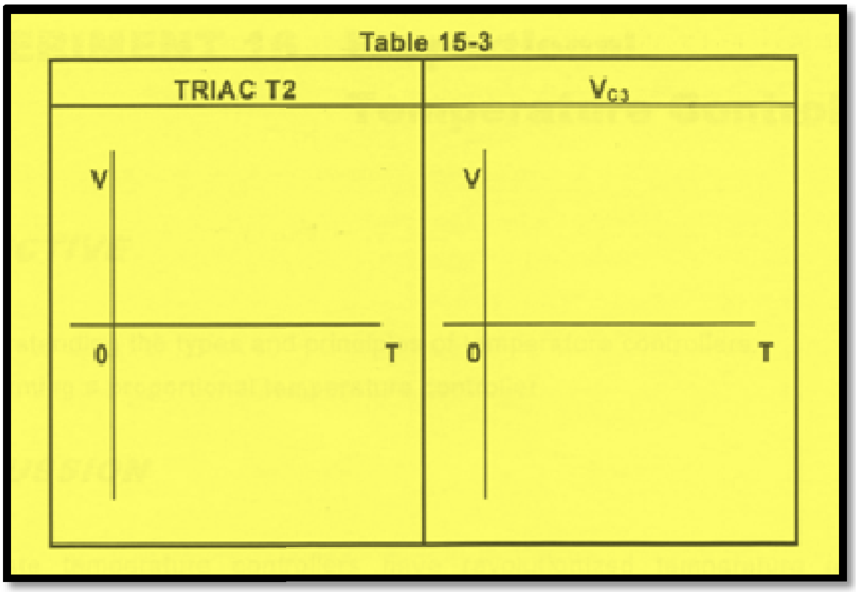
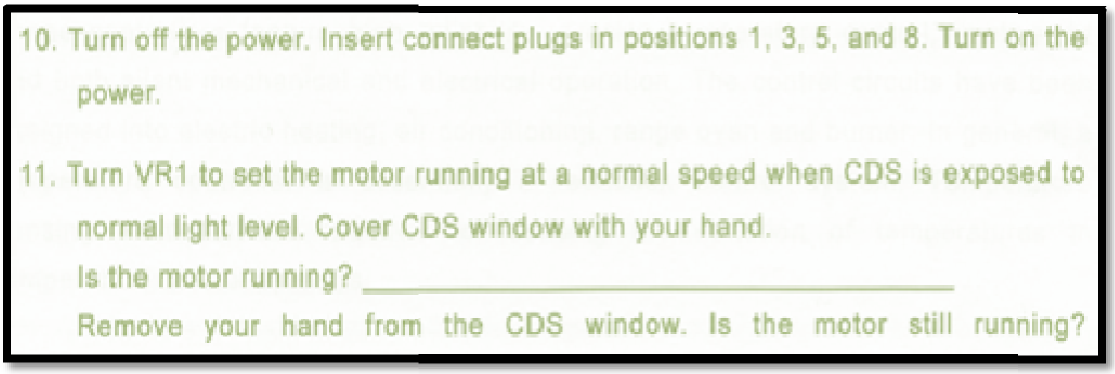


Table 15-3

TRIAC T2	V_{C3}

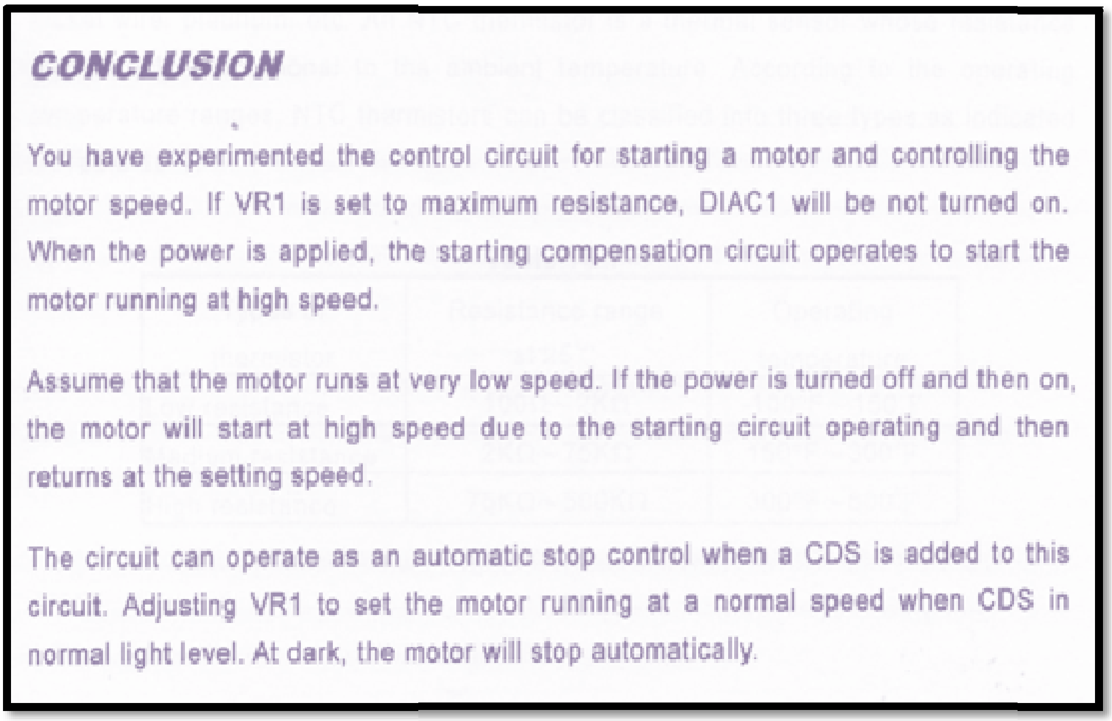


10. Turn off the power. Insert connect plugs in positions 1, 3, 5, and 8. Turn on the power.

11. Turn VR1 to set the motor running at a normal speed when CDS is exposed to normal light level. Cover CDS window with your hand.

Is the motor running? ______________________________

Remove your hand from the CDS window. Is the motor still running?



CONCLUSION

You have experimented the control circuit for starting a motor and controlling the motor speed. If VR1 is set to maximum resistance, DIAC1 will be not turned on. When the power is applied, the starting compensation circuit operates to start the motor running at high speed.

Assume that the motor runs at very low speed. If the power is turned off and then on, the motor will start at high speed due to the starting circuit operating and then returns at the setting speed.

The circuit can operate as an automatic stop control when a CDS is added to this circuit. Adjusting VR1 to set the motor running at a normal speed when CDS in normal light level. At dark, the motor will stop automatically.