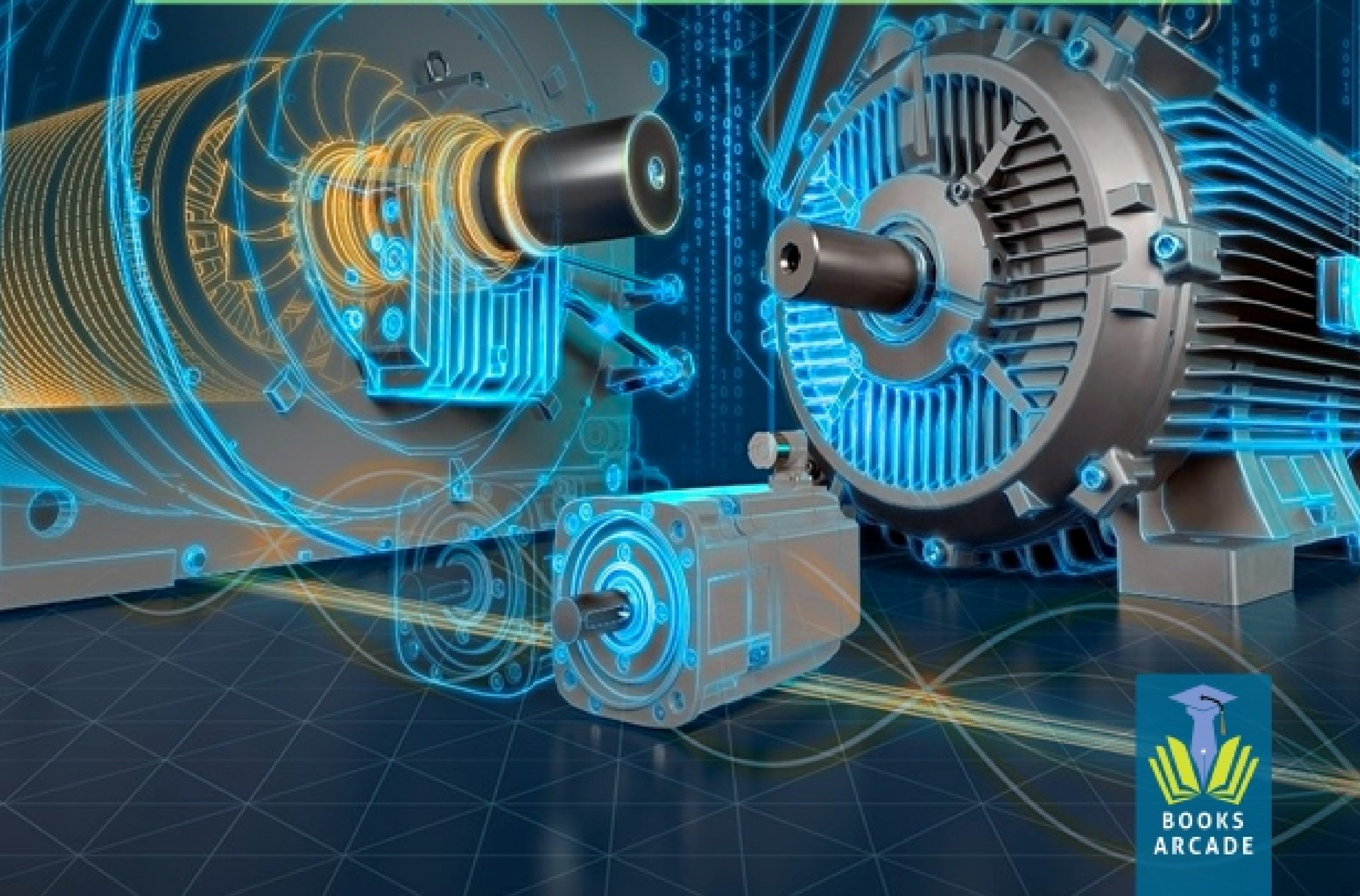
ELECTRICAL MACHINE

M. Sashilal Singh
G. Ezhilarasan



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CHAPTER 1

Electromechanical Energy Conversion

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There are many different types of energy, including magnetic, electrical, and mechanical energy. Energy conversion is the process of transforming one form of energy into some other. Electricity is produced nowadays by converting different forms of energy into electrical energy. Since electrical energy can be communicated, used, and regulated more easily, dependably, and efficiently, it is a tremendously beneficial process.

Electromechanical energy conversion is the process of converting electric energy into mechanical energy or vice versa. For instance, an electrical generator turns mechanical energy into electrical energy whereas an electric motor does the opposite. With the exception of the associated losses, this procedure can be reversed. Therefore, during electromechanical energy conversion, losses in mention below figure and a transition from one type of energy to another form occur (Figure 1.1).

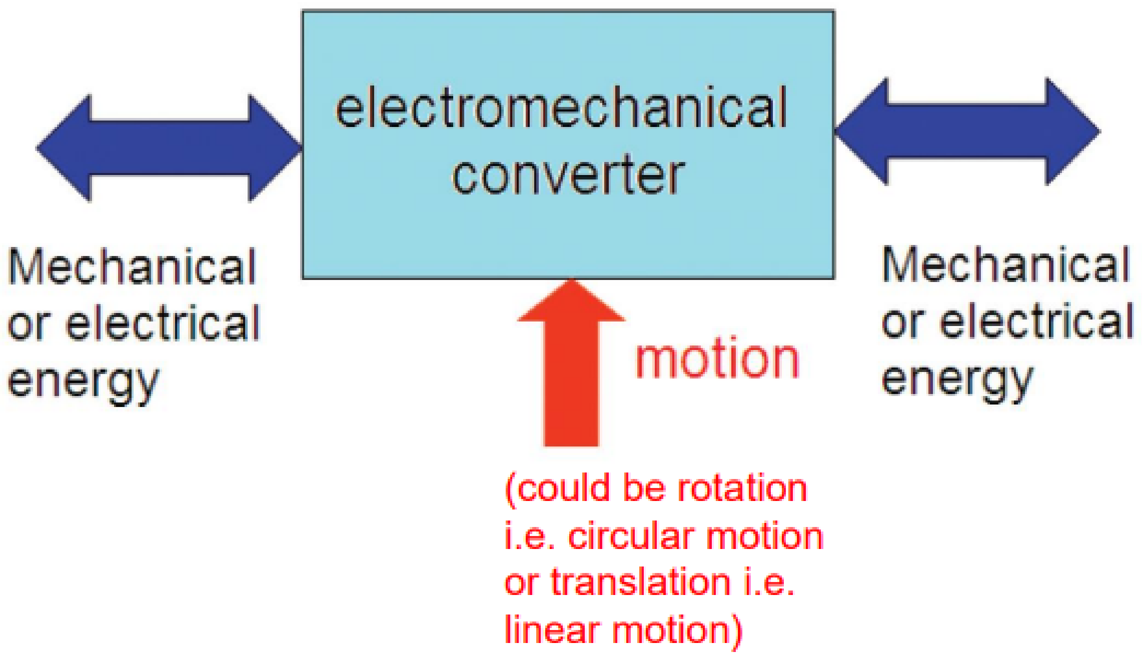

Figure 1.1 Illustrating the Electromechanical Converter.

Electromechanical devices are created to convert energy between electrical and mechanical forms. Devices for electromechanical energy conversion can generally be categorized into three groups: Transducers are devices that translate several signals into one another (for measurement and control). Speakers, pickups, and microphones are a few examples devices that produce force (linear motion devices) Relays, solenoids (linear actuators), and electromagnets are examples of the sort of equipment that produces forces primarily for linear motion drives. These devices function as continuous energy converters and rotate. A device is referred to as a generator or a motor depending on whether it converts mechanical energy into electrical energy (from electrical to mechanical). It is more favorable to employ an electromagnetic field as that of the medium during electromechanical energy conversion since ferromagnetic materials have substantially higher permeabilities than dielectric materials do. An electromechanical system is made up of a mechanical subsystem, element magnetic subsystem, and an electrical subsystem, as shown in the image below. Electrical subsystems include electrical circuits like windings (mechanically movable parts such as a plunger in a linear actuator and a rotor in a rotating electrical machine). Voltages and currents are employed to represent the condition of the electrical subsystem and thus are governed by Ohm's law, KCL, and KVL, the fundamental circuital laws. The Newton's laws regulate the state of the mechanical subsystem, which can be expressed in terms of locations, velocities, and accelerations. The magnetic subsystem but rather magnetic field functions as a "ferry" in the energy transformation and conversion process, fitting between both the electrical and mechanical subsystems. The Maxwell's equations govern the field parameters such as magnetic flux, flux density, and field strength. When connected to an electrical circuits, the magnetic flux would exert a force or torque on the dynamically moving component due to its interaction with the circuit's current. On the other hand side, the movement of the moving component may change the magnetic flux connecting the electrical circuits and cause an electromotive force (emf) to be produced in the circuit. The mechanical power, or torque-speed product, is equal to the active portion of the emf-current product. Consequently, the magnetic field is used to transfer mechanical and electrical energy into one another.

Electromechanical Systems using Induced EM a conductor of length l is put in a magnetic field with flux density B inside the diagram below. The induced emf in the conductor can be calculated using when the conductor is moving at a speed v.

$$\mathbf{e} = l\mathbf{v} \times \mathbf{B}$$

The "right hand rule" for cross products can be employed to determine the direction of both the emf. The induced emf in such a coil of N turns can be computed by.

$$e = -\frac{d\lambda}{dt}$$

The minus sign denotes that the induced current opposed the field's fluctuation, and l is the coil's flux linkage. It has no bearing on whether the flux linkage changes as a result of coil movement or a change in the field. It would be practical to handle the emf like a voltage in practice. Then, the previous expression may be rewritten as.

$$e = \frac{d\lambda}{dt} = L\frac{di}{dt} + i\frac{dL}{dx}\frac{dx}{dt}$$

If the magnetic system is linear, the self-inductance will not rely on the current. Given that there is a moving component in the system, it needs to be noted that perhaps the self-inductance is indeed a function of the displacement x.

Force and Torque Calculation from Energy and Co-energy

A Linear Actuator That Is Signally Excited Consider the singly activated linear actuator (see in figure below). R is the winding resistance. At a given point in time t, we note the excitation winding terminal voltage v, excitation winding current I the location of the movable plunger x, as well as the force acting on the plunger F, with the reference direction selected inside the positive direction of a x axis, as indicated in the diagram, as mention in Figure 1.2. We observe that the plunger has traveled a distance dx underneath the influence of the force F after a time interval dt. Therefore, the mechanical work accomplished by the force applied on the plunger throughout this time period is,

$$dW_m = Fdx$$

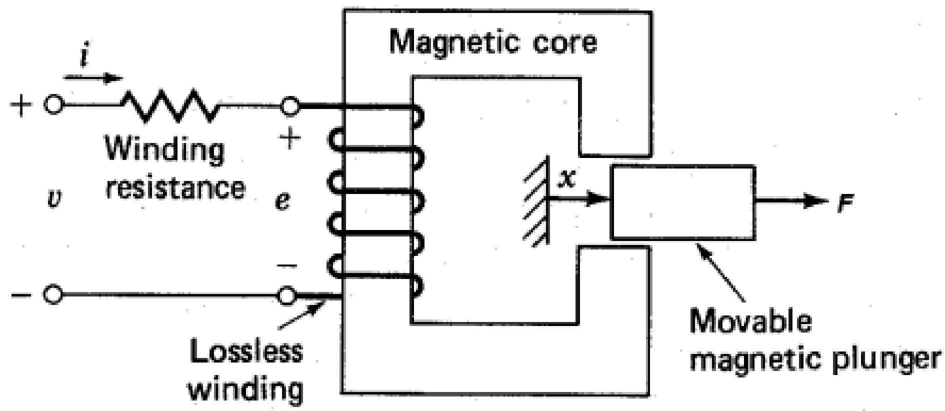

Figure 1.2 Methods to calculate the Force and Torque

By deducting the total power provided into the excitation winding from either the power loss dissipated throughout the winding resistance, the amount of electricity that was transmitted into in the magnetic field and transformed into mechanical work throughout this time can be estimated.

$$dW_e = dW_f + dW_m = vidt - Ri^2dt$$

$$e = \frac{d\lambda}{dt} = v - Ri$$

$$\begin{aligned} dW_f &= dW_e - dW_m = eidt - Fdx \\ &= id\lambda - Fdx \end{aligned}$$

According to the aforementioned equation, the magnetic field's ability to store energy depends on the excitation winding's flux linkage and the plunger's location. People can write mathematical equations as well.

$$dW_f(\lambda,x) = \frac{\partial W_f(\lambda,x)}{\partial \lambda} d\lambda + \frac{\partial W_f(\lambda,x)}{\partial x} dx$$

Therefore, by comparing the above two equations, we conclude

$$i = \frac{\partial W_f(\lambda,x)}{\partial \lambda} \text{ and } \qquad F = -\frac{\partial W_f(\lambda,x)}{\partial x}$$

From the knowledge of electromagnetics, the energy stored in a magnetic field can be expressed as

$$W_f(\lambda,x) = \int_0^{\lambda} i(\lambda,x) d\lambda$$

The aforementioned statement changes to the following for a magnetically linear system (one with constant permeability or even a straight line magnetization curve where the inductance of something like the coil is independent of a excitation current).

$$W_f(\lambda,x) = \frac{1}{2}\frac{\lambda^2}{L(x)}$$

And the force acting on the plunger is then

$$F = -\frac{\partial W_f(\lambda,x)}{\partial x} = \frac{1}{2}\left[\frac{\lambda}{L(x)}\right]^2 \frac{dL(x)}{dx} = \frac{1}{2} i^2 \frac{dL(x)}{dx}$$

The area well above magnetization or l-i curve is represented as the magnetic energy in the diagram below. If, mathematically, the co-energy (which is a hypothetical quantity) is defined as the region beneath the magnetization curve, then.

$$W_f'(i,x) = i\lambda - W_f(\lambda,x)$$

$$\begin{aligned} dW_f'(i,x) &= \lambda di + i d\lambda - dW_f(\lambda,x) \\ &= \lambda di + F dx \\ &= \frac{\partial W_f'(i,x)}{\partial i} di + \frac{\partial W_f'(i,x)}{\partial x} dx \end{aligned}$$

$$\lambda = \frac{\partial W_f'(i,x)}{\partial i} \qquad \text{and} \qquad F = \frac{\partial W_f'(i,x)}{\partial x}$$

From the above diagram, the co-energy or the area underneath the magnetization curve can be calculated by,

$$W_f'(i,x) = \int_0^i \lambda(i,x)di$$

For a magnetically linear system, the above expression becomes,

$$W_f'(i,x) = \frac{1}{2}i^2 L(x)$$

And the force acting on the plunger is then,

$$F = \frac{\partial W_f'(i,x)}{\partial x} = \frac{1}{2}i^2 \frac{dL(x)}{dx}$$

Singly Excited Rotating Actuator

The previously described single excited linear actuator can be converted to a singly excited rotational actuator by swapping out the linearly moveable plunger for a rotor, as shown in the diagram on the right. One can easily obtain that the torque acting here on rotor can indeed be expressed as the negative time derivative of an energy stored inside the magnetic field against the angular displacement either as the positive partial derivative of a co-energy against by the angular displacement throughout a derivation comparable to that against the singly excited robot arm.

Energy	**Coenergy**
In general,	
$dW_f = id\lambda - Td\theta$	$dW_f' = \lambda di + Td\theta$
$W_f(\lambda,\theta) = \int_0^\lambda i(\lambda,\theta)d\lambda$	$W_f'(i,\theta) = \int_0^i \lambda(i,\theta)di$
$i = \frac{\partial W_f(\lambda,\theta)}{\partial \lambda}$	$\lambda = \frac{\partial W_f'(i,\theta)}{\partial i}$
$T = -\frac{\partial W_f(\lambda,\theta)}{\partial \theta}$	$T = \frac{\partial W_f'(i,\theta)}{\partial \theta}$
If the permeability is a constant,	
$W_f(\lambda,\theta) = \frac{1}{2}\frac{\lambda^2}{L(\theta)}$	$W_f'(i,\theta) = \frac{1}{2}i^2 L(\theta)$
$T = \frac{1}{2}\left[\frac{\lambda}{L(\theta)}\right]^2 \frac{dL(\theta)}{d\theta} = \frac{1}{2}i^2 \frac{dL(\theta)}{d\theta}$	$T = \frac{1}{2}i^2 \frac{dL(\theta)}{d\theta}$

Doubly Excited Rotating Actuator

Multi-excited systems may also be calculated using the general rule for force and torque stated above. As an example, consider a doubly stimulated spinning actuator represented schematically in figurebelow, as shown in below Figure 1.3. Following is a derivation of the differential energy plus co-energy functions:

$$dW_f = dW_e - dW_m$$

$$dW_e = e_1 i_1 dt + e_2 i_2 dt$$

$$e_1 = \frac{d\lambda_1}{dt}, \qquad e_2 = \frac{d\lambda_2}{dt}$$

$$dW_m = Td\theta$$

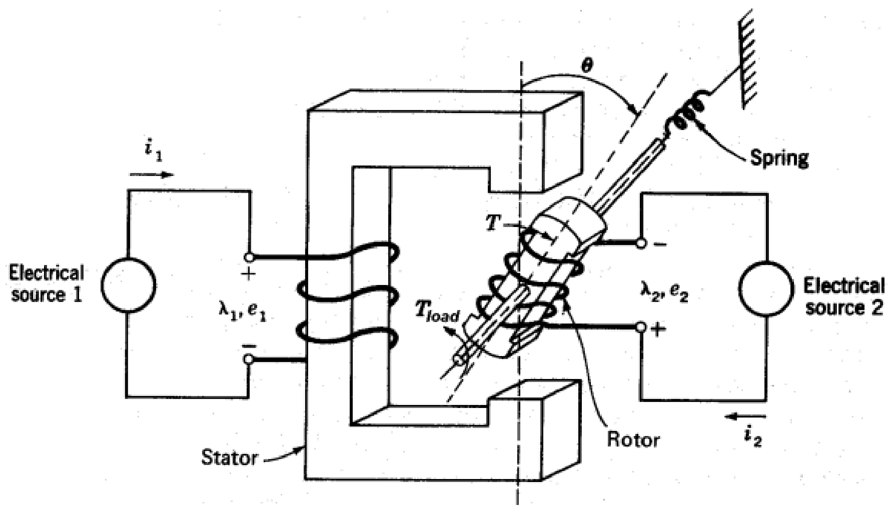

Figure 1.3 Illustrates the Doubly Excited Rotating Actuator

$$\begin{aligned} dW_f(\lambda_1,\lambda_2,\theta) &= i_1 d\lambda_1 + i_2 d\lambda_2 - Td\theta \\ &= \frac{\partial W_f(\lambda_1,\lambda_2,\theta)}{\partial \lambda_1} d\lambda_1 + \frac{\partial W_f(\lambda_1,\lambda_2,\theta)}{\partial \lambda_2} d\lambda_2 \\ &+ \frac{\partial W_f(\lambda_1,\lambda_2,\theta)}{\partial \theta} d\theta \end{aligned}$$

$$\begin{aligned} dW_f'(i_1,i_2,\theta) &= d\left[i_1\lambda_1 + i_2\lambda_2 - W_f(\lambda_1,\lambda_2,\theta)\right] \\ &= \lambda_1 di_1 + \lambda_2 di_2 + Td\theta \\ &= \frac{\partial W_f'(i_1,i_2,\theta)}{\partial i_1} di_1 + \frac{\partial W_f'(i_1,i_2,\theta)}{\partial i_2} di_2 \\ &+ \frac{\partial W_f'(i_1,i_2,\theta)}{\partial \theta} d\theta \end{aligned}$$

Therefore, comparing the corresponding differential terms, we obtain,

$$T = -\frac{\partial W_f(\lambda_1, \lambda_2, \theta)}{\partial \theta}$$

$$T = \frac{\partial W_f'(i_1, i_2, \theta)}{\partial \theta}$$

For magnetically linear systems, currents and flux linkages can be related by constant inductances as following.

$$\begin{bmatrix} \lambda_1 \\ \lambda_2 \end{bmatrix} = \begin{bmatrix} L_{11} & L_{12} \\ L_{21} & L_{22} \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \end{bmatrix}$$

$$\begin{bmatrix} i_1 \\ i_2 \end{bmatrix} = \begin{bmatrix} \Gamma_{11} & \Gamma_{12} \\ \Gamma_{21} & \Gamma_{22} \end{bmatrix} \begin{bmatrix} \lambda_1 \\ \lambda_2 \end{bmatrix}$$

The magnetic energy and co-energy can then be expressed as,

$$W_f(\lambda_1, \lambda_2, \theta) = \frac{1}{2}\Gamma_{11}\lambda_1^2 + \frac{1}{2}\Gamma_{22}\lambda_2^2 + \Gamma_{12}\lambda_1\lambda_2$$

$$W_f'(i_1, i_2, \theta) = \frac{1}{2}L_{11}i_1^2 + \frac{1}{2}L_{22}i_2^2 + L_{12}i_1 i_2$$

Respectively, and it can be shown that they are equal. Therefore, the torque acting on the rotor can be calculated as,

$$T = -\frac{\partial W_f(\lambda_1, \lambda_2, \theta)}{\partial \theta} = \frac{\partial W_f'(i_1, i_2, \theta)}{\partial \theta}$$
$$= \frac{1}{2}i_1^2 \frac{dL_{11}(\theta)}{\partial \theta} + \frac{1}{2}i_2^2 \frac{dL_{22}(\theta)}{\partial \theta} + i_1 i_2 \frac{dL_{12}(\theta)}{\partial \theta}$$

The self-inductance of a stator seems to be a function of the rotor position due to the salient (not round) construction of the rotor, and the first term on the right left corner of the preceding torque calculation is nonzero for that dL11/dq10. Similar to the first term, the second term on the right side of the above torque express becomes nonzero due to the stator's important structure. The reluctance torque ingredient is hence known as these two phrases. However, the last component inside the torque expression solely takes into account the relative positions of the stator and the rotor and is unaffected by the design of the poles on either the stator or the rotor.

