Chapter III

DISCUSSION ON SELECTION OF SYSTEM COMPONENTS

3.1 Introduction

Discussed in this chapter is the basic theory and applications related to the system components, such as the Solar Detector, Inverting Amplifier, Summing Amplifier, Zero-crossing Detector, Regulated Power Supply and D.C. Servomotor.

3.2 Solar Detector[4]

To be used as a solar detector, solar cell possesses many advantages, the most important of which are the absence of moving parts, rapid response, the independence from supply line, and the flexibility in optimizing the operation of the "generator-load" system. An influencing factor in the design of the solar cell is an optimization of its spectral response. Although CdTe promises the highest efficiency, the best overall performance has been obtained with silicon, the material which has benefited from the most intensive technological effort. An efficiency of 14% has been reported for silicon solar cells.

Two conditions must be met for effective utilization of photon-generated current. First, the p-n junction must be effectively exposed to a light source. Second, provision must be made to collect and conduct the photovoltaic current to an external load. A device which realizes the forgoing requirements is illustrated in Figure 3.1.

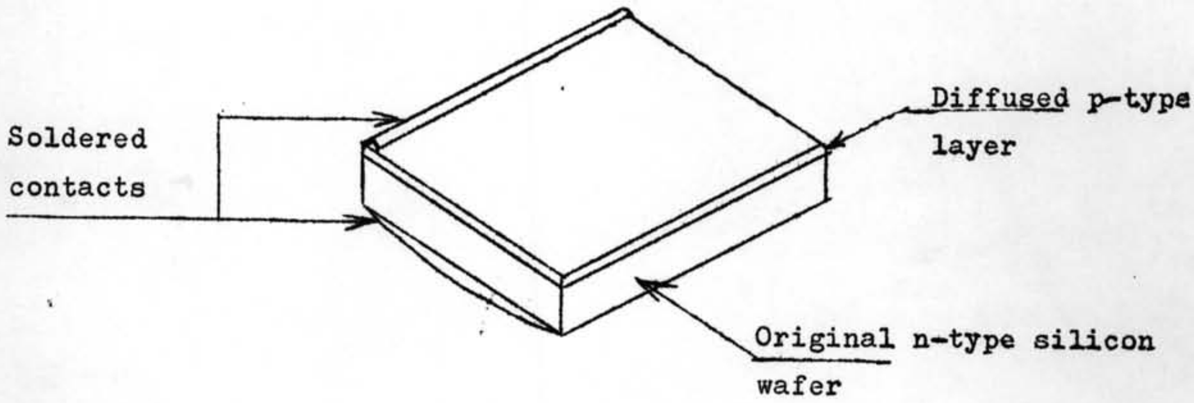

Figure 3.1. Essential Parts of a Solar Cell

Boron is diffused into a heavily doped n-type silicon wafer, and a p-type skin of a few microns thick is formed on the top. Electric contact is made to the top and bottom by first nickel plating the surfaces and then soldering at the places shown in Figure 3.1 . The electrical load is connected across the soldered contacts. When light strikes the top surface, a positive electric current flows from the top contact through the load to the bottom contact as shown in Figure 3.2 .