Model of Electromechanical Systems

Let's continue to utilize the doubly excited spinning actuator stated earlier as an example to show the basic idea for modeling and electromechanical system. They plan it here once again for your convenience.

As was mentioned in the introduction, this same mathematical representation of the electromechanical network consisting of equations for something like the electrical and mechanical regarding the operational' conversations with the magnetic field, which can be expressed in the form of electromagnetic forces and torques and circuit equations for such electrical subsystem.

Thus, we may write for the spinning actuator that is twice stimulated (Figure 1.4).

$$v_1 = R_1 i_1 + \frac{d\lambda_1}{dt} = R_1 i_1 + \frac{d(\lambda_{11} + \lambda_{12})}{dt}$$

$$= R_1 i_1 + L_{11}\frac{di_1}{dt} + i_1 \frac{dL_{11}(\theta)}{d\theta}\frac{d\theta}{dt} + L_{12}\frac{di_2}{dt} + i_2 \frac{dL_{12}(\theta)}{d\theta}\frac{d\theta}{dt}$$

$$= \left[R_1 + \omega_r \frac{dL_{11}(\theta)}{d\theta}\right] i_1 + \omega_r \frac{dL_{12}(\theta)}{d\theta} i_2 + L_{11}\frac{di_1}{dt} + L_{12}\frac{di_2}{dt}$$

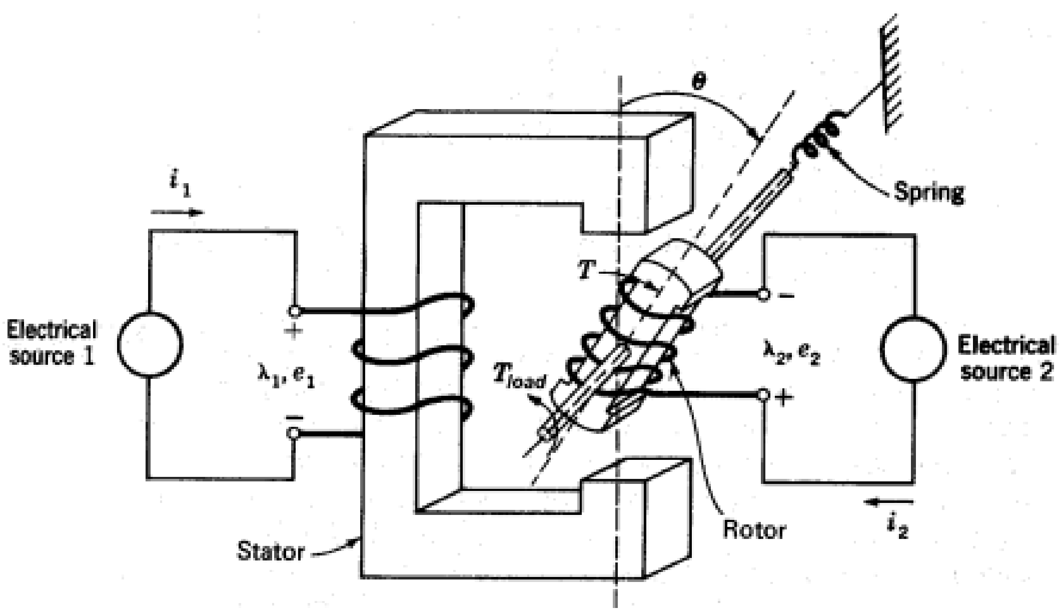

Figure 1.4 illustrates a doubly excited actuator

$$v_2 = R_2 i_2 + \frac{d\lambda_2}{dt} = R_2 i_2 + \frac{d(\lambda_{21} + \lambda_{22})}{dt}$$
$$= R_2 i_2 + L_{12}\frac{di_1}{dt} + i_1 \frac{dL_{12}(\theta)}{d\theta}\frac{d\theta}{dt} + L_{22}\frac{di_2}{dt} + i_2 \frac{dL_{22}(\theta)}{d\theta}\frac{d\theta}{dt}$$
$$= \omega_r \frac{dL_{12}(\theta)}{d\theta} i_1 + \left[R_2 + \omega_r \frac{dL_{22}(\theta)}{d\theta}\right] i_2 + L_{12}\frac{di_1}{dt} + L_{22}\frac{di_2}{dt}$$

$$T - T_{load} = J\frac{d\omega_r}{dt}$$

$$\omega_r = \frac{d\theta}{dt}$$

The rotor's angular speed, Tload, the load torque, and J, the rotor's inertia as well as the mechanical load that are connected to the rotor shaft, are the three variables. Because they are nonlinear differential equations, the aforementioned equations can only be resolved numerically. The aforementioned equations may be rewritten as follows in the framework of state equations,

$$\frac{di_1}{dt} = -\frac{1}{L_{11}}\left[R_1 + \frac{dL_{11}(\theta)}{d\theta}\omega_r\right] i_1 - \frac{1}{L_{11}}\frac{dL_{12}(\theta)}{d\theta}\omega_r i_2 - \frac{L_{12}}{L_{11}}\frac{di_2}{dt} + \frac{1}{L_{11}}v_1$$
$$\frac{di_2}{dt} = -\frac{1}{L_{22}}\frac{dL_{12}(\theta)}{d\theta}\omega_r i_1 - \frac{1}{L_{22}}\left[R_2 + \frac{dL_{22}(\theta)}{d\theta}\omega_r\right] i_2 - \frac{L_{12}}{L_{22}}\frac{di_1}{dt} + \frac{1}{L_{22}}v_2$$
$$\frac{d\omega_r}{dt} = \frac{1}{J}T - \frac{1}{J}T_{load}$$
$$\frac{d\theta}{dt} = \omega_r$$

Together with the specified initial conditions (the state of the system at time zero in terms of the state variables):

$$i_1\big|_{t=0} = i_{10},\ \ i_2\big|_{t=0} = i_{20},\ \ \omega_r\big|_{t=0} = \omega_{r0},\ \text{ and }\ \theta\big|_{t=0} = \theta_0,$$

The dynamic performance of a doubly excited spinning actuator may be simulated using the aforementioned state equations. We may develop the state equation model of just about any electromechanical system by using the same principle.

Energy in Coupling Field

Before they can determine the electromagnetic force fee, we must establish an equation for the energy held in the coupling field. When the field is considered to be conservative and the energy stored there is a function of the state of the electrical and mechanical variables rather than how the variables got to that state, we will disregard any losses related to the electric or magnetic coupling field. This presumption is less limiting than it first seems. To reduce hysteresis and eddy current losses, ferromagnetic material is chosen and used in laminations. The air gap of the electromechanical device contains almost all of the energy held in the coupling field. Since air is a conservative medium, all of the energy it contains may be used to power mechanical or electrical devices again. • In creating a mathematical equation for the field energy, we will benefit from the conservative field assumption. We shall analytically set the mechanical system's location in relation to the coupling field before exciting the electric system while keeping the mechanical system's displacement constant. While electromagnetic and electrostatic forces are present during the excitation of a electric inputs, dx = 0, hence Wm is zero. The energy that was stored in the coupling field during the excitation of both the electric inputs is thus equal to the energy that was provided to the coupling field by that of the electric inputs, holding the displacement constant. The energy provided by the electric system is when dx = 0:

$$W_f = \int \sum_{j=1}^{J} e_{fj} i_j dt - \int f_e \cancelto{0}{dx}$$

$$W_f = \int \sum_{j=1}^{J} e_{fj} i_j dt$$

For a singly excited electromagnetic system:

$$e_f = \frac{d\lambda}{dt}$$

$$W_f = \int (i) d\lambda \quad \text{with } dx = 0$$

$$W_f = \int (i) d\lambda$$

The li connection just has to be single-valued, which is a feature of a conservative or lossless field; it need not be linear. The energy held in the field with l = la and I = ia is also unaffected by the excursion of the electrical and mechanical variables prior to this condition because the coupling field is conservative. Because l and I are connected, just one of them is required in addition to x to represent the state of both the electromechanical system. However, because the displacement x characterizes the impact of the mechanical system mostly on coupling field entirely, It is simple to represent the field energy and the flow connections as if I and x were chosen as the independent factors.

$$W_f = W_f (i, x)$$

$$\lambda = \lambda(i, x)$$

$$d\lambda = \frac{\partial\lambda(i, x)}{\partial i}di + \frac{\partial\lambda(i, x)}{\partial x}dx$$

$$d\lambda = \frac{\partial\lambda(i, x)}{\partial i}di \quad \text{with } dx = 0$$

$$W_f = \int(i)d\lambda = \int i\frac{\partial\lambda(i, x)}{\partial i}di = \int_0^i \xi\frac{\partial\lambda(\xi, x)}{\partial\xi}d\xi$$

Energy stored in the field of a singly excited system, the co-energy in terms of i and x may be evaluated as.

$$W_c(i, x) = \int\lambda(i, x)di = \int_0^i \lambda(\xi, x)d\xi$$

For a linear electromagnetic system, the li plots are straight-line relationships. Thus, for the singly excited magnetically linear system.

$$\lambda(i, x) = L(x)i$$

Let's evaluate Wf (i,x).

$$d\lambda = \frac{\partial\lambda(i, x)}{\partial i}di \quad \text{with } dx = 0$$

$$d\lambda = L(x)di$$

$$W_f(i,x) = \int_0^i \xi L(x)d\xi = \frac{1}{2}L(x)i^2$$

Since the field energy is a state function, its description in terms of the state variables holds true despite changes to the system variables. The field energy is expressed as Wf independent of changes to L(x) and i. The mechanical system being fixed to get an equation for the field energy is only for mathematical convenience and has no bearing on the outcome.

$$W_f(i,x) = \int_0^i \xi L(x)d\xi = \frac{1}{2}L(x)i^2$$

By analyzing the following connection with dx = 0, one may derive a formula for the field energy in the context of a multi-excited electromagnetic system:

$$W_f = \int \sum_{j=1}^{J} i_j d\lambda_j$$

This formula may be assessed regardless of the sequence in which the flux connections or currents are brought to their ultimate values since the coupling field is thought to be conservative. Consider an electric system that is twice stimulated and has one mechanical input.

$$W_f(i_1, i_2, x) = \int \left[i_1 d\lambda_1 (i_1, i_2, x) + i_2 d\lambda_2 (i_1, i_2, x) \right] \quad \text{with } dx = 0$$

The result is:

$$W_f(i_1, i_2, x) = \int_0^{i_1} \xi \frac{\partial \lambda_1 (\xi, 0, x)}{\partial \xi} d\xi + \int_0^{i_2} \left[i_1 \frac{\partial \lambda_1 (i_1, \xi, x)}{\partial \xi} + \xi \frac{\partial \lambda_2 (i_1, \xi, x)}{\partial \xi} \right] d\xi$$

The first integral is the outcome of the evaluation's first step, where i1 serves as the integration variable and i2 and di2 are both set to 0. With i1 equal to its end value (di1 = 0) and i2 serving as the variables of integration, the second integral results from the second stage of the evaluation. It makes no difference in which sequence the currents achieve their ultimate condition.

Electromagnetic and Electrostatic Forces

Energy Balance Equation are:

$$W_f = \int \sum_{j=1}^{J} e_{fj} i_j dt - \int f_e dx$$

$$dW_f = \sum_{j=1}^{J} e_{fj} i_j dt - f_e dx$$

$$f_e dx = \sum_{j=1}^{J} e_{fj} i_j dt - dW_f$$

It is first essential to express Wf before taking its total derivative in order to derive an equation for f e. Here, it is necessary to know the complete difference of the field energy.

Any electromechanical system's force or torque may be measured by using:

$$dW_f = dW_e + dW_m$$

For electromechanical systems having one mechanical input and J electrical inputs, they shall develop the force equations pertaining to an electromagnetic system:

$$f_e dx = \sum_{j=1}^{J} i_j d\lambda_j - dW_f$$

Select i j and x as independent variables:

$$dW_f = \sum_{j=1}^{J}\left[\frac{\partial W_f\left(\vec{i},x\right)}{\partial i_j} di_j\right] + \frac{\partial W_f\left(\vec{i},x\right)}{\partial x} dx$$

$$d\lambda_j = \sum_{n=1}^{J}\left[\frac{\partial \lambda_j\left(\vec{i},x\right)}{\partial i_n} di_n\right] + \frac{\partial \lambda_j\left(\vec{i},x\right)}{\partial x} dx$$

Since each dlj must always be evaluated with changes throughout all currents to account with mutual coupling among electric systems, substitution, and the summation index n are used to prevent misunderstanding with the subscript j:

$$\left.\begin{aligned} dW_f &= \sum_{j=1}^{J}\left[\frac{\partial W_f\left(\vec{i},x\right)}{\partial i_j} di_j\right] + \frac{\partial W_f\left(\vec{i},x\right)}{\partial x} dx \\ d\lambda_j &= \sum_{n=1}^{J}\left[\frac{\partial \lambda_j\left(\vec{i},x\right)}{\partial i_n} di_n\right] + \frac{\partial \lambda_j\left(\vec{i},x\right)}{\partial x} dx \end{aligned}\right\} \xrightarrow{\text{into}} f_e dx = \sum_{j=1}^{J} i_j d\lambda_j - dW_f$$

Result of the equation,

$$f_e\left(\vec{i},x\right)dx = \sum_{j=1}^{J} i_j \left\{\sum_{n=1}^{J}\left[\frac{\partial \lambda j\left(\vec{i},x\right)}{\partial i_n} di_n\right] + \frac{\partial \lambda_j\left(\vec{i},x\right)}{\partial x} dx\right\}$$

$$-\sum_{j=1}^{J}\left[\frac{\partial W_f\left(\vec{i},x\right)}{\partial i_j} di_j\right] + \frac{\partial W_f\left(\vec{i},x\right)}{\partial x} dx$$

$$f_e\left(\vec{i},x\right)dx = \left\{\sum_{j=1}^{J}\left[i_j \frac{\partial \lambda_j\left(\vec{i},x\right)}{\partial x}\right] - \frac{\partial W_f\left(\vec{i},x\right)}{\partial x}\right\} dx$$

$$+\sum_{j=1}^{J}\left\{i_j \sum_{n=1}^{J}\left[\frac{\partial \lambda_j\left(\vec{i},x\right)}{\partial i_n} di_n\right] - \frac{\partial W_f\left(\vec{i},x\right)}{\partial i_j} di_j\right\}$$

This equation is satisfied provided that,

$$f_e\left(\vec{i},x\right)=\sum_{j=1}^{J}\left[i_j\frac{\partial\lambda_j\left(\vec{i},x\right)}{\partial x}\right]-\frac{\partial W_f\left(\vec{i},x\right)}{\partial x}$$

$$0=\sum_{j=1}^{J}\left\{i_j\sum_{n=1}^{J}\left[\frac{\partial\lambda_j\left(\vec{i},x\right)}{\partial i_n}di_n\right]-\frac{\partial W_f\left(\vec{i},x\right)}{\partial i_j}di_j\right\}$$

When I and x are chosen as independent variables within the first equation, the force acting here on mechanical system may be calculated. It is possible to derive a second force equation by including an expression for co-energy:

$$W_c=\sum_{j=1}^{J}i_j\lambda_j-W_f$$

Since i and x are independent variables, the partial derivative with respect to x is,

$$\frac{\partial W_c\left(\vec{i},x\right)}{\partial x}=\sum_{j=1}^{J}\left|i_j\frac{\partial\lambda_j\left(\vec{i},x\right)}{\partial x}\right|-\frac{\partial W_f\left(\vec{i},x\right)}{\partial x}$$

Substitution as:

$$f_e\left(\vec{i},x\right)=\sum_{j=1}^{J}\left[i_j\frac{\partial\lambda_j\left(\vec{i},x\right)}{\partial x}\right]-\frac{\partial W_f\left(\vec{i},x\right)}{\partial x}=\frac{\partial W_c\left(\vec{i},x\right)}{\partial x}$$

Elementary Electromagnet

The system comprises of a block of magnetic material that is free to move in relation to the stationary component and a stationary core with an N-turn winding, as shown in Figure 1.5.

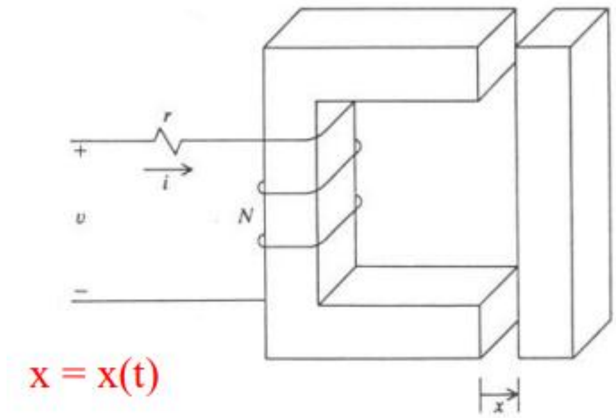

Figure 1.5 illustrates the schematic diagram of electromagnet.

$$v = ri + \frac{d\lambda}{dt}$$

$\lambda = N\phi$

$\phi = \phi_\ell + \phi_m$

$\phi_\ell =$ leakage flux

$\phi_m =$ magnetizing flux

$$\phi_\ell = \frac{Ni}{\Re_\ell}$$

$$\phi_m = \frac{Ni}{\Re_m}$$

The electric system's voltage equations, flux linkages (the magnetizing flux is common to both stationary and rotating members), As with stationary coupled circuits, they may define the fluxes in measures of reluctances if the magnetic system is thought of as linear (with saturation omitted).

$$\lambda = \left(\frac{N^2}{\Re_\ell} + \frac{N^2}{\Re_m}\right) i$$

$$= \left(L_\ell + L_m\right) i$$

Flux linkages

mL =leakage inductance

L =magnetizing inductance

$$\Re_m = \Re_i + 2\Re_g$$

$$\Re_i$$

$$\Re_g$$

The entire reluctance of both the magnetic material in the fixed and moving part as well as the reluctance of the one of the air gaps make up the reluctance of a magnetizing route.

$$\Re_i = \frac{\ell_i}{\mu_{ri}\mu_0 A_i}$$

$$\Re_g = \frac{x}{\mu_0 A_g}$$

Assume that the cross-sectional areas of the stationary and movable members are equal and of the same material.

$$A_g = A_i$$

$$\Re_m = \Re_i + 2\Re_g$$
$$= \frac{1}{\mu_0 A_i}\left(\frac{\ell_i}{\mu_{ri}} + 2x\right)$$

$$L_m = \frac{N^2}{\frac{1}{\mu_0 A_i}\left(\frac{\ell_i}{\mu_{ri}} + 2x\right)}$$

Although this may be oversimplified, it serves the function for which we need it. Inductance leakage is assumed to be constant. It is obvious that the magnetizing inductance depends on displacement. Lm = Lm and x = x(t) (x). The change throughout flux linkages over respect to time was L(di/dt) when dealing about linear magnetic circuits when mechanical power is absent, as in the instance of a transformer. Here, that is not the case.

$$\lambda(i,x) = L(x)i = \left[L_\ell + L_m(x)\right]i$$

$$\frac{d\lambda(i,x)}{dt} = \frac{\partial\lambda}{\partial i}\frac{di}{dt} + \frac{\partial\lambda}{\partial x}\frac{dx}{dt}$$

$$v = ri + \left[L_\ell + L_m(x)\right]\frac{di}{dt} + i\frac{dL_m(x)}{dx}\frac{dx}{dt}$$

$$L_m(x) = \frac{N^2}{\dfrac{1}{\mu_0 A_i}\left(\dfrac{\ell_i}{\mu_{ri}} + 2x\right)}$$

$$L_m(x) = \frac{k}{k_0 + x} \quad \begin{cases} k = \dfrac{N^2\mu_0 A_i}{2} \\ k_0 = \dfrac{\ell_i}{2\mu_{ri}} \end{cases} \qquad L_m(0) = \frac{k}{k_0} = \frac{N^2\mu_0\mu_{ri}A_i}{\ell_i}$$

$$L_m(x) \cong \frac{k}{x} \quad \text{for } x > 0$$

CHAPTER 2

Magnetic Circuit

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A magnetic circuit is a constrained, closed channel to which a magnetic field represented by lines of magnetic flux is contained. A magnetic circuit has no real flow of charge, in contrast to something like an electric circuit where electric charge does. The magnetic field or flux is almost totally restricted to the metal core as well as the air gap, that together make up the magnetic circuit, in a ring-shaped electromagnet with the a tiny air gap. The magnetic field of an electric motor is mostly contained inside the metal frame, the rotor, the air gaps between both the rotor as well as the pole pieces, and the magnetic pole pieces. Every magnetic field line forms a seamless loop. The total flux is made up of all of the lines together. The magnetic circuit is said to be parallel if the flux is split because then part of it is constrained to one area of the device and section to another. The circuit is known as a series magnetic circuit if all the flux is contained inside a single closed loop, as in a ring-shaped electromagnet. A comparable relationship has been established to represent a magnetic circuit, analogous to an electric circuit where the current, electromotive force (voltage), and resistance are connected by Ohm's equation (current I equals electromotive force V multiplied by resistance R; V = IR). The magnetic flux and electric current are comparable. Similar to the electromotive force V, the magnetomotive force, also known as mmf or f, may be thought of as the element that creates the flux. The mmf is measured in ampere-twists and is equal to the quantity of wire turns carrying an electric current.