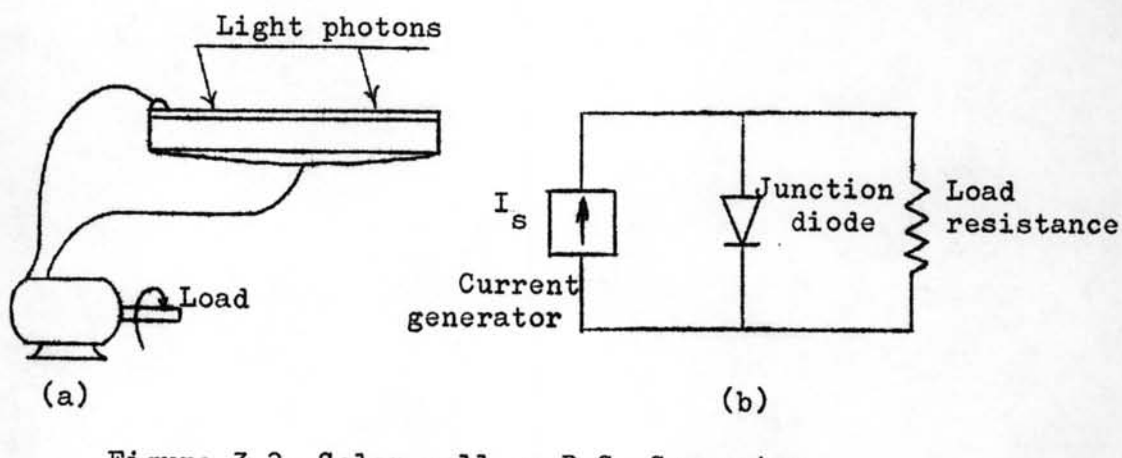

Figure 3.2. Solar cell as D.C. Generator.

3.2.1 Efficiency versus Light Intensity

The efficiency of a photovoltaic cell increases with the intensity of the light beam.

3.2.2 Failure Mechanisms

The failure mechanisms of solar cells can generally classified as follow :

1. an open circuit due to a poor interconnection,
2. an increased series resistance due to deterioration of a contact on the solar cell or terminal post.
3. melting of solder contact, causing the shorting of the p-n junction. In the case of a cell system used in space, the following are also relevant :

   3.1 a short due to micrometeorite damage, and

   3.2 radiation-induced damage.

3.3 Operational Amplifier[9]

To amplify signals extending over a wide frequency range, the operational amplifier is selected as the working component. The operational amplifier (abbreviated OP AMP) is a direct-coupled high-gain amplifier to which feedback is added to control its overall response characteristic. An OP AMP may be used to perform many mathematical operations. This feature accounts for the name " operational amplifier ".

The integrated operational amplifier has gained wide acceptance as a versatile, predictable and economic system building block. It offers all the advantages of monolithic integrated circuits : small size, high reliability, reduced cost, temperature tracking, and low offset voltage and current. The schematic diagram of the OP AMP is shown in Figure 3.3 (a), and the equivalent circuit in Figure 3.3 (b).

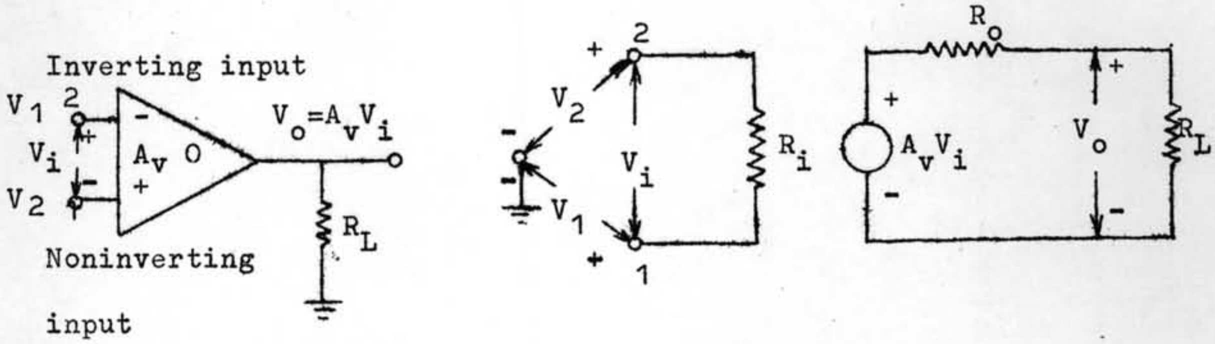

Figure 3.3.(a) A Basic Operational Amplifier.

(b) Low Frequency Equivalent Circuit of an OP AMP ($V_i=V_1-V_2$)

The open circuit voltage gain is A_v and the gain under load is A_V .

The ideal OP AMP has the following characteristics :

1. Input resistance $R_i = \infty$,
2. Output resistance $R_o = 0$,
3. Voltage gain $A_v = -\infty$,
4. Bandwidth $= \infty$,
5. Perfect balance : $V_o = 0$ when $V_1 = V_2$,
6. Characteristics do not drift with temperature.