The mmf rises if either the current through with a coil (such as in an electromagnet) or perhaps the number of wire turns in the coil is increased. If the remainder of the magnetic circuit is left unchanged, the magnetic flux increases correspondingly. The resistance of the electric circuit is comparable to the reluctance (r) of a magnetic circuit. The geometrical and material characteristics of the circuit that provide resistance to the presence of magnetic flux determine resistance. The permeability of the provided material is a magnetic property that is inversely related to the length of a given component of a magnetic circuit and inversely proportional towards its cross-sectional area. Iron, for instance, has a comparably low reluctance or provides minimal resistance to the presence of a magnetic flux since it has an extraordinarily high permeability when compared to air. The sum of the individual lateness and absenteeism found around the closed flux route determines the overall reluctance in a parallel magnetic circuit. In a nutshell, the magnetic flux in a magnetic circuit is proportional to the magnetomotive displacement caused by the reluctance, or f/r.

Magnetic Pole

The strongest external magnetic field is located at the magnetic poles, which are located at either end of the magnet. A bar magnet hung in the magnetic field of the Earth automatically points northward and southward. A north magnetic pole is any pole that seeks the north, such as the north-seeking pole of this kind of magnet. A south magnetic pole is the south-seeking pole or any pole that resembles it. Different magnets' unlike poles pull together while their similar poles repel one another. Inverse square law was used as early as 1750 to explain the magnetic force between the poles of two long bar magnets. For instance, the magnetic force drops to one-fourth of its original magnitude if the distance between the two poles is doubled. A magnet's north pole and south pole are not separated by splitting it in half. It is discovered that each half has its own north and south poles. In contrast to electric forces, which are produced by real discrete electric charges like electrons and protons, magnetic forces cannot be directly linked to unit magnetic poles with submicroscopic size. In fact, while electric charges are moving, magnetic forces also inherently develop between they likewise see magnetic dipole.

Diamagnetism

Diamagnetism is a kind of magnetism that is present in materials that align at right angles to something like a nonuniform magnetic field so this partially expel the magnetic field they are put in from inside. Michael Faraday identified and researched the phenomenon of diamagnetism, which was first noticed in bismuth and antimony by S.J. Brugmans (1778). He and other experimenters later discovered that the majority of compounds and certain elements display this "negative" magnetism. All materials are in fact diamagnetic since Lenz's law states that an external magnetic field's influence is countered by the speed or slowness of the electrons in atoms rotating inside it. However, the diamagnetism of certain materials is concealed by either a very strong magnetic attraction (superattraction) or a mild magnetic attraction (paramagnetism) (ferromagnetism). In substances possessing symmetric electronic structure (such as ionic crystals and rare gases) but no permanent magnetic moment, diamagnetism may be seen. The effects of temperature fluctuations on diamagnetism are nonexistent. The susceptibility value for diamagnetic materials is usually negative and generally falls close to the negative one millionth range (a measure of the relative amount of induced magnetism).

Ferromagnetism

Due to the scientific phenomena known as ferromagnetism, some electrically uncharged materials are strongly attracted to one another. Lodestone (or magnetite, an oxide of iron, Fe3O4) and iron are two naturally occurring minerals that have the capacity to develop such appealing properties, and they are sometimes referred to as natural ferrimagnets. They have been known for more than 2,000 years, and they were the subject of all early scientific investigations on magnetism. Today, a broad range of daily necessities, such as electric motors and generators, transformers, phones, and loudspeakers, all require ferromagnetic materials. Iron, cobalt, nickel, and various alloys or compounds comprising one or more of these metals all exhibit ferromagnetism, a kind of magnetism. Gadolinium and a few other rare-earth elements also include it. Ferromagnetic materials, in contrast to other substances, are readily magnetized, and under large magnetic fields the magnetization approaching a certain limit known as saturation. The magnetization does not revert to its original state whenever a field is applied and then withdrawn; this phenomenon is known as hysteresis. Ferromagnetic materials lose their distinctive qualities and stop being magnetic when heated to a certain temperature known as the Curie point, which varies for each substance. However, they resume their magnetic properties upon cooling. The alignment patterns of an atoms that make up ferromagnetic materials—which function as basic electromagnets—are what give them their magnetic properties. Some types of atoms have a magnetic moment, which means that they are fundamental electromagnets formed by the motion and spin of the electrons that orbit their nucleus. Atoms that act as small magnets in ferromagnetic materials impulsively align themselves underneath the Curie point. Their magnetic fields strengthen one another as a result of their being aligned in the same direction.

A ferromagnetic substance must, among other things, contain persistent magnetic moments in its atoms or ions. Since the nuclear component of an atom's magnetic moment is small, it is its electrons that are responsible. The parallel alignment of numerous atoms' magnetic moments due to quantum mechanical phenomena is another need for ferromagnetism. Two electrons at the same place cannot have their spins pointed in the same direction, in accordance with the Pauli Exclusion Principle. They must have antiparallel spins. If two electrons in neighboring atoms were antiparallel, it would imply that the two electrons would experience a significant repulsive force from being in close proximity to one another. The material is operating in a lower energy configuration than a situation in which close-by electrons are experiencing a strong repulsive force on one another because their spins and therefore their magnetic moments are parallel. Without any of these quantum mechanical processes, heat agitation would cause the atoms to become disorganized, nearby atoms' moments would cancel each other out, and ferromagnetic materials' enormous magnetic moments would not be present.

There is a lot of evidence to suggest that certain atoms or ions contain a permanent magnetic moment, which may be seen as a dipole with a positive and negative pole. In ferromagnets, a net magnetization results from the strong coupling between both the atomic magnetic moments, which in turn causes some degree of dipole alignment. Domain structure, a sort of large-scale magnetic order for ferromagnets, was proposed by French scientist Pierre-Ernest Weiss. A ferromagnetic solid, in accordance with his hypothesis, is made up of a great number of tiny areas, or domains, where all of the atomic or ionic magnetic moments were aligned. The object as a whole won't be magnetic if the resultant moments of the these domains seem to be randomly oriented, but instead an externally applied magnetizing field would then, depending on its resilience, rotate each domain into alignment with the external field, causing aligned domains to develop at the expense of nonaligned ones. The whole object will consist of a single domain when it reaches the limiting stage known as saturation. Direct observation of domain structure is possible. One method involves coating a ferromagnet with a colloidal solution containing tiny magnetic particles, typically magnetite. When there are surface poles, the particles have a tendency to condense in certain areas to produce a pattern that can be easily seen under an optical microscope. Polarized light, polarized neutrons, electron beams, and X-rays have all shown domain patterns. The strong coupling causes the dipole moments in many ferromagnets to be parallel. The fundamental metals iron (Fe), nickel (Ni), and cobalt (Co), as well as their alloys with one another and with certain other elements, have this magnetic configuration. These materials continue to make up the majority of frequently used ferromagnets. The rare-earth metals gadolinium (Gd), terbium (Tb), and dysprosium (Dy) are the other elements with a collinear ordering, however the latter two only form ferromagnets very much below room temperature. Even though they don't include any of the aforementioned components, certain alloys do have a parallel moment structure.

The Heusler alloy CuAlMn3, which has magnetic moments in the manganese (Mn) atoms but is not ferromagnetic, is an illustration of this. It has been shown that a number of ionically bonded substances are ferromagnetic. Some of these substances are electrical insulators, whereas others have conductivities that are comparable to those of semiconductors. These substances include chalcogenides (oxygen, sulfur, selenium, or tellurium compounds), halides (fluorine, chlorine, bromine, or iodine compounds), and their mixtures. Manganese, chromium (Cr), and europium (Eu) are the only ions in these minerals with permanent dipole moments; the rest are diamagnetic. The rare-earth metals erbium (Er) and holmium (Ho) have a nonparallel momentum arrangement that results in a significant spontaneous magnetization at low temperatures. Some spinel-crystal-structured ionic chemicals also have ferromagnetic ordering. Thulium (Tm) below 32 kelvins spontaneously magnetizes due to a distinct structure (K). The spontaneous magnetism of the ferromagnetic material disappears above the Curie point, also known as the Curie temperature, and it becomes antiferromagnetic (i.e., it remains weakly magnetic). This happens because the material's internal alignment forces can no longer be resisted by the heat energy. Some significant ferromagnets have Curie temperatures of 1,043 K for iron, 1,394 K for cobalt, 631 K for copper, and 293 K for gadolinium.

Antiferromagnetism

A type of magnetism found in solids like manganese oxide (MnO) called antiferromagnetism occurs when nearby ions that act as tiny magnets—in this case, manganese ions, Mn^{2+}spontaneously align themselves into opposing, or antiparallel, accommodations throughout the material at relatively low temperatures. As a result, the material shows almost no obvious external magnetism. The magnetism from magnetic atoms or ions orientated in one way is cancelled eliminated by the set of magnetic atoms or ions that are aligned in the opposite direction in anti - ferromagnetic materials, which include numerous metals and alloys in addition to some ionic solids. Heating causes the spontaneous antiparallel interaction of atomic magnets to be broken, and at a certain temperature, known as the Néel temperature, which is unique to each antiferromagnetic material, it completely vanishes. (The Néel temperature is named after French scientist Louis Néel, who introduced antiferromagnetism in 1936 by providing one of the first explanations.) Néel temperatures for certain antiferromagnetic materials are at or above several hundred degrees above ambient temperature, although these temperatures are often lower. For manganese oxide, for instance, the Néel temperature is 122 K (151° C or 240° F). Depending on the temperature, antiferromagnetic materials behave differently under an applied magnetic field. So because antiparallel ordering of the atomic magnets is rigorously maintained at extremely low temperatures, this solid shows no reaction to the external field. Some atoms deviate from the structured arrangement and align with the outside field at higher temperatures. At the Néel temperature, this alignment and the resulting weak magnetism in the solid are at their strongest. The feeble magnetism created in the material by the alignment of its own atoms reduces steadily when temperature is raised above this point because thermal agitation gradually inhibits the atoms from aligning with the magnetic field.

Mirror with a magnet

Magnetic mirror: A static magnetic field which, in a specific area, has a form that causes charged particles to be repelled back in the direction they were originally traveling. Usually, a distribution of roughly parallel, non-intersecting field lines is used to characterize a magnetic field. The intensity of the magnetic field depends on both the density (closeness) of the lines and the direction in which they run. The most common way for charged particles to flow in a magnetic field is by taking a helical route around the magnetic field line. The particle is approaching an area with a larger magnetic field if the field lines along its route are convergent. The particle keeps circling the field line, but as it moves ahead, it slows down until it ultimately comes to a halt and is pushed back on its initial course. The starting pitch angle characterizing its helical course is the single factor affecting the precise position at which this mirroring takes place. A magnetic bottle that really can trap charged particles in the center may be created by combining two of these magnetic mirrors.

Para magnetism

The British scientist Michael Faraday identified and thoroughly studied paramagnetism, a kind of magnetism typical of materials weakly attracted by a powerful magnet, starting in 1845. Paramagnetic substances include the majority of elements. Strong Compounds including iron, palladium, platinum, and rare-earth elements show paramagnetism, which is distinct from the ferromagnetism of the metals iron, cobalt, nickel, as well as other alloys. Because part of the inner electron shells on all these elements' atoms in these compounds are incomplete, individual unpaired electrons spin like tops and orbit like satellites, creating the atoms a permanent magnet that tends to align with and so amplify an applied magnetic field. Due to the de-alignment caused by the increased relative velocity of the atomic magnets, strong paramagnetism becomes less effective as temperature increases. Because an applied magnetic field influences the spin of a number of the loosely bound conduction electrons, many metallic elements inside the solid state, such as sodium as well as other alkali metals, exhibit weak paramagnetism that is temperature independent. At ambient temperature, the susceptibility value for paramagnetic materials is normally between 1/100,000 and 1/10,000 for weakly paramagnetic compounds and between 1/10,000 and 1/100 for significantly paramagnetic substances. This number is always positive.

Magnet

Any substance that can draw iron and create a magnetic field around itself is a magnet. All known elements and several compounds had been investigated for magnetism by the end of the 19th century, and it was discovered that every one of them has some kind of magnetic characteristic. The most prevalent was diamagnetism, which is the term used to describe materials that weakly repel both poles of a magnet. When placed close to a magnet, certain materials, like chromium, exhibited paramagnetism, or the ability to weakly induce magnetization. Whenever the magnet is taken out, this magnetism is lost. Only three elements—iron, nickel, and cobalt—exhibited the ferromagnetism feature (i.e., the capability of remaining permanently magnetized).

Magnetization technique

William Thomson (Lord Kelvin) developed and gave names to the variables presently used to describe magnetization in 1850. The magnetic flux density within a magnetized body is represented by the symbol B, and the magnetizing force, or magnetic field that produces it is represented by the symbol H. The equation B = H, in which the Greek letter mu, or, stands in for the permeability of the material and indicates the amount of magnetization that may be generated in it by a certain magnetic field, represents the two. The current SI units for B and H are teslas (T) or webers per square meter (Wb/m2) and amperes per metre (A/m), respectively. The units were traditionally referred to as gauss and oersted, respectively. Henrys per meter are the units for this. Hysteresis, a lag in reaction to shifting pressures due on energy losses from internal friction, is a property shared by all ferromagnetic materials. A loop of the kind illustrated in the following figure is produced when B is measured for different values of H and the results are graphically shown. This loop is known as a hysteresis loop. The term refers to a circumstance in which the values of B take a different course when H is growing as opposed to when it is dropping. This diagram may be used to establish the properties necessary to explain a material's performance when utilized as a magnet. The saturation flux density, or Bs, is a gauge of the material's magnetic field strength. Br is a measure of a permanent magnet's quality since it refers to the residual, permanent magnetism that remains after the magnetizing field has been eliminated. Typically, it is expressed in webers per square meter. A reversed magnetizing field that opposes the specimen's magnetization must be applied in order to demagnetize it from its remanent condition. The coercive force, Hc, expressed in amperes per meter, is the size of the field required to bring the magnetization to zero. Hc should be as big as feasible for a permanent magnet to maintain its magnetism without loss over an extended length of time. Typically, a material with a high saturation flux density that needs a high field to magnetize will have big Br and large Hc. As a result, the highest value of the material's B/H product, or (BH) max, is often used to describe permanent-magnet materials. This product (BH) max, which is also known as the energy product, measures the lowest volume of permanent-magnet material needed to create the requisite flux density in a certain gap.

A ferromagnetic substance, according to a theory put out in 1907, is made up of a lot of little compartments called domains, each of which is fully magnetized. The first direct experiment to prove the existence of such realms was conducted in 1931. When the orientations of the individual domain magnetizations are dispersed randomly, the ferromagnetic body as a whole seems to be magnetic. A domain wall separates each domain from its neighbor. The magnetization orientation of one domain switches to that of its neighbor in the wall area. Starting from a fully magnetic condition, the magnetization process consists of three stages: (1) A weak magnetic field When the magnetizing field is removed, the domain walls revert to their initial positions, and there is no remanent magnetization. Instead, domains that are generally facing the magnetizing field increase at the cost of those that are not. (2) A medium-sized magnetic field. The number of favorably oriented domains significantly increases when larger, often irreversible shifts of domain barriers take place. All the sidewalls do not restore to their former places once the field is removed, and a residual magnetization remains. (3) A strong magnetic field. Many domain walls are entirely wiped out of the specimen as a result of large domain wall motions. As the field strength is raised, the remaining domains' magnetization orientations progressively rotate until the magnetization is uniformly parallel towards the field and the material has reached saturation. Domain walls return after the field is removed, as well as the domain magnetizations can spin in the opposite direction of the initial field direction. The value of the remanent magnetization is at its highest. The ease with which domain walls may traverse the material and domain magnetization could rotate will determine the values of Br, Hc, and (BH) max. The presence of discontinuities or flaws in the material creates barriers to the movement of the domain wall. The wall won't be able to return to its previous place until a reversed field is provided to push it back after the magnetizing field had moved the wall beyond an obstruction. Therefore, these impediments have the effect of making the remanence stronger. On the other hand, it will be simple to magnetize a pure, homogenous material to saturation with just modest magnetic fields, and the remanent magnetization will indeed be minimal.

Demagnetization and magnetic anisotropy. As far as domain rotation is concerned, there are two important factors to be considered, demagnetization and magnetic anisotropy (exhibition of different magnetic properties when measured along axes in different directions). The first of these concerns the shape of a magnetized specimen. Any magnet generates a magnetic field in the space surrounding it. The direction of the lines of force of this field, defined by the direction of the force exerted by the field on a (hypothetical) single magnetic north pole, is opposite to the direction of field used to magnetize it originally. Thus, every magnet exists in a self-generated field that has a direction such as to tend to demagnetize the specimen. This phenomenon is described by the demagnetizing factor. If the magnetic lines of force can be confined to the magnet and not allowed to escape into the surrounding medium, the demagnetizing effect will be absent. Thus a toroidal (ring-shaped) magnet, magnetized around its perimeter so that all the lines of force are closed loops within the material, will not try to demagnetize itself. For bar magnets, demagnetization can be minimized by keeping them in pairs, laid parallel with north and south poles adjacent and with a soft-iron keeper laid across each end. The relevance of demagnetization to domain rotation arises from the fact that the demagnetizing field may be looked upon as a store of magnetic energy. Like all natural systems, the magnet, in the absence of constraints, will try to maintain its magnetization in a direction such as to minimize stored energy; i.e., to make the demagnetizing field as small as possible. To rotate the magnetization away from this minimum-energy position requires work to be done to provide the increase in energy stored in the increased demagnetizing field. Thus, if an attempt is made to rotate the magnetization of a domain away from its natural minimum-energy position, the rotation can be said to be hindered in the sense that work must be done by an applied field to promote the rotation against the demagnetizing forces.