The ideal OP AMP with feedback impedances (Z and Z') and the positive-grounded terminal is shown in Figure 3.4. This is a basic inverting circuit.

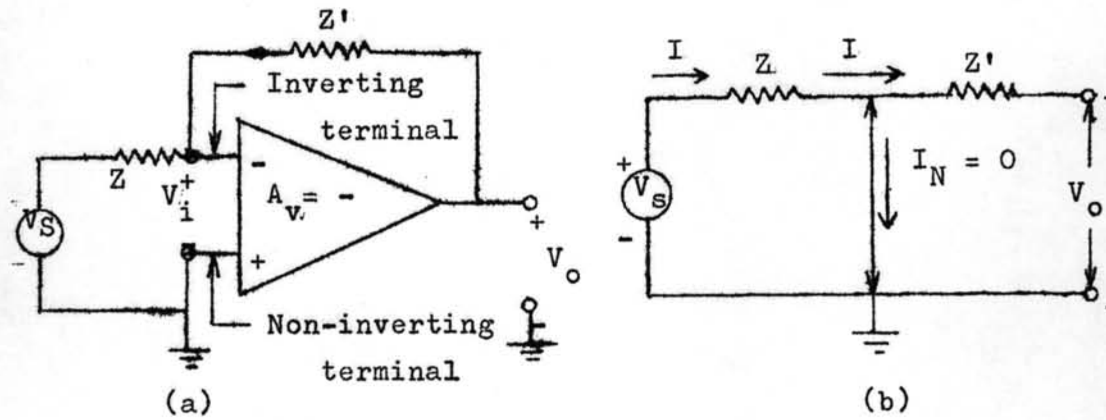

Figure3.4. (a) An Inverting Operation Amplifier with Voltage-Shunt Feedback.

(b) Virtual Ground in the OP AMP.

The voltage gains A_{vf} with feedback is given by :

$$A_{vf} = -\frac{Z'}{Z} \qquad (3.1)$$

Based upon this equation the following elements can be performed :

3.3.1 An inverting amplifier,

3.3.2 An adder or summing amplifier,

3.3.3 A zero-crossing detector.

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3.3.1 Inverting Amplifier

If the ratio $Z'/Z = k$, a real constant, then $A_{vf} = -k$, the input voltage V_i will be amplified with gain = -k. Usually, in such a case of multiplication by a constant, "-1" or "-k", Z and Z' are selected as precision resistors.

3.3.2 Adder or Summing Amplifier

The arrangement of Figure 3.5 may be used to obtain an output which is a linear combination of a number of input signals.

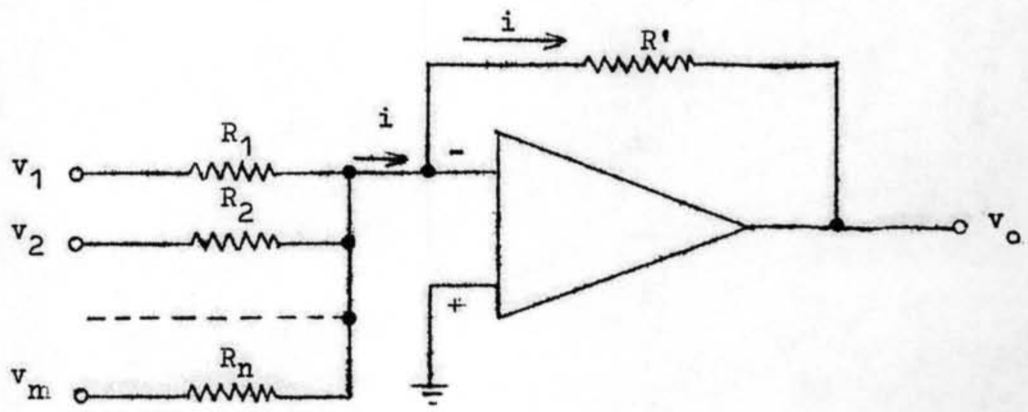

Figure3.5. An Operational Adder or Summing Amplifier.

Since a virtual ground exists at the OP AMP input, then

$$i = \frac{v_1}{R_1} + \frac{v_2}{R_2} + \cdots\cdots\cdots + \frac{v_n}{R_m}$$

and

$$v_o = -R'i = -\frac{R'}{R_1} v_1 + \frac{R'}{R_2} v_2 + \cdots\cdots\cdots + \frac{R'}{R_m} v_n$$

If

$$R_1 = R_2 = \cdots\cdots\cdots = R_m, \text{ then}$$

$$v_o = -\frac{R'}{R_1}(v_1 + v_2 + \cdots\cdots\cdots + v_n). \qquad (3.2)$$

and the output is proportional to the sum of the inputs.

Many other methods may, of course, be used to combine signals. The present method has the advantage that it may be extended to a very large number of inputs requiring only one additional resistor for each additional input. The result depends, in the limiting case of a large amplifier gain, only on the resistors involved, and because of the virtual ground, there is a minimum of interaction between input sources.

3.3.3 Zero-crossing Detector

The typical circuit of the zero crossing detector is shown in Figure 3.6 (a)

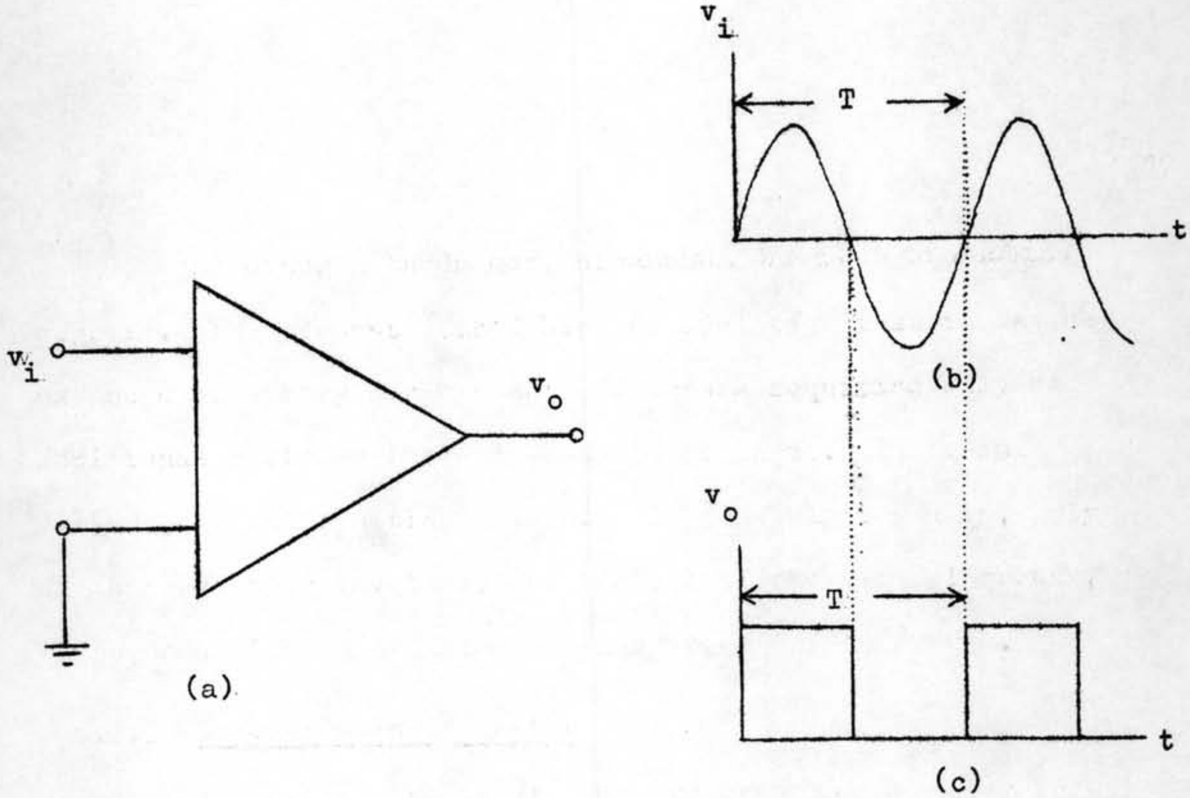

Figure 3.6 A Zero-crossing Detector Converts a Sinusoid v_i into a Square Wave v_o .