This phenomenon is often called shape anisotropy because it arises from the domain's geometry which may, in turn, be determined by the overall shape of the specimen. Similar minimum-energy considerations are involved in the second mechanism hindering domain rotation, namely magneto crystalline anisotropy. It was first observed in 1847 that in crystals of magnetic material there appeared to exist preferred directions for the magnetization. This phenomenon has to do with the symmetry of the atomic arrangements in the crystal. For example, in iron, which has a cubic crystalline form, it is easier to magnetize the crystal along the directions of the edges of the cube than in any other direction. Thus the six cube-edge directions are easy directions of magnetization, and the magnetization of the crystal is termed anisotropic. Magnetic anisotropy can also be induced by strain in a material. The magnetization tends to align itself in accordance with or perpendicular to the direction of the in-built strain. Some magnetic alloys also exhibit the phenomenon of induced magnetic anisotropy. If an external magnetic field is applied to the material while it is annealed at a high temperature, an easy direction for magnetization is found to be induced in a direction coinciding with that of the applied field. Description explains why steel makes a better permanent magnet than doe's soft iron. The carbon in steel causes the precipitation of tiny crystallites of iron carbide in the iron that form what is called a second phase. The phase boundaries between the precipitate particles and the host iron form obstacles to domain wall movement, and thus the coercive force and remanence are raised compared with pure iron. The best permanent magnet, however, would be one in which the domain walls were all locked permanently in position and the magnetizations of all the domains were aligned parallel to each other. This situation can be visualized as the result of assembling the magnet from a large number of particles having a high value of saturation magnetization, each of which is a single domain, each having a uniaxial anisotropy in the desired direction, and each aligned with its magnetization parallel to all the others.

Powder magnets

Controlling particle sizes to ensure that they are small enough to form a single domain but not so tiny that they completely lose their ferromagnetic characteristics is the fundamental challenge in creating magnets made of crushed powders. Such magnets have the benefit of being easily machined and molded into the necessary forms. The drawback of powder magnets is that strong magnetic interactions that lower the coercive force and, to a lesser degree, the remanentmagnetization occur when single-domain particles are packed close together. The interaction restricts the highest possible values of Hc and (BH) max since it effectively reduces a specific particle's demagnetizing force as a result of the existence of its neighbor. Magnetic alloy development has been more successful.

Alloys with high anisotropy

The form of the materials depends on their high uniaxial anisotropy. Additionally, a lot of research has been done on materials with a significant uniaxial magneto crystalline anisotropy. The cobalt-platinum (CoPt) and manganese-bismuth (MnBi) alloys have been the most effective of these.

Alnico alloys

Where domain wall movement can be stopped, a high coercive pressure will be produced. When two phases coexist in an alloy, particularly when one phase is a highly split precipitate inside the matrix of the other, this situation might develop. As a result, permanent magnet access to materials on this system with other additions, such as cobalt, copper, or titanium, are commonly referred to as Alnico alloys. Alloys comprising the three elements iron, nickel, but also aluminum exhibit this behavior.

Rare-earth alloys with cobalt. Numerous elements' isolated atoms have limited magnetic moments (i.e., the atoms are themselves tiny magnets). However, the majority of the atoms interact in the solid form of the element so that their magnetism cancels out and the solid is indeed not ferromagnetic. The cancelling-out process only leaves an effective net magnetic moment per molecule in the region at room temperature and above in the common elements iron, nickel, and cobalt. Unfortunately, it ceases to be ferromagnetic at temperatures higher than 16° C (60° F), making it of little practical use. Many of the rare-earth elements have high atomic moments and exhibit ferromagnetic behavior at very low temperatures. However, their practical utility is little.

Ferrites of barium

The fundamental magnetic iron-oxide mineral magnetite is modified by barium ferrite, which is simply $BaO{:}6Fe_2O_3$ but has a hexagonal crystalline structure. It has an extremely high uniaxial magnetic anisotropic as a result of this structure, which might result in high values of Hc. The material may be compressed and sintered after being magnetically aligned. The size of the crystallites is controlled by the temperature and length of the sintering process, which also allows for customization of the magnet's characteristics. The coercive force is strong and the remanence is approximately half the saturation flux density for very small crystallites. Higher Br but lower Hc are produced by larger crystallites. For focusing magnets for television tubes, this material has been extensively employed in the television industry.The bonding of the powdered ferrite with a synthetic resin or rubber to create individual molds, extruded strips, or sheets that are semi-flexible and can be cut with knives is a further advance of economic significance. This substance has been used as a refrigerator door gasket (to create an airtight seal) and magnetic closing.

Permeable materials

Magnetic materials with properties completely different from those needed for good permanent magnets are needed for a wide variety of magnetic devices that use magnetic fields, including such motors, generators, transformers, and electromagnets. These materials must be able to magnetize to high flux densities in comparatively weak magnetic fields and then completely demagnetize when the field is removed.

Iron continues to be the best material for uses requiring a high-saturation flux density because it possesses the highest value of magnetic moment per atom among the three ferromagnetic metals. In order to achieve the simplest domain wall motion, extensive research has been done to learn how to produce iron as unrestricted from flaws as possible. Sheet materials used in electronic systems have such a total impurity material of less than 0.4 percent because the presence of certain elements, even in small amounts, is particularly harmful. These elements include carbon, sulfur, oxygen, and nitrogen. Iron may be alloyed with silicon in modest amounts (approximately 4%), which has significant benefits. The additional silicon lessens the iron's magnetocrystalline anisotropy, which affects the coercive force and hysteresis loss of the material. The other benefits, including higher electrical resistivity, offset the decrease in saturation flux density, which does occur. Because it causes eddy currents inside the magnetic material, the latter is crucial in applications in which the magnetic flux alternates. These currents increase with decreasing resistivity and increasing alternation frequency. By heating the material, they result in an energy loss that can be reduced at a specific frequency by increasing the material's resistivity. A silicon-iron sheet material that has a high degree of the crystallites' preferential orientation can be produced using the right manufacturing process.

The material then develops a preferential magnetization direction, because high permeability and high efficiency are reached in this direction. It is known as cold-reduced, grain-oriented steel laminations and contains about 3.2 percent silicon. Permalloy is the collective term for alloys that include different amounts of nickel and iron. The saturation magnetization rises as the quantity of nickel decreases, reaching a maximum at around 50%, dropping to zero at 27 percent nickel, and then increasing once more approaching the value for pure iron. Additionally, the magnetocrystalline anisotropy decreases from its value for pure nickel to a relatively low value around 80% nickel, then steadily increases beyond that. Permalloy A, which has the highest permeability value, has a nickel content of 78.5 percent. At low flux densities, Permalloy A is superior to iron and silicon iron due to its highest relative permeability, which in properly produced material may reach a value of 1,000,000.

The majority of the ferrites with the general formula $MeOFe_2O_3$, in which Me is a metal, are helpful magnetically in addition with barium ferrite, which has a hexagonal crystal structure. They have a unique crystal structure termed spinel, named after the cubic-crystallizing mineral spinel ($MgAl_2O_4$). All of the spinel ferrites constitute soft magnetic materials, meaning that they have small hysteresis loops but also low coercive forces. They are all suited for use in high-frequency electronic equipment because to their high electrical resistivity but also high relative permeabilities. However, compared to the alloys, their saturation magnetization is low, which prevents them from being used in high-field, high-power power transformer. They are materials that resemble ceramic and are tough, brittle, and challenging to process. However, they are frequently used, particularly in computer memory.

CHAPTER 3

The Nature of a Magnetic Field

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The force that exists between magnets but instead magnetic materials is referred to as magnetism. For instance, we are aware that magnets draw iron particles to them, deflect compass needles, and attracted or repel other magnets. The "field of a magnet" or "magnetic field" is the area in which the force is sensed. Consequently, a force field is indeed a magnetic field. Magnetic fields are represented by streams in space in Faraday's model. These lines, also known as flux lines or line segments of force, depict the field's direction and strength at all places. Flux lines never crossover in the magnetic field, which is greatest near the magnet's poles (where they are most dense). The magnetic field always runs from north to south outside of the magnet (Figure 3.1). The Greek letter is used as the magnetic flux sign (phi).

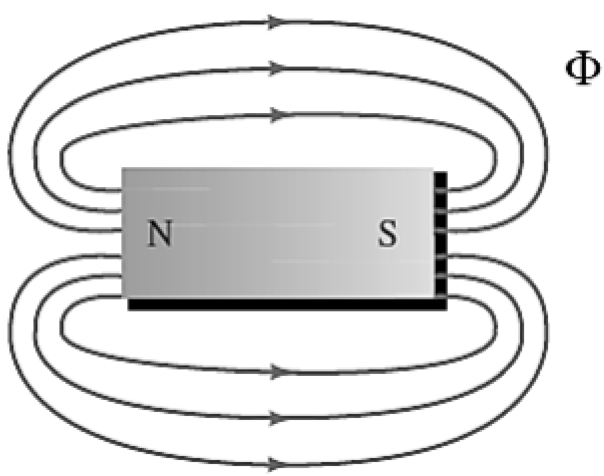

Figure 3.1.Illustrates the magnet with field line.

<u>Flux and Flux Density:</u>

The sign stands for the magnetic flux. The weber is the unit of flux in the SI system (Wb). However, rather than total flux, people are often more interested about flux density B (i.e., flux per unit surface area). The unit of flux density is termed the tesla (T), where 1 T = 1 Wb/m2, since flux is measured in Wb and surface A in m2, flux density being measured as Wb/m2. Figure 3.2. belowillustrates how to calculate flux density by dividing the entire flux perpendicularly travelling through a region by the area's size,

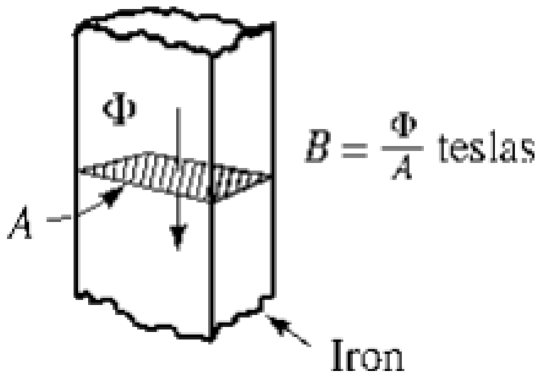

Figure 3.2. Illustrates the relation among flux and flux density

<u>Magnetic Field Intensity and Magnetization Curves:</u>

Let's now consider a more realistic method for studying magnetic circuits. First, we need a parameter called magnetic field intensity, abbreviated H (also known as magnetizing force). It gauges the mmf of a circuit per unit length (Figure 3.3). The ratio of applied magnetic field strength to the length of the route it operates across may be used to describe magnetic field intensity. Thus,

$$H = \frac{\mathcal{F}}{\ell} = \frac{NI}{\ell} \quad \left(\frac{AT}{m}\right)$$

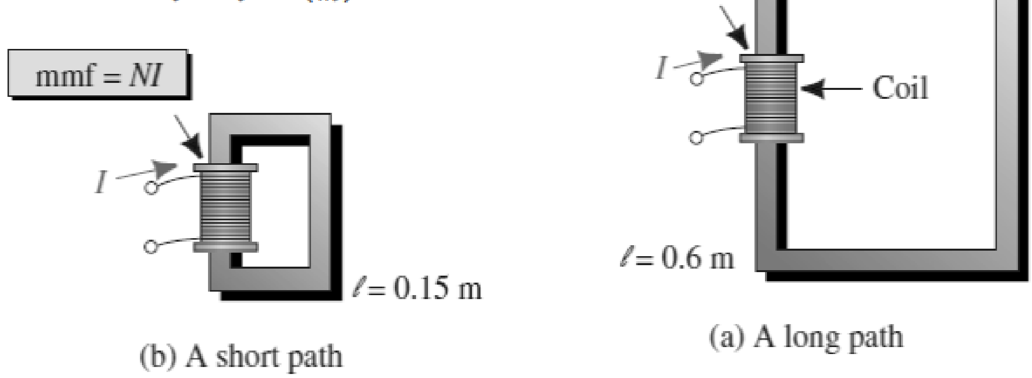

Figure 3.3. Illustrating the magnetic field intensity along short path and long path

Rearranging Equation yields an important result

$$NI = H\ell \quad \left(\frac{At}{m}\right)$$

The NI product is ammf source inside an analogy like electric circuits, while the product is a mmf drop.

3.3. The Relationship between B and H

The flux density and the magnetizing force are related by the following equation:

$$\mathcal{B} = \mu H$$

The greater the value of, the greater the flux density for just a given magnetizing current depending on the permeability of a core. Air and other nonmagnetic substances have permeability's that are, for all intents and purposes, equivalent to a vacuum. In air gaps, then,

$$\mathrm{B}_g = \mu_o H_g = 4\pi \times 10^{-7} \times H_g$$

$$H_g = \frac{B_g}{4\pi \times 10^{-7}} = 7.96 \times 10^5 B_g \qquad (\frac{At}{m})$$

B-H Curves

The graph between magnetic flux density (B) and magnetizing force is known as the B-H curve or magnetization curve (H). The B-H curve illustrates how the magnetic flux density changes as the magnetizing force changes. The overall contour of a magnetic material's B-H curve is seen in the following image.

The nonlinearity of the graph demonstrates that the relative permeability r of a magnetic material fluctuates according to the magnetic flux density rather than being constant. There is no simple method to calculate for ferromagnetic materials since is not constant but changes with flux density. However, you are really not interested in me at all: You truly want to know what H is given B and vice versa.

This knowledge is provided through a collection of curves known as B-H or magnetization curves. (These curves were discovered by experimentation and may be found in manuals. Each material requires a different curve.) Figure 3.4 displays typical contours for cast steel, sheet steel, and iron.

Magnetic Hysteresis

Magnetic hysteresis is the term for the phenomena wherein the magnetic flux density (B) lags behind the magnetizing force (H) in a magnetic material that has undergone a cycle of magnetization, whereby it is first magnetized in one direction and subsequently in the opposite direction.

Hysteresis Loop

Consider a magnetized iron bar AB with a coil of N turns coiled on it (see the figure). By altering the current flowing through the coil, the magnetizing force (H = NI/l) generated by the coil may be altered. As can be seen, when the iron bar has gone through one full cycle of magnetization, the resulting B-H curve forms what is known as a hysteresis loop.

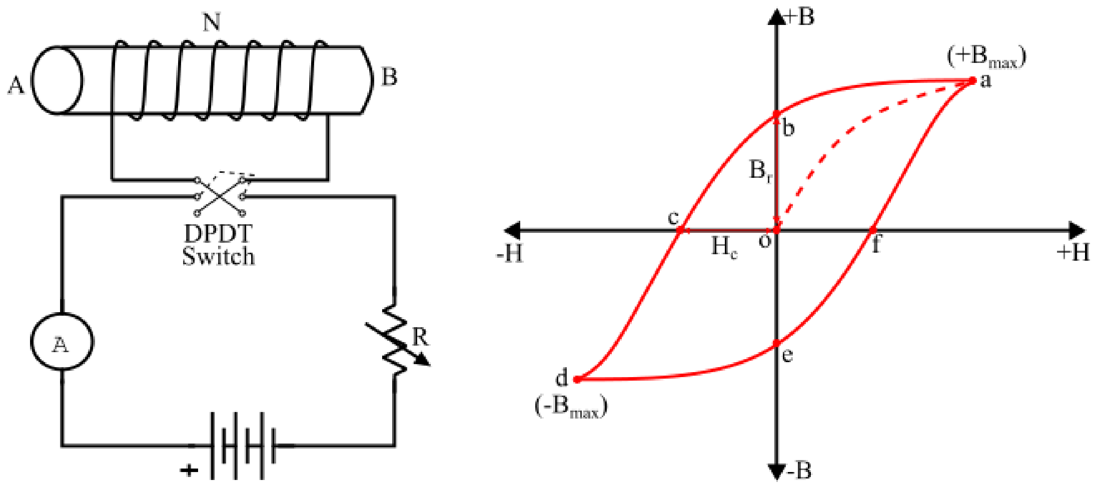

Figure 3.4. Illustrating the B-H curve

When the coil's current is zero, the H is also zero, which results in a zero B for the iron bar. Up until the point of maximum magnetic flux density (+Bmax), when H is raised by increasing coil current, the magnetic flux density likewise increases. Beyond this limit, the material is saturated, and no matter how much the magnetizing force is increased, the magnetic flux density won't rise (H).

The B-H curve for this follows the oa (see the hysteresis loop). Now, it is discovered that now the magnetic flux density follows the route ab rather than the path oa when the H is progressively reduced by reducing the coil current. The magnetizing force is zero at point b, but the remaining flux density (+Br) in the material seems to have a finite value (equal to ob). A magnetic material's capacity to retain residual magnetism is referred to as the material's retentivity. The magnetizing force is reversed by inverting the coil current in order to demagnetize the iron bar, or to eliminate the residual magnetism (ob).

The B-H curve continues the route bc as H is steadily raised in the opposite direction, resulting in zero residual magnetism at H = oc. Coercive force is defined as the amount of H = oc necessary to entirely eliminate the remaining magnetism (Hc). The material now becomes saturated in the opposite direction if H is raised further (point d). The defa curve is traced by reducing H to zero and afterwards raising it in a positive manner.

Therefore, the B-H curve follows a closed loop abcdefa known as the hysteresis loop after an iron bar undergoes one full cycle of magnetization.

Importance of Hysteresis Loop

The hysteresis loop's size and form are determined by the material's properties. The size and form of the hysteresis loop determines which magnetic material is best for a certain application. To comprehend the significance of hysteresis loop, consider the following examples: A magnetic material's hysteresis loss decreases with decreasing hysteresis loop area (e.g. silicon steel). As a result, silicon steel is often utilized to create the cores of transformers and spinning electric equipment that experience quick magnetization reversals (Figure 3.5).

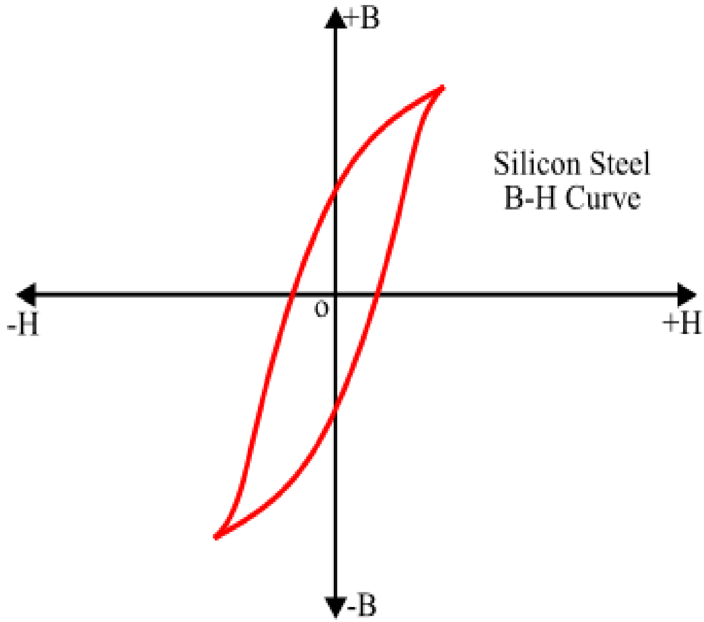

Figure 3.5.Illustrating the silicon steel B-H curve

The hysteresis loss of such a magnetic material increases with the size of its hysteresis loop. Although hard steel has a high retentive and coercive strength, it is utilized to make permanent magnets (Figure 3.6).

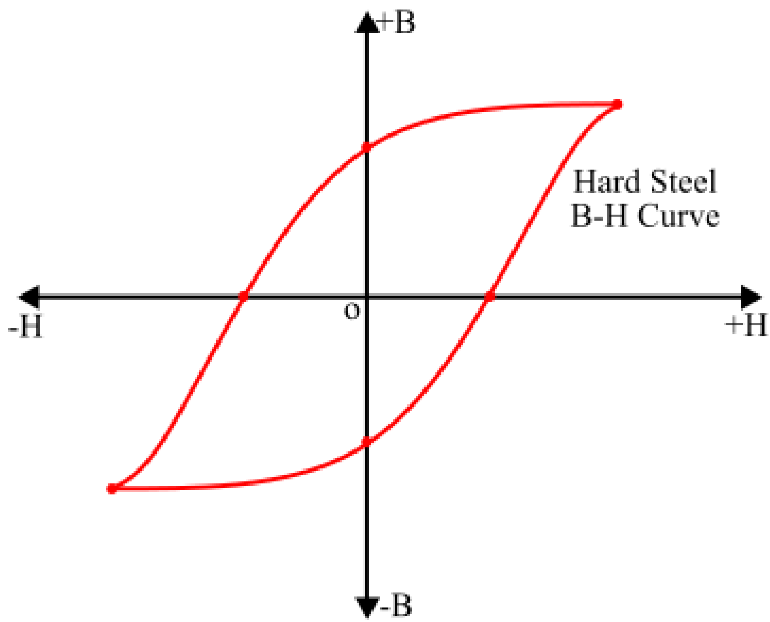

Figure 3.6.Illustrating the hard steel B-H curve

The hysteresis loop for wrought iron has fairly good residual magnetism and coercively. Therefore, it is used for making cores of electromagnets (Figure 3.7).