The output responds almost discontinuously every time the input passes through zero. It has a nonlinear characteristic.

3.4 Regulated Power Supply[9]

An ideal regulated power supply is an electronic circuit designed to provide a predetermined d.c. voltage V_o which is independent of the current I_L drawn from V_o, of the temperature, and also of any variations in the a.c. line voltage.

An unregulated power supply consists of a transformer, a rectifier, and filter. There are three reasons why an unregulated power supply is not acceptable for many applications. The first is its poor regulation, the output voltage is not constant at the load varies. The second is that the d.c. output voltage varies with the a.c. input. In some locations the line voltage of a nominal value 220 V may vary over as wide a range as 200 to 230 V and yet it is necessary that the d.c. voltage remains essentially constant. The third reason is that the d.c. output voltage varies with the temperature, particularly, because semiconductor devices are used.

3.5 D.C. Servomotor[1,2]

The basic requirements of a servomotor are the capability to control torque at varying speeds in either direction and to be easily reversible. For larger power requirements, d.c. motor are more efficient, as no reference voltage is required. In order to reverse the direction of rotation, the polarity of the voltage either to the field or rotor must be reversed.

Practically, there are two modes of operation of a d.c. servomotor. The first one is the armature voltage control where the field is held constant and an adjustable voltage is applied to the armature. The second is field control, where the armature current is held constant and an adjustable voltage is applied to a field.

The control of field current is much less common, since it is undesirable to supply the large constant armature current necessary for large d.c. servomotors. There are also dynamic advantages in armature control.

At the lower end of the power range, a permanent-magnet motor is selected because it gives good control characteristics. The permanent-magnet servomotor has only one mode of operation which is the armature-voltage control.

The field of permanent-magnet motor consists of permanent-magnets which do not require any field windings; therefore, only two terminals are required for connecting the permanent-magnet motor into a servoloop. For large power applications, permanent-magnet motors are difficult to control because of the varying air gap between the rotor and the magnets. The electric schematic is comparatively simple as shown in Figure 3.7 .

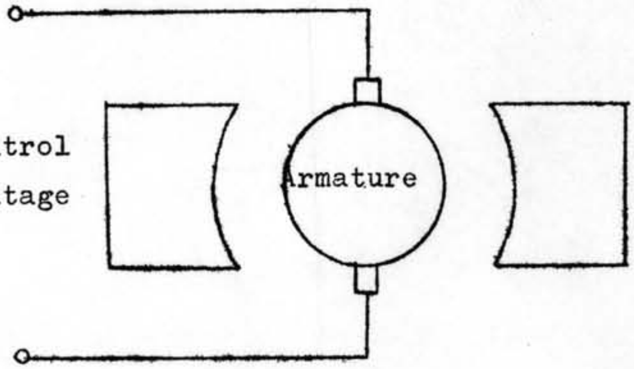

Figure 3.7. The Schematic of a Permanent-magnet Motor.

These motors have a very linear torque-speed relationship and when mechanical rotation is the input, the motor becomes a d.c. voltage generator and can be used for tachometer feedback. Figure 3.8 shows the outline and performance curves of such a motor.