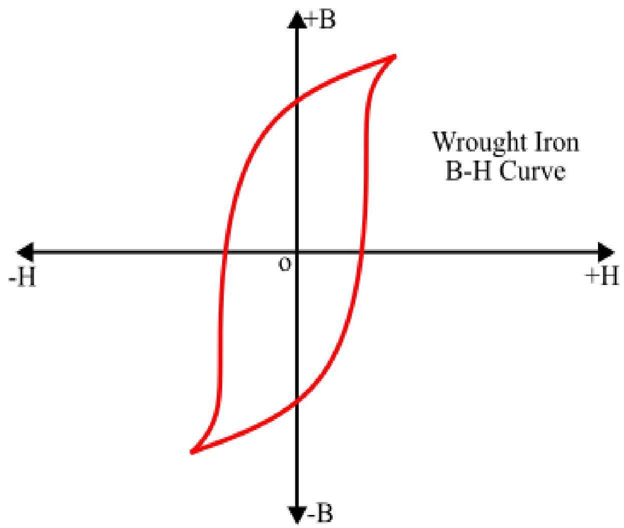

Figure 3.7.Illustrates the B-H curve of Wrought Iron.

Laminated cores, fringe, and air gaps fringing is the extension of the flux lines beyond the common region of the fundamental for the air gap. We will disregard this impact for the sake of our objectives and assume that the flow distribution is as shown in Figure. When fringing occurs in magnetic circuits containing air gaps, the flux density inside the gap decreases. Fringing may normally be ignored for small gaps. Alternately, to approximate the drop in flux density, adjustment may be accomplished by increasing each cross-sectional dimension of both the gap by the gap's size (Figure 3.8).

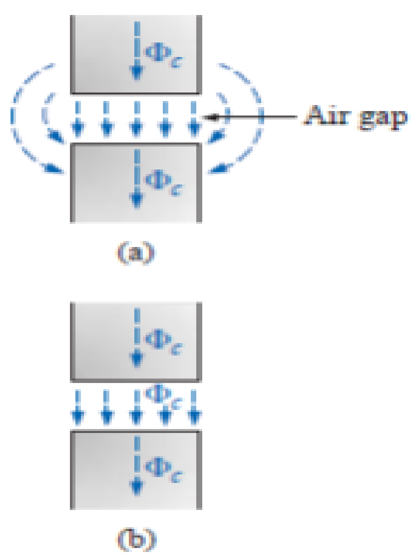

Figure 3.8.Illustrates the air gap distance between two conductors.

Ampere's Circuital Law:

If we apply the analogy to Kirchhoff's voltage law (for magnetic circuits).

$$\sum_{\circlearrowleft} \mathcal{F} = 0$$

Declares that the algebraic total of the mmf rises and falls around a closed loop of an armature winding is equal to zero, or that the mmf rises and falls around a closed loop are equal. Ampère's circuital law is the name given to equation. The equation is used to represent the sources of mmf in magnetic circuits. Depending on the flux direction and how the coils are twisted, the summing is algebraic and the components may be either additive or subtractive.

$$\mathcal{F} = NI \qquad (At)$$

$$\sum_{\circlearrowleft} NI = \sum_{\circlearrowleft} H\ell$$

Consider the three distinct ferromagnetic materials that make up the magnetic circuit displayed in Figure 3.9. Ampère's circuital law is used to create,

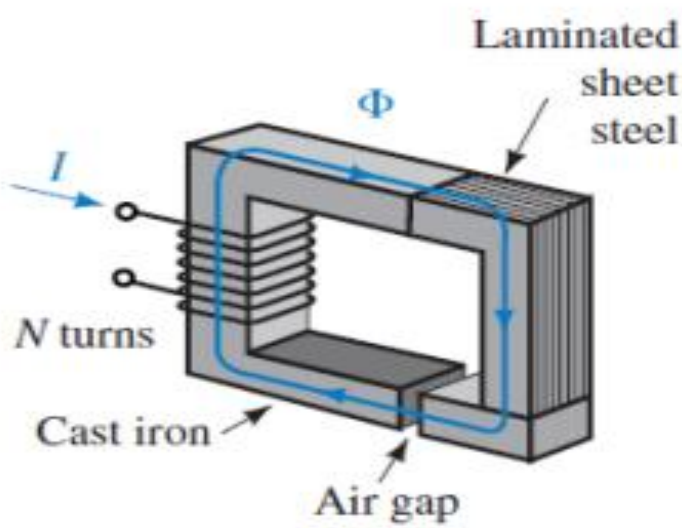

Figure 3.9. Illustrating the magnetic circuit

$$NI - H_{iron}\ell_{iron} - H_{steel}\ell_{steel} - H_g\ell_g = 0$$

Which declares that the mmf NI applied is equivalent to the total of the drops around the loop. The mean (average) route should be used when defining the words. Visitors now have two models of magnetic circuits. Although the reluctance model (a) is not very helpful for problem-solving, it helps in connecting magnetic circuit issues to well-known electrical circuit ideas. On the other hand, the Ampere's law model enables us to address real-world issues (Figure 3.10).

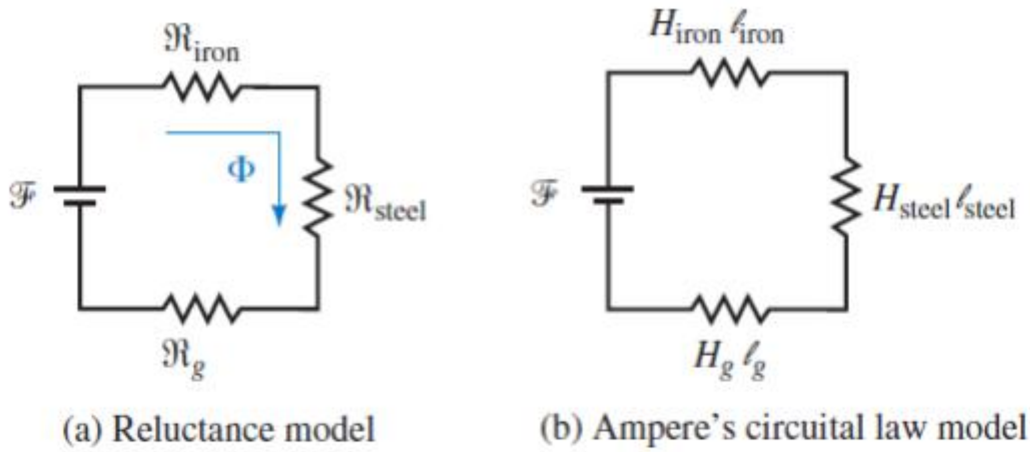

Figure 3.10. Illustrating the reluctance and ampere's circuital model

3.5 Series Elements and Parallel Elements

Sections of magnetic circuits might be made of many materials. For instance, the circuit shown in Figure includes cast iron, sheet steel, and air gap components. Flux for this circuit is constant throughout. A circuit of this kind is known as a parallel magnetic circuit. The flux is the same throughout all parts, but as you saw previously, depending upon every section's effective cross-sectional area, the flux density might differ.

Parallel components may also be present in a circuit (Figure). The total fluxes entering and exiting at each junction are equal. This is Kirchhoff's current law's opposite. Thus,

$$\boldsymbol{\Phi_1 = \Phi_2 + \Phi_3}$$

3.6 Flux Linkage, Inductance, and Energy

The Greek symbol m stands for total magnetic flux, and when this amount is divided by surface area, the result is magnetic flux density B. We can determine the flux linkage, which corresponds to the magnetic flux connected by each loop multiplied by the total number of loops, when a magnetic flux goes through one or even more loops in a coil of wire. Equation illustrates this computation, and Example illustrates how this equation could be used (Figure 3.11).

$$\Lambda = N \cdot \Psi_m \qquad \text{(E}$$

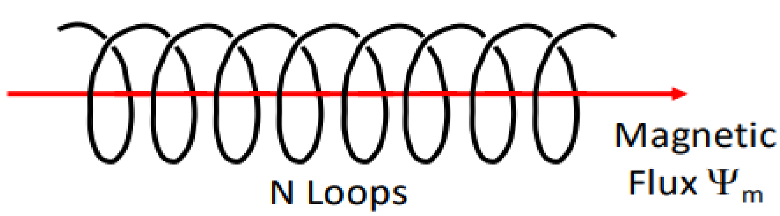

Figure 3.11 Illustrating the relation among the flux linkage, inductance and energy

The ratio of the magnetic flux linkage of an item (j) divided by the current (Ik) that generated the magnetic flux is known as inductance:

$$L_{jk} \equiv \frac{\Lambda_j}{I_k}$$

It's likely that the coil that is also connecting it is traveling through the same current that is creating the magnetic flux linkage. It is referred to as self-inductance. We shall address mutual inductance in the next section if the coils that produce and connect the magnetic flux linkage are different. When self-inductance is included, j=k in and the equation becomes.

$$L = \frac{\Lambda}{I}$$

Since there is just one coil to keep track of, humans no longer need to utilize subscripts. Let's figure out the inductance of a straightforward wire coil around a core (Figure 3.12).

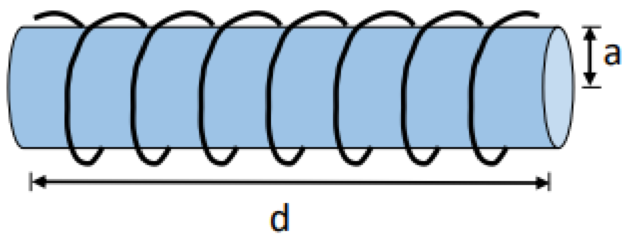

Figure 3.12.Inductance of strait coil

$$B = \frac{\mu_0 N I}{d}$$

Since this coil has a ferromagnetic core, we can modify this equation to include the relative permeability as well as the permeability of free space:

$$B = \frac{\mu_o \mu_r N I}{d}$$

We can calculate the total magnetic flux by multiplying the magnetic flux density by the area:

$$\Psi_m = \frac{\mu N I}{d} \pi a^2$$

Recall that the total permeability μ is equal to μrμ0.

$$\Lambda = N\Psi_m = \frac{\mu N^2 I}{d}\pi a^2$$

Mutual Inductance

The letter M is often used to denote mutual inductance, in which the magnetic flux is generated by one conductor and coupled by another. To indicate which current elements are connected by the magnetic flux, subscripts may be appended:

$$M_{jk} \equiv \frac{\Lambda_j}{I_k}$$

The subscripts aren't necessarily necessary, particularly if the problem's context makes it plain that there are only two coils at play. Interestingly, Mjk=Mkj, meaning that the mutual inductance between any two objects is symmetrical. Think about the two coils in Figure 3.13. A magnetic flux density was produced by the current flowing through the primary coil and is connected by the second coil.

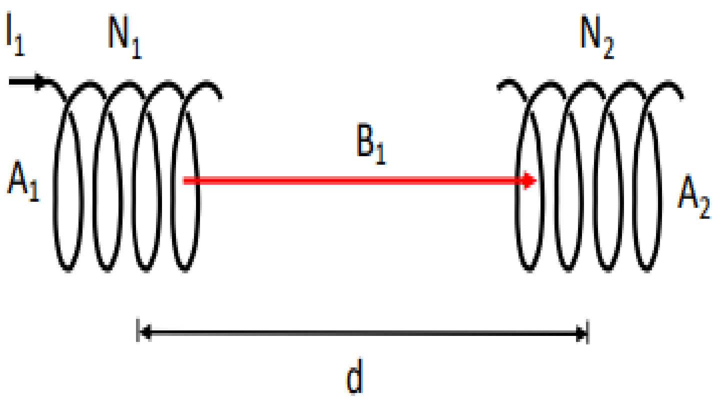

Figure 3.14 represent the magnetic flux density

A coil of radius A has the following magnetic flux density at a distance d (formerly termed z) from it:

$$B_1(z) = \frac{\mu_0}{2\pi}\frac{I\pi a^2}{(a^2 + d^2)^{3/2}}$$

The equation becomes simpler if we assume that d is much bigger than replace a_2 with the more generic A1:

$$B_1 = \frac{\mu_0 N_1 I_1 A_1}{2\pi d^3}$$

The magnetic flux density generated by the first coil is multiplied by that of the surface area and the number of turns mostly on second coil to get the flux linkage of the second coil:

$$\Lambda_2 = N_2 \Psi_2 = N_2 B_1 A_2 = \frac{\mu_0 N_1 N_2 I_1 A_1 A_2}{2\pi d^3}$$

The mutual inductance is finally calculated by dividing this flux linkage by the current in the first coil:

$$M = \frac{\Lambda_2}{I_1} = \frac{\mu_0 N_1 N_2 I_1 A_1 A_2}{2\pi d^3 I_1} = \frac{\mu_0 N_1 N_2 A_1 A_2}{2\pi d^3}$$

The magnetic flux density generated by the first coil is multiplied by that of the surface size and the number of turns mostly on second coil to get the flux linkage of both the second coil.

Energy Contained in an Inductor:

Any electrical component's power is calculated by multiplying the voltage by the current. Students also understand that the voltage across an inductor may be determined using the following equation, which we shall soon demonstrate:

$$v_L(t) = L\frac{di(t)}{dt}$$

Let may describe the energy in the following equation since the energy stored in an inductor equals the integral of power over time:

$$W_L = \int_0^t IV\,dt' = \int_0^t IL\frac{di(t')}{dt'}dt'$$

When the integral of the derivative is simplified using the chain rule (or, if you want to use a little looser language, "cancelling the dt' terms," they obtain:

$$W_L = L\int_0^t I\,dI = \frac{1}{2}LI^2$$

It is a useful result in its own right, but we can go further.

$$L = \frac{\mu N^2}{d}\pi a^2$$

It also know from Equation that,

$$B = \frac{\mu_o \mu_r N I}{d}$$

Solving this equation for I, we obtain:

$$I = \frac{Bd}{\mu N}$$

Substituting Equations,

$$W_L = \frac{1}{2}\left[\frac{\mu N^2}{d}\pi a^2\right]\left[\frac{Bd}{\mu N}\right]^2$$

Simplifying this equation gives:

$$W_L = \frac{1}{2}\frac{B^2}{\mu}(d \cdot \pi \cdot a^2)$$

Since the term in parentheses is the volume of the inductor, we can write this as:

$$W_L = \frac{1}{2}\frac{B^2}{\mu}V$$

Perhaps may remember that previously mentioned Equation as this equation's proof in the previous chapter. Now now know where it originated. In a broader sense, we may formulate an equation for the energy held in any magnetic field, not only one with a cylinder-shaped inductor.

$$W_m = \int_{\Delta v}\left(\frac{B^2}{2\mu}\right)dV$$

CHAPTER 4

Properties of Magnetic Materials

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Magnetic materials have two functions in the context of electromechanical energy conversion devices. By using them, it is feasible to achieve high magnetic flux densities at comparatively modest magnetizing forces. The performance of energy storage devices is greatly influenced by this phenomenon because magnetic forces and power density rise with increasing flux density. Magnetic materials may also be used to control magnetic fields and steer them in certain directions.

They are used in transformers to increase coupling between both the windings and reduce the excitation current needed for proper operation. Magneto materials are utilized in electric equipment to sculpt the fields to achieve desired torque generation and electrical terminal properties. Therefore, a skilled designer may use magnetic materials to provide certain desired gadget features. The majority of magnetic materials are ferromagnetic, which are primarily made of iron and iron alloys with chrome, tungsten, nickel, aluminium, and other metals. Although these materials exhibit a broad variety of characteristics, they all share the fundamental processes that give rise to those characteristics. It has been discovered that ferromagnetic materials are made up of a lot of domains, or areas where all of the atoms' magnetic moments are parallel and provide a net magnetic moment for just that domain.

The domain magnetic moments in a magnetized sample of a material are orientated arbitrarily, and the net resultant magnetic flux inside the material is zero. The domain magnetic moments have a tendency to line up with the applied magnetic field whenever an external magnetizing force is exerted to this substance. Due to the domain magnetic moments' contribution to the applied field, the flux density is substantially higher than it would be if the magnetizing force alone were the only factor at play.

Therefore, in comparison to the permeability of free space,o, the effective permeability, which is equal towards the ratio of the total magnetic flux density towards the applied magnetics-field strength, is greater. This tendency continues with increased magnetizing force until all magnetic moments are lined up with the applied electric field; at this point, the material is considered to be completely saturated since the magnetic flux density can no longer be increased by the magnetic moments. Axes of easy magnetization are certain paths associated with the domain's crystal structure that the domain's magnetic moments spontaneously align along in the absence of the an externally applied magnetizing force. The domain magnetic moments will so stretch to the orientation for easy magnetism closest to the applied field if indeed the administered magnetizing force is lowered. The magnetic dipole moments will thus no longer be completely random in their orientation whenever the applied field is zero, even though they will tend to relax towards their original orientation. Instead, they will still have a net magnetization component along of the applied field direction.

This outcome is what causes the phenomena described as magnetic hysteresis. The connection between B and H for just a ferromagnetic material is nonlinear and multivalued as a result of this hysteresis phenomenon. Generally speaking, an analytical description of the material's features is impossible. They are often shown graphically as a collection of empirically calculated curves based on test samples of the substance and following procedures recommended by the American Testing and Materials Association (ASTM).

The B-H curve, often known as the hysteresis loop, is the most typical curve used to characterize a magnetic material. Figure 4.1 below depicts the first and second quadrants of a series of hysteresis loops for M-5 steel, a common grain-oriented electrical metal used during electrical equipment. These quadrants correspond to B= 0.

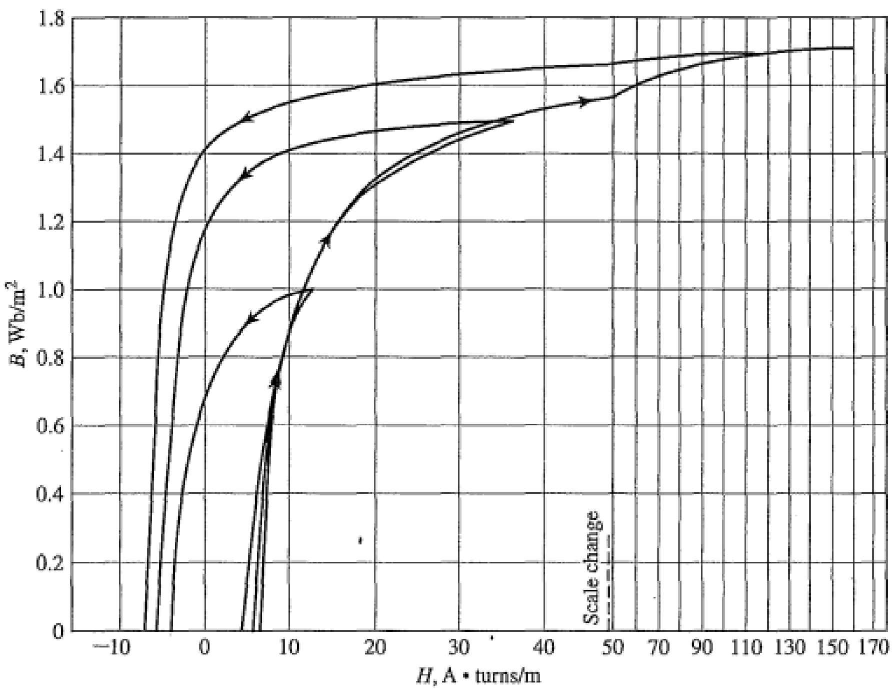

Figure 4.1. First and second quadrants of a series of hysteresis loops

These loops demonstrate the interaction between the magnetizing force H and the magnetic flux density B. The applied magnetizing force is cycled between equal positive and negative values of constant magnitude to produce each curve. These curves have several values because to hysteresis. The B-H curves produce closed loops as illustrated after a number of cycles. The arrows represent the routes taken by B with changing and rising H. As the material leans toward saturation, you'll see that the curves start to flatten as H's magnitude increases. One may see that this material is highly saturated at a flux density of roughly 1.7 T. Also note that the flux density declines but does not reach zero when H is reduced from its greatest value. This is the outcome of the domains' magnetic moments' orientation relaxing in the manner previously explained. As a consequence, even when H is zero, there is still some residual magnetization. Fortunately, a single-valued curve known as a de or conventional magnetization curve may adequately represent the material in many technical applications. This curve is created by charting the location of the highest values of B and H just at points of the hysteresis loops. Figure 4.2below depicts a demagnetization curve for M-5 grain-oriented electrical steel. The pseudo magnetization curve vividly demonstrates the material's nonlinear properties without ignoring its hysteretic nature.

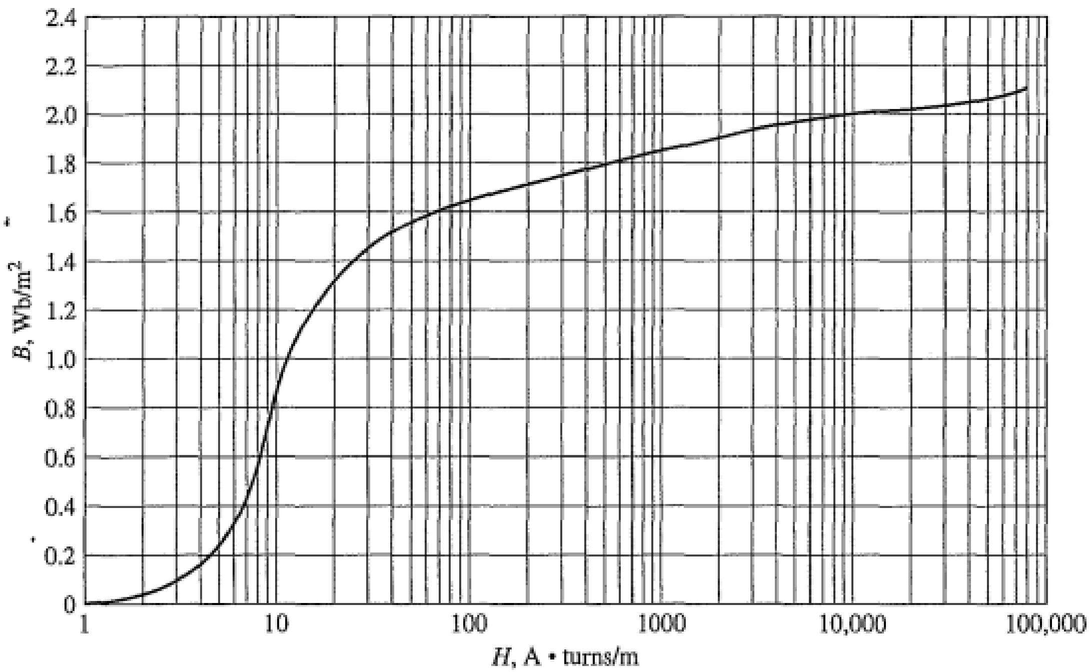

Figure 4.2. Demagnetization curve for M-5 grain-oriented electrical steel

Ac Excitation

The voltage and flux waveforms of ac power systems closely resemble sinusoidal functions of time. This section explains the steady-state ac functioning of magnetic materials under this kind of operating circumstances, including the excitation properties and losses involved. We employ a closed-core magnetic circuit one without an air gap as our model. Along the length of the core, the cross-sectional area is Ac, and the magnetic path length is le. We additionally suppose that the core flow will vary sinusoidally.

$$\varphi(t) = \phi_{\max} \sin \omega t = A_c B_{\max} \sin \omega t$$

Where,

$$\begin{aligned} \phi_{\max} &= \text{amplitude of core flux } \varphi \text{ in webers} \\ B_{\max} &= \text{amplitude of flux density } B_c \text{ in teslas} \\ \omega &= \text{angular frequency} = 2\pi f \\ f &= \text{frequency in Hz} \end{aligned}$$

The voltage induced in the N-tum winding is,

$$e(t) = \omega N \phi_{\max} \cos(\omega t) = E_{\max} \cos \omega t$$

$$E_{\max} = \omega N \phi_{\max} = 2\pi f N A_c B_{\max}$$

Scientists are often more interested inside the root-mean-square, or rms, values of the voltages and currents in steady-state ac operation than in the instantaneous or maximal values. A periodic functional of time with period T, f (t), has an rms value that is often described as,

$$F_{\text{rms}} = \sqrt{\left(\frac{1}{T}\int_0^T f^2(t)\,dt\right)}$$

It may be shown that the sine wave's rms value is equal to 1/J2 times its peak value. Consequently, the induced voltage's rms value is,

$$E_{\text{rms}} = \frac{2\pi}{\sqrt{2}} f N A_c B_{\text{max}} = \sqrt{2}\,\pi f N A_c B_{\text{max}}$$

Almost all transformers and specific electric machine components are made of sheet steel, which has very advantageous magnetization directions along which is something the core loss is minimal as well as the susceptibility is high. Grain-oriented steel is the substance in question. The atomic structure of a silicon iron alloy crystal, which consists of a body-centered cube with one atom at each comer and one in the cube's core, accounts for this feature. The diagonal across the square is the most challenging axis of magnetization in the cube; the diagonal throughout the cube face is more challenging. In order to make the rolling direction the preferred way for magnetization, the majority of the edges of the crystalline cubes are aligned in that direction during production. When compared to no-oriented steels, where the crystals are haphazardly orientated to create a material with properties that are uniform in all directions, the behavior throughout this direction is better in core loss and permeability. In contrast to non-oriented grades, orientated steels may thus be used at greater flux densities. In situations where minimal cost is crucial or when the flux doesn't really follow a route that can be orientated with the rolling direction, no oriented electrical metal parts are employed. Compared to grain-oriented steels, these steels have considerably larger losses and substantially lower permeability.

Application of Permanent-Magnet Materials

Take into account the behavior of permanent magnets on the presumption that the operating point may be easily ascertained from knowledge of the magnetic circuit's architecture and the characteristics of the different magnetic materials involved. In actuality, the issue is much more complicated in real engineering equipment. These topics will be expanded addressed in this section. The magnetic properties of a few popular permanent magnet materials are shown in Figure. For each material, these curves are just the second-quadrant features of the hysteresis loops that are produced when the material is forced strongly towards saturation. A popular iron, nickel, aluminum, and cobalt alloy called Alnico 5 was first discovered in 1931. There is a sizable residual flux density. Compared to Alnico 5, Alnico 8 has a greater coercive and a lower residual flux density. Consequently, it is less vulnerable to demagnetization that Alnico 5. The Alnico materials' mechanical brittleness and relatively low coercive strength are drawbacks. Iron-oxide and barium- or strontium-carbonate powders are used to make ceramic permanent magnets, often referred to as ferrite magnets, which have substantially greater cervicitis but lower residual flux densities then Alnico materials. They are substantially less susceptible to demagnetization as a consequence. Figure 4.3 depicts Ceramic 7, one of these materials, with a nearly straight-line magnetization characteristic. Ceramic magnets are produced cheaply and have high mechanical properties.

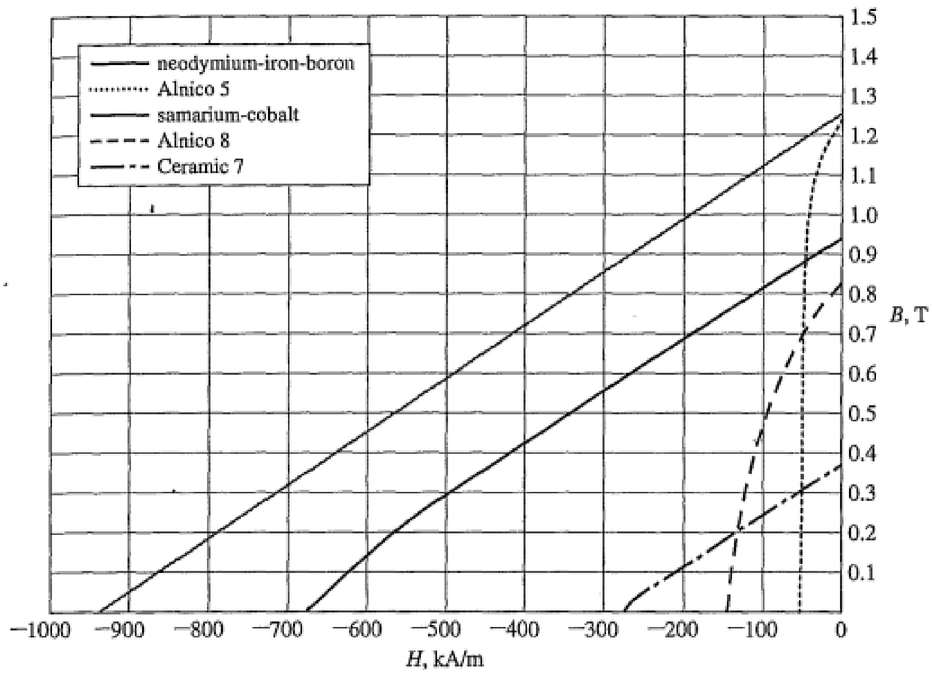

Figure 4.3. Magnetization characteristic of Ceramic 7

The development of rare-earth permanent magnet materials in the 1960s led to the beginning of permanent magnet technology, which was further advanced by the discovery of samarium-cobalt. Figure shows that it has a much greater coercivity but also maximum energy production while also possessing a high residual flux density similar to that of Alnico materials. The family of neodymium-ironboron compounds is the most recent of the rare-earth magnetic materials. They have higher coercivity, maximal energy product, and residual flux density then samarium-cobalt. Manufacturers all around the globe are creating permanent-magnet motors with progressively high ratings as a consequence of the development of neodymium iron boron magnets, which has had a significant influence on the field of rotating machines. It is important to note that although the magnetization characteristics of the other materials seem to be mostly straight lines in Figure 26, the hysteretic nature of a magnetization characteristics with Alnico 5 and Alnico 8 is immediately visible. This seemingly straight-line property of the material is misleading since it bends steeply downward in each instance, much as the Alnico materials do. In contrast to the Alnico materials, the above bend, also known as the magnetization curve's knee, lies in the third quadrant and doesn't show up. The magnetic circuit is an example.

This consists of an N-turn excitation coil and a portion of hard magnetic material in some kind of a core of very permeable softer magnetic material. Consider what transpires when current is given to both the excitation winding while assuming that the hard magnetic substance is first magnetized (equivalent to point (a) of the image). Because it is believed that the core has infinite permeability, the horizontal axis may be seen as a measurement of both the applied current I = Hlm/N) and the magnetic material's H content. The B-H trajectory climbs from point (a) towards its own optimum amount at point (b) as the current I is raised to its maximum value (b). They suppose that now the current has been raised to a value imax big enough to push the material far into saturation at point in order to completely magnetize it (b). The B-H characteristic will then start to create a hysteresis loop when the current is reduced to zero, eventually reaching point (c). Observe that the material is zero but that B is at its residual value at point (c), as mention in Figure 4.4 and Figure 4.5.

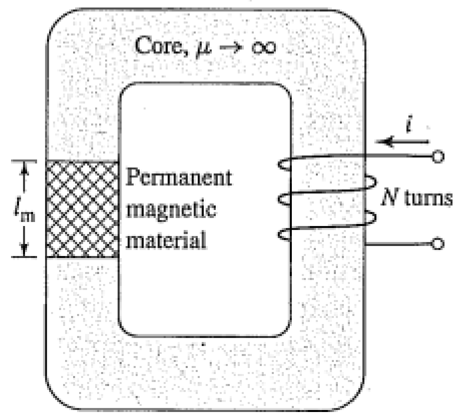

Figure 4.4.Illustrates the Magnetic circuit including both a permanent magnet and an excitation winding.

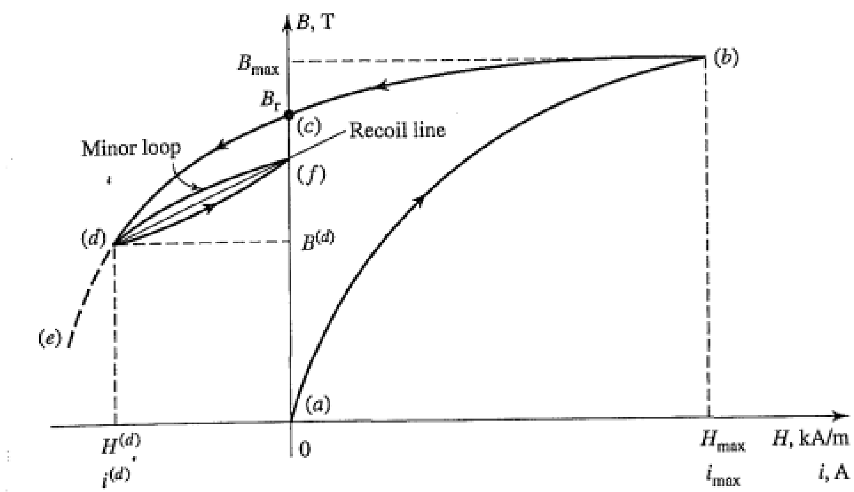

Figure 4.5.Illustrates the Portion of a B-H characteristic showing a minor loop and a recoil line.

The B-H characteristic then continues to draw a hysteresis loop as the current becomes negative. This is thought to be the path between points (c) and in (d). The operating point of both the magnet would be point I (d) if the current is then sustained at that value (d). The identical operating point would've been obtained, as in Example 1.9, if the material were ever to start at point (c) and an air gap of length g = lm(Ag/ Am)(-, 0H(d) / B(d)) were subsequently put in the core while keeping the excitation at zero. In the event that the current were to become more negative, then trajectory could continue to follow the hysteresis loop in the direction of point (e). The trajectory does not often retrace the hysteresis loop approaching point if, however, the current is set to zero (c). Instead, it starts to draw a tiny hysteresis loop and eventually gets to point (f) whenever the current zeroes out. The minor loop will be traced out by the B-H characteristic if somehow the current is then modulated between zero and I(dl. As shown from, a straight line, referred to as the recoil line, may be used to illustrate the B-H trajectory between points (d) and (f). The recoil permeability of this line is its slope. Jl,R· Thus can observe that after demagnetization at point (d), the magnetic material's actual residual magnetization is point (f), which is lower than the remaining magnetization Br that would be predicted based upon that hysteresis loop. Note that a new minor loop with something like a new recoil vector and recoil j'Jermeability will be produced if the demagnetization is lowered beyond point (d), for example, to point (e). Negative excitation has demagnetizing effects similar to an air gap inside the magnetic circuit, which were just addressed. For instance, it is obvious that the magnetic circuit shown in Fig. 1.20 might be employed as a device to magnetize materials that are hard magnetic. It would only be necessary to provide a significant excitation to the winding and then to decrease it to zero, leaving the material with a residual magnetization Br (point (c). If the material were to be withdrawn from the core after this magnetization process, this would result in akin to creating a large air gap in the armature winding, demagnetizing the substance in a manner similar to what is seen. The magnet has now essentially been weakened since, if it were to be put into the magnetic core once again, it would revert to a residual magnetism that was slightly weaker than Br. The danger of inappropriate operation may greatly demagnetize hard magnetic materials, including the Alnico materials, is generally present since they often do not function steadily in circumstances with variable mmf and geometry.

Biot-Savart law

Based on the tests conducted in 1820 by the French scientists Jean-Baptiste Biot and Félix Savart, the Biot-Savart law is a basic quantitative connection between an electric charges I as well as the magnetic field B it generates. Magnetic field lines B which create loops from around current are produced by a current in a loop. The Biot-Savart section stipulates the partial B field contribution of a current inside a conductor from a tiny conductor segment. For a conductor segment of lengths and orientation dl but also current I,

$$dB = \mu 0/4\pi\ Idl \times \hat{r}\ /r2.$$

0 represents the permeability of empty space in this equation and has a value of 4 107 newtons per square ampere.

This equation is shown for a short wire segment carrying a current, where the wire segment is of length dl and located along the x axis there at origin of the co - ordinate system. The inverse square dependency of the field's magnitude with distance may be seen by comparing the difference between points 1 and 2 in dB. The direction of dB inside a circle around the wire is shown by the vectors at points 1, 3, then 4, which seem to be all located at the same distance from dl. Position 1's contributions to the field, dB1, is perpendicular to both the vector r1 and the current direction. The vectors at 1, 5, 6, and 7 show how the magnitude of dB at a location depends on its angular position. The sine of a angle among both dl and r, where r is the direction between dl to the point, determines how much dB fluctuates in magnitude. It is strongest at an angle of 90° to dl and becomes zero at points that are exactly parallel to dl. Considering the vector character of the field, the magnetic field of the a current in a loop or coil is created by adding up the individual partial contributions of each circuit segment. Although for a few current combinations straightforward mathematical formulas for the magnetic field may be obtained, the majority of real-world applications call for the usage of high-speed computers. Using a long, straight wire and current I, the magnetic field B at a distance r from the wire is expressed as

$$B = \mu 0I/2\pi r\ \theta$$

Where the unit vector pointing inside the wire's direction is. In other words, the perpendicular distance r from either the wire to the provided location, r, and the value of a magnetic field B at quite a nearby point, B, are exactly proportional to each other.

Induction heating

By exposing an electrically conductive substance to that of an alternating electromagnetic field, induction heating raises its temperature. Despite being electrically insulated from the field's source, the item experiences electric currents that cause power to be lost as heat. Metalworking uses induction heating techniques most often to heat metals during soldering, tempering, and annealing. Additionally, the technique is used in induction furnaces to melt and treat metals. The induction heating technique works on a similar premise as a transformer. The substance to also be heated (the workpiece), which serves as the secondary winding of such a transformer, is encircled by a water-cooled coil, or inductor. The main coil's alternating current heats up the workpiece by creating eddy currents there. The main alternating current frequency, the magnetic permeability, and the resistivity of the material all affect how deeply the eddy currents pierce an item and, therefore, how heat is distributed within it. By briefly exposing steel to a high-frequency field, induction hardening, a process used to enhance the durability of steel objects to wear, may be induced.

Lenz's law

The electromagnetic principle known as Lenz's law states that an induced electric current will flow in a direction that opposes the change that caused it. The Russian scientist Heinrich Friedrich Emil Lenz derived this rule in 1834. (1804–65). For instance, when a permanent bar magnet's pole is pushed through a coil of wire, strong electric current is induced, which creates a magnetic field from around coil and turns it into a magnet. The induced current's direction is shown by Lenz's law. (Faraday's law of induction's negative sign comes from Lenz's law and the orientation of the induced current.) Lenz's law says that while the north pole of a bar magnet starts approaching this same coil, the induced current that flows in a manner that make the side of the coil closest to the pole of the electromagnet itself a north pole towards oppose another approaching bar magnet. This is because similar magnetic poles repel one another. The near coil's opposite side turns into the south pole when the bar magnet is removed from the coil, creating an attractive force that pulls the magnet back into the coil. In order to draw the magnet out of the coil and put it into the coil against the magnetic influence of the generated current, some effort must be done. Because the generated current encounters resistance in the coil's material, the tiny quantity of energy generated by this effort causes a modest heating effect. The overall idea of energy conservation is upheld by Lenz's law. Inducing the current in the other direction would have the additional consequence of drawing the bar magnet into in the coil while also heating it up, which would go against the law of conservation of energy.

CHAPTER 5

Classification of DC generators

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DC generators and DC motors are two subcategories of DC machinery. The preponderance of DC machines are equivalent to alternating current (AC) machines since they comprise simultaneously AC currents and AC polarities. DC machines only produce DC voltage because they convert AC electricity to DC voltage. Because the transformation that this mechanism accomplishes is known as a commutator, these machines are in fact referred to as commutating machines. DC machines are the sort that are most often utilized for motors. The major benefits of this machine are torque control and straightforward speed. Only railroads, factories, and mines are permitted to utilize the DC machine. For example, both trolleys and underground subway carriages employ DC motors. Previously, DC dynamos were incorporated into the creation of cars in order to recharge their batteries [2].A DC machine is a device for changing electromechanical energy. The magnetic field produces a torque that rotates the DC motor due to the magnetic force produced by an electric current passing through a coil inside of it. DC motors and DC generators are two subcategories of DC machinery. A DC generator's main function is to transform mechanical power directly to electrical power, whereas a DC motor converts DC energy to mechanical energy. The AC motor is often used in industrial applications to transform mechanical energy into electrical energy. A DC motor may still be utilized in applications that need great speed control as well as a broad speed range, like those used in electrical transaction systems.An electro-mechanical energy conversion system is known as a DC machine. There are two different kinds of DC machines: a DC motor and a DC generator.