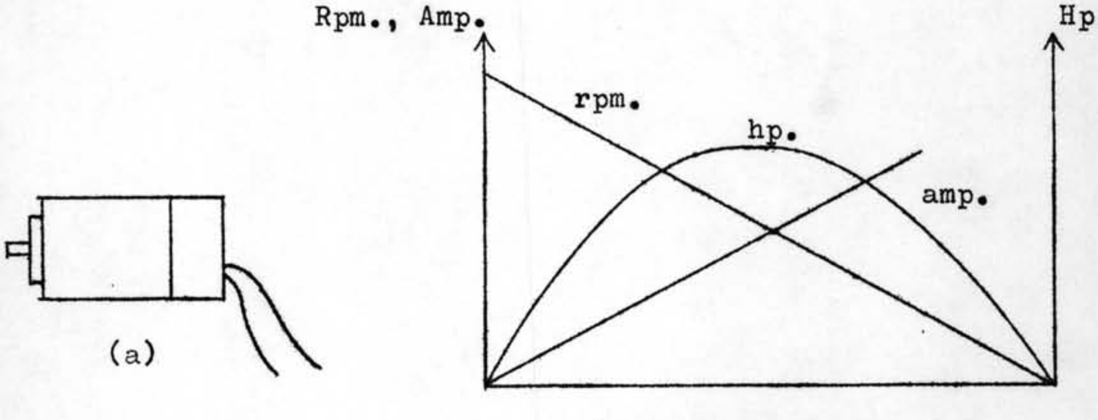

Figure 3.8. A Permanent-magnet Motor.

3.5.1 Armature-Controlled D.C. Servomotor [14]

A schematic diagram of the armature-controlled d.c. servomotor is shown in Figure 3.9. The symbols R_m and L_m represent the resistive and inductive components of the armature circuit. The field excitation is constant, being supplied from a d.c. source. The motor is shown driving a load having an inertia J_L and a damping B_L.

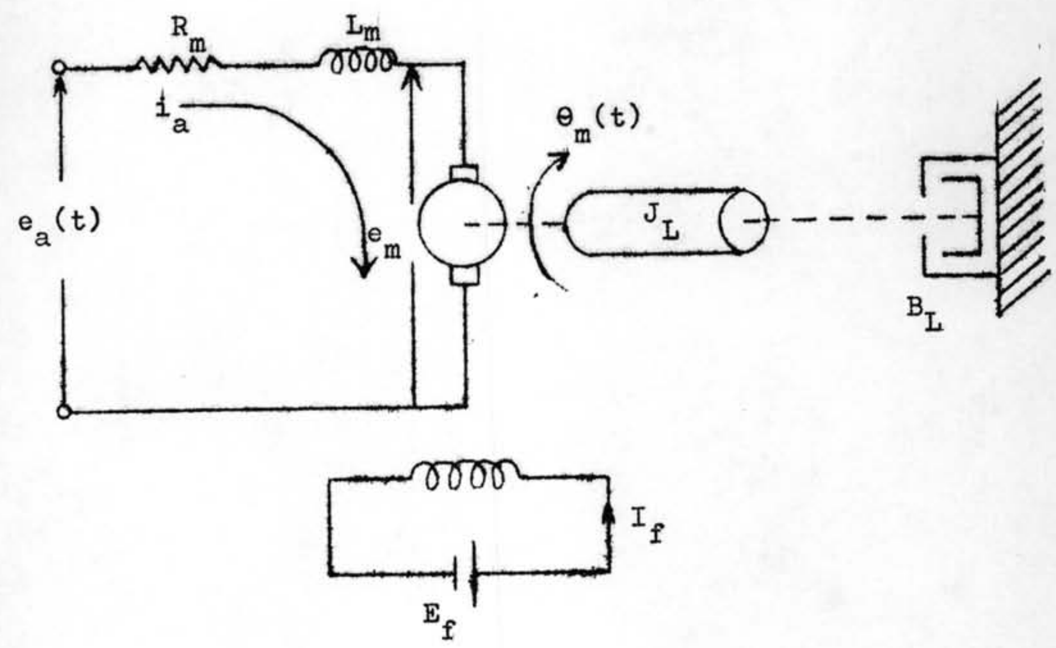

Figure 3.9. Armature-Controlled D.C. Servomotor Schematic Diagram.

As the armature rotates, it develops an induced voltage e_m which is in a direction opposite to the control voltage $e_a(t)$. The induced voltage e_m is called the back emf. It is proportional to the speed of rotation ω_m and the flux created by the field current. Since the field current is assumed to be constant, the flux must also be constant. Therefore, the induced armature voltage is only dependent on the speed of rotation and can be expressed as :

$$e_m = K_e \omega_m = K_e \frac{d\theta_m}{dt} . \qquad (3.3)$$

where K_e = voltage constant of the motor in volts/(rad./sec.)

The voltage equation of the armature circuit is :

$$e_a(t) = R_m I_a + L_m \frac{dI_a}{dt} + e_m . \qquad (3.4)$$

Substituting equation (3.3) into (3.4) and taking the Laplace transform :

$$E_a(S) = (R_m + L_m S)\, I_a(S) + K_e S\theta_m(S) . \qquad (3.5)$$

The developed torque of the motor, T_D, is a function of the flux developed by the field current, the armature current, and the length of the conductors. Since the field current is held constant, the developed torque T_D can be expressed as :

$$T_D = K_T\, i_a , \qquad (3.6)$$

where K_T = torque constant of the motor in foot-pounds/ampere .

The developed torque is used to drive the system having a total inertia J_L, and to overcome the damping B_L. This can be expressed as :

$$T_D = J_L \frac{d^2\theta_m}{dt^2} + B_L \frac{d\theta_m}{dt} . \qquad (3.7)$$

Substituting equation (3.6) into equation (3.7) and taking the Laplace transform :

$$K_T\, I_a(S) = (J_L S^2 + B_L S)\theta_m(S) , \qquad (3.8)$$

$$I_a(S) = \frac{1}{K_T}(J_L S^2 + B_L S)\theta_m(S) . \qquad (3.9)$$

Substitut ing equation (3.9) into equation (3.5), the overall system transfer function is obtained :

$$\frac{\theta_m(S)}{E_a(S)} = \frac{1}{(R_m+L_m S)\cdot \frac{1}{K_T}(J_L S^2+B_L S)+K_e S} ,$$

$$= \frac{K_T}{L_m J_L S^3+(L_m B_L+R_m J_L)S^2+(R_m B_L+K_e K_T)S} . \qquad (3.10)$$

Equation (3.10) can also be written in terms of velocity ω_m :

$$\frac{\omega_m(S)}{E_a(S)} = \frac{K_T}{L_m J_L S^2+(L_m B_L+R_m J_L)S+(R_m B_L+K_e K_T)} . \qquad (3.11)$$

The block diagram for the armature-controlled motor is shown in Figure 3.10 which shows the relationship of the Laplace transform equations for small amplitude variation.

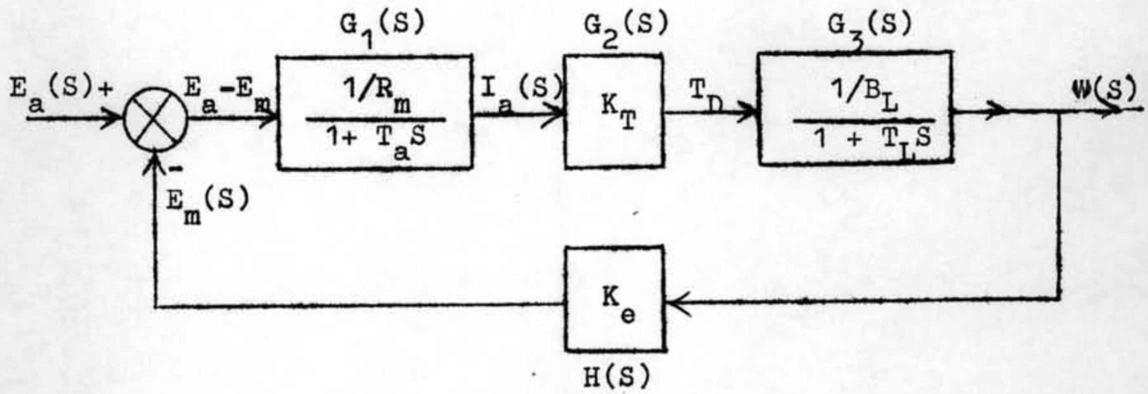

Figure 3.10. A Block Diagram of an Armature-controlled D.C. Motor. ($T_a = L_m/R_m$, $T_L = J_L/B_L$)

The transfer function of the block diagram is the same as shown in Equation (3.11).

$$\frac{\omega_m(S)}{E_a(S)} = \frac{K_T/R_m B_L}{(1+T_a S)(1+T_L S) + K_T K_e/R_m B_L}, \quad (3.12)$$

where $T_a = L_m/R_m$ = electrical time constant,

and $T_L = J_L/B_L$ = mechanical time constant.