A DC motor transforms D.C. electrical power into mechanical power, while a DC generator converts mechanical power (T) into DC electrical power (EI). The AC motor is always used in industry to convert electrical energy into mechanical energy, while a DC motor is employed in applications where a broad range of speeds and effective speed control are necessary, such as in electric traction systems. DC motor and generator architecture is quite similar. The generator is used in a very safe manner. Consequently, there is the open construction style. However, since the motor is utilized in an environment where it is exposed too dust and moisture, it needs enclosures that are, for example, dustproof, fireproof, etc., as needed. Despite being a significant source of DC electricity, the battery has a limited capacity to run any devices. Large amounts of DC electricity are necessary for various applications like electroplating, electrolysis, etc. As a result, DC generators are employed to provide electricity in these locations.

Basic Structure of Electrical Machines

The Stator and Rotor are the two primary components of a rotating electrical or DC machine (Figure 5.1). An air gap separates the stator and rotor between them. The machine's fixed outer frame is known as the stator. The internal component of the machine is the rotor, which is free to rotate. Ferromagnetic materials are used to create the stator and indeed the rotor. Both the outer and inner peripheries of the rotor and stator have slots carved into them. In the slots of a stator or rotor, conductors are inserted. Windings are created by connecting them together. The Armature windings are the windings in which voltage gets induced. The Field windings are the windings that a current is carried through to create the primary flux in below Figure. Permanent magnets are also employed in certain machines to provide the primary flux.

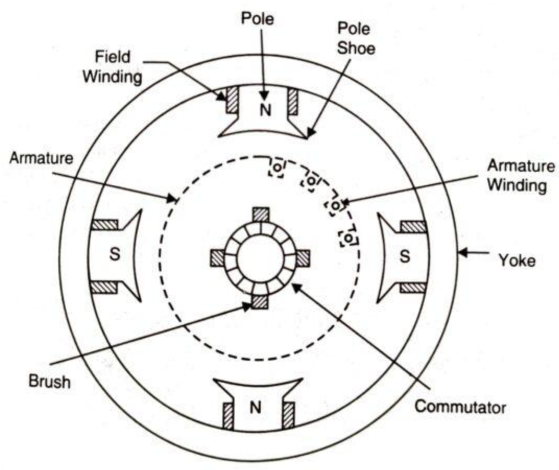

Figure 5.1Structure of Electrical Machines

<u>Faraday's Laws of Electromagnetic Induction</u>

An EMF develops within a conductor whenever the flux of a magnetic field is interrupted. The induced EMF enables current to be flowing in the circuit if somehow the conductor's connected to both ends are connected to an external circuit.

5.3 Construction of DC Machine

The primary components that may be employed in the construction of the DC machine include the yoke, pole core as well as pole shoes, pole coil as well as field coil, armature cores, armature winding alternate conductor, commutator, brushing, and bearings. Figure shows the details some of the components of the DC machine (Figure 5.2).

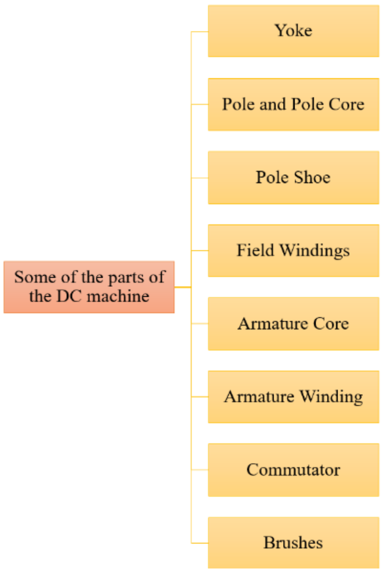

Figure 5.2 Parts of DC machine

Yoke/body

The yoke's main function throughout the machine is to protect the whole structure from moisture, debris, etc. and to mechanically support the poles. The yoke is made out of cast iron, steel plate, or rolled steel. The body is the container for all the other components; it serves as their exterior covering. Two end covers that also hold the bearings needed to enable the spinning of the rotor as well as the shaft will be used to seal this at both ends. A spinning conductor arrangement is chosen for D.C. machines even though a relative movement between both the field as well as the conductor would be sufficient for the formation of an emf in a conductor. As a result, the magnetic system's poles and yoke are supported by the shell or frame. The shell often functions as a component of the magnetic circuit altogether. The frame and yoke are made of cast steel since the flux does not change in these components. These are constructed in massive machines by properly welding the various sections together. They refer to them as "manufactured frames." Fabrication as opposed to casting prevents the need of costly patterns. These might be constructed in tiny special machines from a stack of laminations that have been properly glued together to make a solid structure.

Poles and Core

The DC machine's pole seems to be an electromagnet, as well as the rotor windings is wrapped between the poles. Every time the field winding is turned on, the pole produces magnetic flux. The materials used for this include pole core, steel plate, and cast iron. It might be built utilizing annealed steel reinforcement bars to reduce the power loss brought on by eddy currents.

Shoe Pole

The pole shoe, which further increases the area of the pole, is a crucial part of the DC machine. This region enables both the redistribution of flux within the air-gap and the movement of extra flux across the air space in the orientation of the armature. Pole shoes are made from cast iron or cast steel. Furthermore, annealed steel laminating is utilized to reduce the loss of energy brought on by eddy currents.

Field Windings

This is referred to as an armature winding and has damaged windings close to the pole core. The poles produce the required flux electromagnetically whenever current is delivered through a field winding. Fields windings' main component is copper. Contrary to permanent magnet stimulated machines, wound field machines have their field winding throughout the form of a concentric coil looped around the primary poles. These create the machine's primary field and transport the excitation current. The poles are thus produced electromagnetically. Usually, two different kinds of windings are used. A high number of rotations of copper conductor with a tiny section are utilized in shunt winding. Such winding would have resistance that was orders of magnitude greater than armature winding. A few turns of a conductor with a large cross section are needed when series winding is being employed. Such windings have low resistance that is equivalent to armature resistance. Both windings may be located on the poles in certain devices. The magnetic circuit calculations are used to determine the total ampere turns needed to provide the requisite flux beneath the poles. Since the poles are constructed in pairs, the total mmf needed is split evenly between the north and south poles. The amount of mmf that must be distributed between the series and shunt windings is determined by the design specifications. These have the shape of concentric coils because they operate within the same magnetic system. Usually, Mmf "per pole" is used in these computations.

Armature Core

There are a ton of slots along the armature core's edge. The armature conductor is stored in these holes. Again for flux created by field winding, it provides a low-resistance route. In this cores, low-reluctance, permeability-improving materials including cast iron are used. The use of laminating reduces eddy current loss. Steel structures in the shape of cylinders make form the armature (rotor). It cannot be made of solid steel, however, since the eddy induced hysteresis losses may be too great and harm the insulation of the armature windings in Figure 5.3. Fabricating an armature core out of insulated laminated steel laminations helps reduce eddy current losses. To create the geometry of the armature slots and teeth, 0.35 mm thick silicon metal sheets were punched. The sheets are then insulated with both sides and joined to create the armature core. By modifying the quantity of silicon throughout the steel to ensure that the alloy's hysteresis loop area is maintained as small as feasible, hysteresis loss may be decreased.

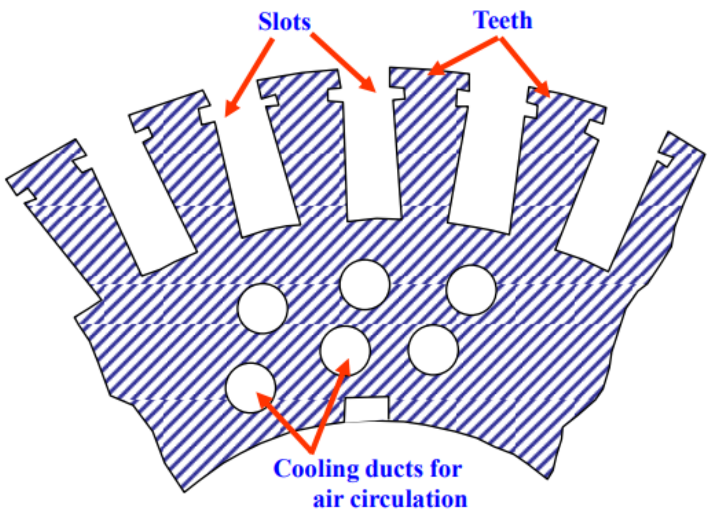

Figure 5.3 Construction of armature core

Armature Winding

To make the armature winding, the armature conductor may very well be linked. A magnetic flux as well as voltage is induced within an armature winding that whenever a primary mover twists the winding. This winding is linked to an outside circuits. To create this winding, conducting elements like copper are used. Armature windings are constructed using pre-wound coils in the manner seen in the image. The armature is coiled in two layers to prevent end connections with uneven shapes. In order to achieve voltage summation around the coil, coil pitch needs to be as close as feasible to pole pitch in Figure. On the other hand, the coils are linked in series while preserving that their voltages are the same in order sense to achieve a fair value of collected voltage. This is accomplished using two alternate winding techniques, namely the lap and wave kinds. Two conductors are joined together at one end of a turn by an end connector. A coil is created by stringing together multiple turns. By stringing up numerous coils, a winding is created (Figure 5.4).

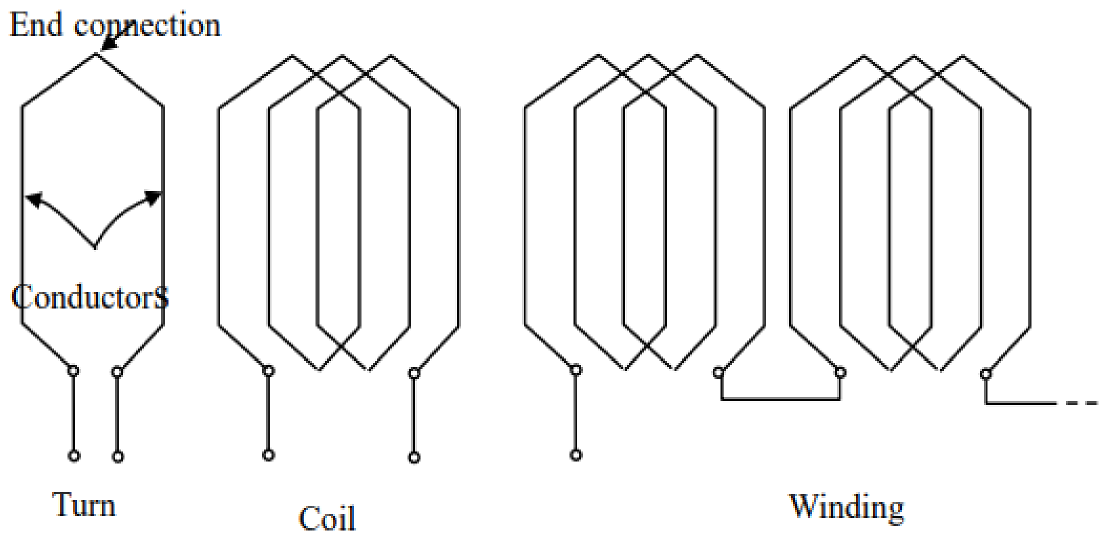

Figure 5.4 Construction of armature winding

In a drum winding, slots carved out on the armature contain the forward and return conductors (or drum). There is induced emf in both conductors. To put it another way, the complete flux of the pole is connected to a turn that induces a considerably higher voltage in the same. The rotor has a larger surface available for transporting the flux and is mechanically durable. The presence of a rotor bore is not required. Smaller rotor diameters are used. Drum windings eliminate the mechanical issues that arose with ring winding. One conductor (single turn coils) or multiple conductors in series might be used to make the coils (multi turn coils). A closed winding is created by connecting each of these coils in turn. Due to the fact that the coil's two sides are beneath two poles, one north and one south, the induced emf within them is always additive. The sum of an emfs would always be 0 even when the whole winding is closed. Thus, whenever the armature is not loaded, there is no circulating current. If the coil's two sides are left on the surface, centrifugal forces will cause them to fall away. To hold the conductors in place, slots are created in the surface, and they are then inserted into the slots and secured with steel wires. Two layers, a top layer as well as a bottom layer, separate each armature slot.

Double layer winding is the name given to the winding. The symmetry consideration has led directly to this. Pole pitch is the measurement along the armature's perimeter from any location beneath one pole to a comparable point under an adjacent pole. The return wire is housed throughout the bottom layer of a slot that is separated by roughly one pole pitch, while the forward conductor is stored in the top layer.

A portion of the commutator terminates the junction between two coils. As a result, there are exactly as many commutator segments that there are coils. There are two S layers within a double layer winding inside an S slot. A coil takes up two layers, meaning that there are S coils overall. These S coils' S connections are finished off with S commutator segments. The brushes are arranged such that even a maximum voltage is seen across them. When using drum winding, a multiplicity of windings are conceivable, in contrast to ring winding, where the numbers of parallel circuits is proportional to the amount of poles. The number of parallel pathways and brushes therefore varies greatly.

Commutator

The main responsibility of a DC machine's commentator is to collect current from the current-carrying conductors and send it through brushes to the load. Provides unidirectional torque for a DC motor as well. A significant number of segments might be placed in the form of a hard drawing copper's edge to create the commutator. The segments of the commutator are protected by a thin mica coating.

A cylinder-shaped piece of hard drawn copper that rotates with the shaft makes up the commutator. This is accomplished for small machines by putting the segments on even a Bakelite ring that is attached to the shaft. Adhesives are used to secure the segments to the Bakelite ring and isolate them from one another. The commutator is put together for machines with high ratings using segments that have the same form as the illustration. The segments are inserted into two guides as seen in the Figure 5.5, and mica paper is used to insulate them from one another and from the guides.

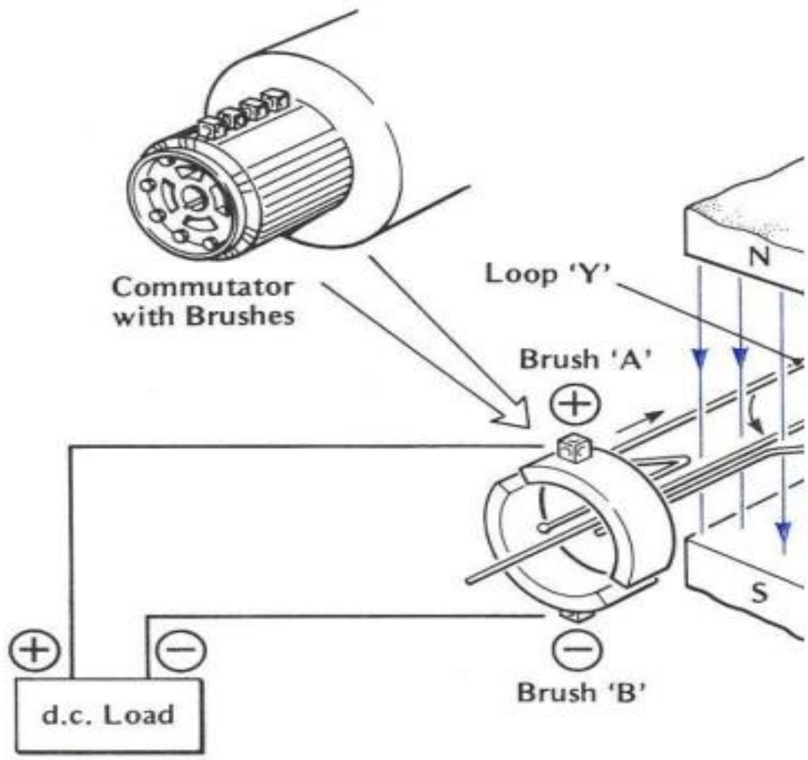

Figure 5.5 Construction of commutator

Brushes

Brushes on the DC machine draw current whether from commutator and deliver it to an externally applied. In order to prevent brush deterioration, examine them often. Brushes are made of graphite or rectangular carbon. Brushes are designed to draw electricity from or direct it into the armature. To guarantee a long service life, they are comprised of highly hardened graphite. Typically, brushes that are installed in brush boxes (holders) are forced onto the commutator segments by such a spring. The brush holder was isolated from and fastened to the machine frame. Figure below depicts the brush holder's specifics, as shown in Figure 5.6.

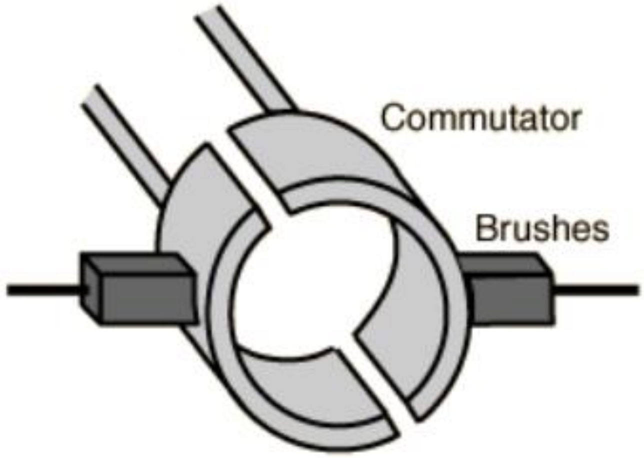

Figure 5.6 Construction of brushes

Bearings

Ball bearings are used on both ends of small devices. Roller bearings are employed, particularly at the drive end, in bigger equipment. On the shaft, the bearings are press-fitted into place. It is not required to remove the bearings from the shaft during disassembly since they are located within the end shield. The bearings must always be maintained in a sealed housing with the proper lubrication to keep out dust and other extraneous objects. In some circumstances, bearings like as thrust, roller, pedestal, etc. are employed. It is important to watch out for bearing currents and axial stresses on the shaft, both of which may damage the bearings.

Other mechanical components

Other crucial mechanical components are shaft bearings, end caps, and fan bearings. End coverings are either entirely solid or include ventilation openings. They help to sustain the shaft-mounted bearings. It is important to guarantee proper machining for simple assembly. There are internal and exterior fans. Most machines have a fan that draws air from the commutator end and expels it at the non-commutator end. A sufficient amount of hot air evacuation must be achieved.

CHAPTER 6

Principles of D.C. Machines

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Basic principles Electric machines can be broadly classified into electrostatic machines and electromagnetic machines. The electrostatic principles do not yield practical machines for commercial electric power generation. The present day machines are based on the electro-magnetic principles. Though one sees a variety of electrical machines in the market, the basic underlying principles of all these are the same. To understand, design and use these machines the following laws must be studied.The basic laws of electrical circuits focus on the basic circuit parameters of voltage, current, power, and resistance. These laws define how each circuit parameter is interrelated. These laws were discovered by Georg Ohm and Gustav Kirchhoff, and are known as Ohm's law and Kirchhoff's laws.

Ohm's Law

The relationship between voltage, current, and resistance in such a circuit is known as Ohm's law. It is the most typical (and straightforward) formula used in electronics. There are various accepted methods to express Ohm's law. All of them are widely utilized. (I=V/R) The voltage applied across a resistance determines the amount of current flowing through it. Voltage (V=IR) is defined as the product of the current flowing through such a resistor and its resistance. Resistance (R=V/I) is determined by dividing the voltage across a resistor by the current passing through it. So because power draw of a circuit is proportional to the current flowing through this one, multiplied either by voltage (P=IV), Ohm's law is also helpful in estimating the amount of power a circuit consumes. As provided as two of a variables and Ohm's law were known for the circuit, Ohm's law may be used to calculate the power draw of a circuit. Using the power connection and Ohm's law, one simple use is to calculate how so much power is lost as heat in some kind of a component. With the use of this knowledge, you may choose the ideal component for a certain application in terms of size and power rating.