Equation (3.11) can be written in another form as follows :

$$\frac{\omega_m(S)}{E_a(S)} = \frac{1/K_e}{T_a T_m S^2 + (T_m + \delta T_a)S + (\delta + 1)}, \quad (3.13)$$

where T_a = armature time constant = $L_m/R_m < 1$,

T_m = motor time constant = $J_L R_m / K_e K_T < 1$,

and $\zeta = \frac{R_m B_L}{K_e K_T}$ = damping factor .

Equation (3.13) can be reduced in the simple form as follows :

$$\frac{\omega_m(S)}{E_a(S)} = \frac{1/K_e}{T_m S + 1} = \frac{K_m}{T_m S+1} , \qquad (3.14)$$

where $K_m = 1/K_e$.

The permanent-magnet d.c. servomotor is a type of armature-controlled d.c. servomotor. Its transfer function is the same as shown in Equation (3.14).

3.6 Gear Trains

A gear train in a servo receives information from a motor in the form of torque and angular speed, and delivers this mechanical power to a load at a proper angular speed and torque requirements of the load. It should introduce a minimum of friction and inertia into the system over wide ranges of temperature and other atmospheric conditions. The gear train designer must develop the best functional gear train possible, and select the optimum ratio for a given system.

In the derivation of an optimum gear ratio, two practical conditions are neglected for the purpose of simplicity. The gear trains are assumed to be 100% efficient and the servomotor speed-torque curve is regarded as a straight line.

Under ideal conditions, the servomotor is operated at the point where it delivers maximum mechanical power and the gear ratio should be determined with this in mind. For some instrument servos, it is necessary to use a motor-gear train combination to accelerate a load with a sizable moment of inertia. Consider Figure 3.11, hear a gear ratio selected must be the one which applies maximum acceleration to the load in question. Since acceleration is equal to the ratio of torque-to-moment of inertia, the acceleration at the load at stall is

$$\alpha_L = \frac{nT_S}{J_m n^2 + J_L} \qquad (3.15)$$

where

α_L = angular acceleration at the load.

n = gear ratio.

T_S = torque required to prevent the motor from rotating.

J_m = moment of inertia of the motor.

J_L = moment of inertia of the load.

The value of n for which the value of α_L is a maximum is given by :

$$\frac{d\alpha_L}{dn} = \frac{T_S(J_L - n^2 J_m)}{(n^2 J_m + J_L)^2} = 0$$

$$n^2 = \frac{J_L}{J_m} \quad \text{or} \quad n = \sqrt{J_L/J_m} \qquad (3.16)$$

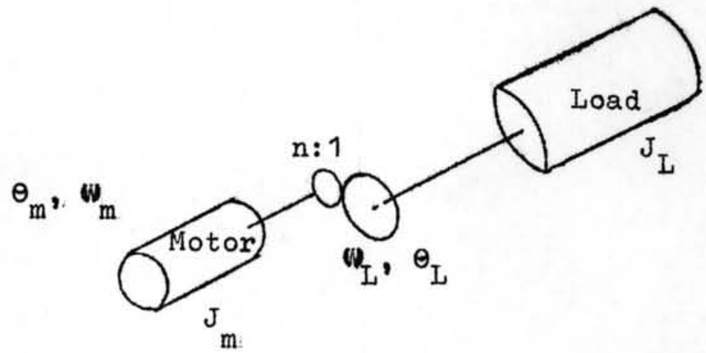

Figure 3.11. A Servomotor Geared to Load.

The optimum gear ratio n determines the minimum motor torque required and the size of the motor.