Kirchhoff's Circuit Laws

Ohm's law is included into a full system by Kirchhoff's circuit laws. Energy conservation is a fundamental premise that Kirchhoff's Current Law upholds. It declares that the total amount of current flowing into and out of a node (or point) on a circuit must equal one another. A power source and resistive circuit with numerous parallel resistors serve as a straightforward illustration of Kirchhoff's Current Law. Every single of the resistors are connected to the power source at one of the circuit's nodes. Current is generated at this node by the power supply, which distributes it among the resistors before flowing out of the node and entering the resistors. Kirchhoff's Voltage Law likewise adheres to the idea of energy conservation. It specifies that the total voltage in a circuit's full loop should be zero. Continuing the previous example of a power supply with numerous resistors connected in parallel, each individual loop of the power supply, a resistor, but also ground experiences the same voltage crossing the resistor because there is only single resistive element. The voltage between each resistor in a series-connected loop is split in accordance with the Ohms law relationship.

Laws of the Magnetic Circuit

It claimed that it is simple to alter the regulations guiding the continuous flow of electricity in some kind of a circuit. In order to instantly apply to the magnetic circuit. Thus,

Magnetomotive Motive Force = Flux x Reluctance

$$F = \Phi \times S$$

Corresponding exactly to Electromotive Force = Current x Resistance

$$\text{Reluctance} = (\text{length/area}) \times (1/\text{Permeability})$$

$$= l/A\mu$$

For a magnetic of uniform sectional area corresponding exactly to

$$\text{Resistance} = (\text{length/area}) \times (1/\text{conductivity})$$

D.C. machines have electromechanical energy converters that provide mechanical power or transform mechanical power into a form that may be used by a D.C. source. These devices may be roughly divided into two groups based on the magnetic composition of their components. Those are,

Homopolar Machines

Homopolar power plants although the magnetic poles are found in pairs, the conductors of a homopolar generator are set up such that they only ever move in one direction. They might utilize either the North or South Poles for this. The conductor is referred to as a homopolar generator because it always encounters magnetic flux with the same polarity. It is decided to use a cylindrically symmetric geometry. One slip-ring may be placed at either end of the conductor to position it on the rotor's surface. Below mention figure 6.1depicts a simple arrangement with a single cylindrical conductor and ring brushes at either end. A field is created by the excitation coil and enters into inner member from the outside along the perimeter. Thus, the conductor only perceives one pole of polarity or one direction of flux. At any rotational speed, a constant voltage is now visible across the brushes. Reversing either that the excitation or the rotational direction, but not both, may change the polarity of the produced voltage. Such devices can provide currents with extremely big amplitudes even if the voltage induced would be remarkably modest. These sources are used in a variety of systems, including plasma rockets, liquid metal pumps, and pulse-current and MHD generators. A permanent magnet in the form of a ring that has been radially magnetized may likewise be used to create the constant field. One must connect more wires in series if greater voltages are necessary. It is necessary to do this series connection outside. On the rotating construction, a number of conductors must be placed, each one linked to a pair with slip rings. This alteration, however, adds parasitic air gaps and complicates the mechanical structure significantly. Given that the field flux density is 1 Tesla across the air gap and the conductor is 10 cm long and maintained on a rotor that is moving at 3000 rpm, the magnitude of the induced EMF has been given by.

$$\mathbf{e = BLv}$$

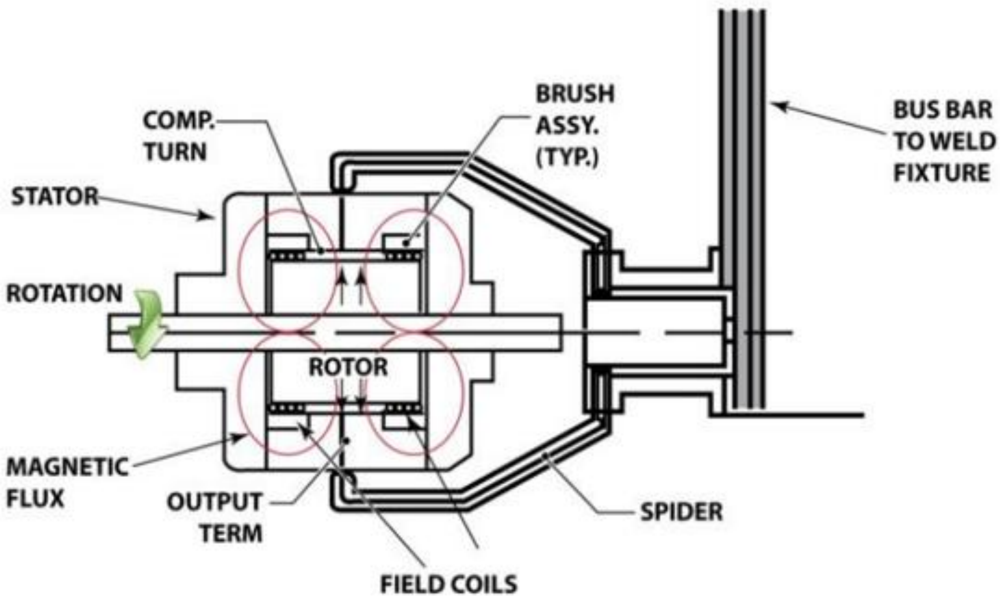

Figure 6.1 Construction of homopolar machine

At this level, the voltage dips at the brushes grow significantly, decreasing the power conversion efficiency conversion. Although homopolar machines technically qualify as D.C. generators since they produce constant voltages, they are not very practical for everyday usage. The hetero-polar machine family of D.C. devices include more useful converters. It is sad that the applications described above and many more that need to be investigated are not progressing because homopolar pulsed power systems have not made the transition toward the commercial sector owing to their high cost. The design of a low-cost HPG system that makes use of advances in rotating equipment technology over the last 30 years that have made the machine now economically viable. Some of the topics that will be covered include the utilization of commercial electrical brush mechanisms in preference to of special purpose brushes, ceramic rolling element bearings throughout place of hydrostatic bearings, variable speed low air resistance induction motors throughout place of high pressure hydraulic motors, the elimination of highly pressurized hydraulic auxiliary systems entirely, and the use of specialized bus bars with cross sections to react forces.

Hetero-polar D.C. generators

A conductor's generated EMF undergoes a cyclic shift in voltage as it passes alternately beneath the north and south poles of a hetero-polar generator. Thus, the induced EMF throughout the conductor is indeed not constant but varies in strength. The induced EMF is exactly proportional towards the flux density it is travelling through for a fixed sweep speed. A sine wave voltage results from a sinusoidal fluctuation in flux density in space. The AC generators use this theory. In the situation of DC generators, our goal is to achieve a constant DC voltage somewhere at terminals of a winding, to just not change the conductors' EMF form. This is accomplished by combining a commutator, an external component, with the winding. The induced emf is exactly proportional towards the flux density it is travelling through at a fixed sweep speed. A sine wave voltage results from a sinusoidal fluctuation in flux density in space. The a.c. generators use this theory. In the situation of DC generators, our goal is to achieve a constant DC voltage at the winding's terminals rather than to control the conductors' emf distribution. This is accomplished by combining a commutator, an external component, with the winding. A simple two-pole heteropolar machine with one coil of armature. The coil's ends are attached to a split ring that functions as a commutator. The connection to the brush is switched when the induced voltages' polarity changes, resulting in a voltage at the brushes that has a unidirectional polarity. The utilization of commutators in contemporary machinery further develops this concept. On the commutator are the brushes. The single point of connection to a winding is the commutator. The concept of a commutator is brilliant. The value of the this induced emf is indeed a constant at any point of the conductor since the field is fixed, even if the instantaneous value fluctuates depending on the flux density within which it is traveling in each conductor. The total of a group of coils is constant in a similar way. The commutator was created as a result of this idea. No matter where the rotor is really positioned, the coils connecting the two brushes must always be "similarly located" in relation to the poles. This is referred to as the symmetry condition. A winding may be used as the armature winding of a D.C. machine if it meets this requirement. One such example is Gramm's ring winding. Since a ring winding makes the operation of the D.C. machine simple to understand, it is used here as an example.

Torque Production

The armature conductors convey currents whenever the armature is loaded. These conductors that transport current engage with the field and feel its influence. This force is acting against their intended outcome, which in this instance seems to be the relative movement of the conductors and indeed the field. Therefore, the motion is immediately opposed by the force. As a result, it takes in mechanical energy. The converted electrical power is indeed a manifestation of the absorbed mechanical power. When an armature delivers a current of Ia towards the load at such an induced emf of E, EIa Watts of electrical power are produced. The ability to compare electrical and mechanical power,

$$2\pi n T = E I_a$$

Where T is the torque in Nm.

Motoring operation of a D.C. machine

The D.C. machine is designed to operate from a D.C. source and consume electrical power throughout the driving operation. It transforms this power into mechanical form. Therefore, it is briefly explored. A current flows into the armature winding of a DC machine if it’s at-rest armature is coupled to a DC source. If the field has been excited, the armature feels a torque and these current-carrying conductors encounter a force in accordance with the law of interactions stated above. The armature would begin spinning in the force's direction if the restraint torque could be ignored. Now that the conductors are moving there under field and cutting the magnetic flow, they are experiencing an induced emf. The induced emf's polarity is such that it opposes the current's cause, which in this instance seems to be the applied voltage. As a result, a "back emf" develops and attempts to lower the current. The machine behaves as a drain for the electrical energy that the source gives since the current and induced emf operate in opposite directions. This electrical energy is transformed into mechanical energy. Thus, depending on the operating circumstance, the same electrical equipment functions as an electrical power generator or an electrical power absorber. The absorbed energy is transformed into mechanical or electrical power.

Dummy coils and dummy commutator segments

A practical challenge occurs because lap and wave windings limit the options for the number of slots and commutator segments. The certain number of slots and commutator segments could be necessary for each machine with a specific pole number, voltage, and power ratings in order to build it properly. This allows for the customization of each machine to a particular standard. For this, a variety of armature and commutator diameters will need to be stocked and handled. Sometimes one is obliged to construct the winding in an armature that is easily accessible in stock owing to the lack of a sufficient slot number or commutator. Such designs plainly break the symmetry rules since the commutator section and armature slots could not line up. If one is OK with approximations, the designer may finish the design without the excess coil or surplus commutator section. This is referred to as using a "dummy." The armature slots have been filled with all of the coils. The excess coil is taped but also electrically isolated. It acts as a mechanical counterbalance to centrifugal forces. Similar to this, two neighboring commutator segments that are excess are joined together and considered as a single segment. Dummy coils and dummy commutator strands are what these are. As was previously noted, this strategy must be avoided as much as possible by choosing appropriate slot numbers and commutator. In machines with a lower rating and fewer poles, a little asymmetric winding could be acceptable.

Types of DC machine

In a DC machine, current-carrying field coils create the magnetic flux. Excitation is the process of creating magnetic flux within the apparatus by moving current through the field coil. In a DC machine, there are two different forms of excitation. Separate self-excitation from excitation. In self-excitation, the machinery itself provides the current flowing through into the field winding, while in separate excitation, a different D.C. source energizes the field coils [7]. Separately excited DC machines, Shunt wound or shunt machines, Series wound or series machines, as well as Compound wound or compound machines are the four main kinds of D.C. machines.

Separately Excited DC Motor

These devices also have stators and rotors, much as ordinary motors. The term "stator" designates the component's static portion, which houses the field windings. The revolving armature, known as the rotor, is made up of armature coils termed windings. A DC motor that is stimulated independently has some field coils that resemble those of the shunt-wound kind. The name clearly identifies the design of this kind of motor. The armature coil as well as the field coil are often both driven from a centralized repository in other DC motors. There is no need for a distinct excitation in the field of them. A separate supply is applied to excite both of the armature coil as well as the field coil in some kind of a separately excited DC motor, although. These motors have a stator as well as a rotor, much as conventional DC motors. The stator, which constitutes the motor's static component, is made up of a field windings. The rotating armature, or rotor, in contrast hand, is composed of armature windings called coils. An independently stimulated dc motor's field coils are similar to a shunt wound dc motors. The name makes a reference to the design of this kind of engine. Separately excited DC motors are offered by a wide range of Suppliers and Organizations, as well as different producers and sellers. There are also a number of Separately Excited DC Motors for Sale around Liquid. On the Liquid platform, there exists a comprehensive list of individually excited DC motor services that includes all OEM fleets. Learn more about how you can connect with a variety of service providers that consistently provide high-quality goods by contacting Separately Excited DC Motor Experts throughout Liquid.

In the case of a DC motor that is activated individually, the armature and field windings each get their own separate main supply. Because the field winding is supplied by a separate external DC source from either the torque equations of motors, the armature current somehow doesn't travel through the field windings within those types of DC motors,

$$T_g = K_a \emptyset I_a$$

Because of this, the torque in this situation may be altered without regard to the armature's current by altering the field flux (). (Ia). Figure 6.2 shows the independently stimulated DC motor.

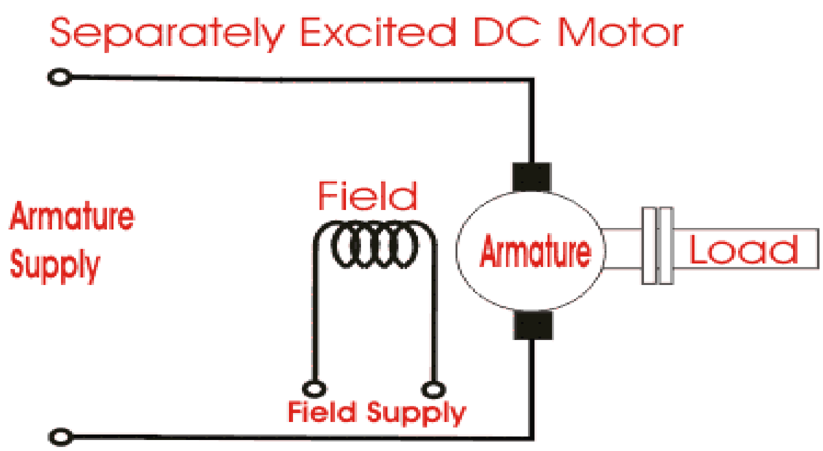

Figure 6.2 Separately excited DC motor

Working Principle of a Separately Excited DC Motor

The following illustration shows a schematic cross-section of a two-pole DC motor that includes the cylindrical rotor, designated armature A, and the fixed stator, designated S. The remainder of the stator is laminated only in large machines, whenever the device is required to perform with quickly widely different torque and speed or when a stationary power converter with significantly distorted the voltages and currents is used as the power source. This is done to reduce the iron waste materials caused by that of the varying magnetic flux.

The primary flux, or field current, passes through the rotor and stator when the basic magnets (M and P) are linked to the field windings. The brushes supply the closed armature coil, which is connected with the commutator bars and placed throughout the axial slots of the rotor; the commutator creates the armature current goal. In order to provide the greatest output torque for such armature current, this creates a dispersed ampere-turn (MMF) wave that is stationary in space and rotates orthogonally to the fundamental axis in the direction of the quadrature axis. The resultant armature flux in the situation of the large distance throughout the quadrature orientation is much lower than the initial flux. By placing compensatory coils in the axial slots on the pole shoes and connecting them in series with the armature, it may be reduced even further. The armature's quadrature fields is stopped by each opposing ampere-turn, which also prevents the undesirable armature response that would otherwise seek to skew the distribution of the primary flux evenly beneath the poles throughout the rotor's circle (Figure 6.3).

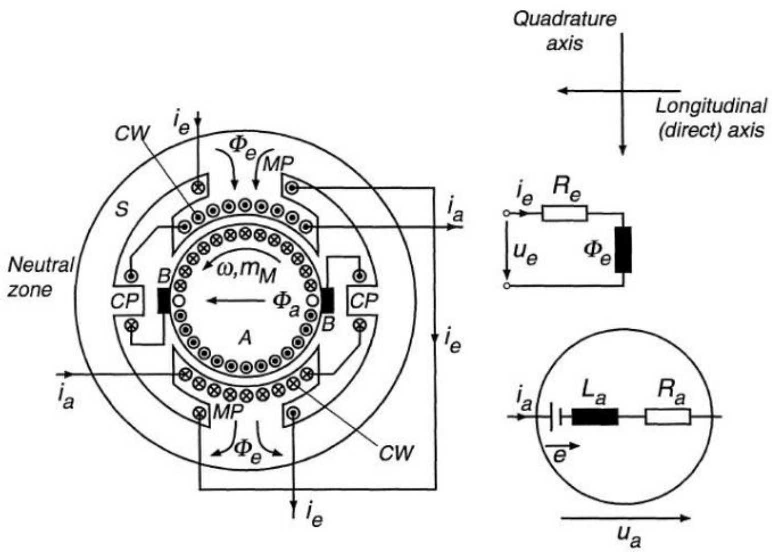

Figure 6.3 Working Principle of a Separately Excited DC Motor

Only on large machines or converter-fed equipment for use in heavy-duty applications like steel mills or traction motors are compensating coils prevalent. DC motors with compensation may withstand greater overloads than uncompensated versions. Greater current harmonics are permitted without negatively affecting the commutation, such as sparking of brushes, as well as the armature current might grow much more quickly. If the motor is backed by a static converter, this is too crucial. The primary function of the commutating poles (C and P), which are situated between both the main poles and also transport the armature current, is to locally change the field in the neutral location to provide quick and spark-free commutation. This is accomplished by briefly reducing the voltage of the brushes throughout the armature coil to a suitable level.

Shunt Machine

The DC shunt motor's armature winding is made to carry more current, while the field winding was wound with numerous turns to improve the flux linkage. This is accomplished because the torque is inversely proportional to the flux and armature current. Due to the fact that the field and armature windings are powered by the same DC source, DC shunt motors are self-excited types of motors. By enabling us to physically move electrical power, electric motors have provided us with almost all contemporary comforts. Our ability to build such marvels as cars, computers, and air conditioning, to mention a few, is entirely due to the range of electric motors that are readily accessible in industry. One of our earliest but most popular designs seems to be the DC motor, an electric engine that draws power from a DC source like a battery. This post will focus on one particular DC motor, called shunt DC motor. It may be difficult to immediately recognize this motor's special qualities, but this page seeks to draw attention to them and explain why designers would choose this type over others (Figure 6.4). This document explores the configuration, functionality, and features of shunt DC motors in the hopes that it would assist designers in making better educated decisions when installing the best machine for their application. Simply put, the shunt DC motor is a particular type of brushed DC motor, thus it will be helpful to first discuss the fundamental ideas that underlie all of these designs (a similar explanation is provided in our article on series wound DC motors throughout Figure).

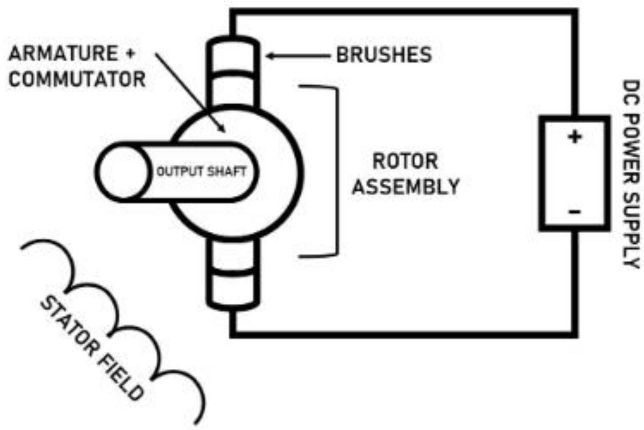

Figure 6.4 Block diagram of Shunt Machine

All DC motors have two basic components: the rotor, which rotates and is linked towards the DC power source, and the stator, which is the external housing that houses the stator field. A winding of wire or genuine permanent magnets may be used to create the stator field, and both options will maintain a magnetic field through into the rotor assembly. The output shaft, commutator, brushes, armature, and armature windings make up the rotor. The armature winding is indeed a coil of wire that winds from around engine crankshaft of the armature or across the metal grooves that serve as its guides. These armature windings come to an end somewhere at commutator rings, which also are mechanically isolated from the DC power supply (in other words, they "hover" over through the output shaft awaiting to be pushed by that of the brushes) and are mechanically connected to the output shaft. When the motor is started, the commutator rings as well as brushes come into contact and completed the circuit, allowing current to flow via the commutator rings, armature windings, and then brushes. Whenever this occurs, the permanent stator field was opposed by an electromagnetic field created in the armature. The interplay between these two fields creates rotation upon that output shaft, which leads to usable speed/torque because the rotor is free to revolve.

Specifications for Shunt DC Motors

Knowing the values to consider while picking a shunt DC motor is useful. In this post, typical requirements to watch out for will be briefly discussed.

Field/Armature Voltage

Due to the parallel wiring of the armature and field windings, each component has two different voltages applied to it (not across the whole circuit though; remember, they share the same power source). As a consequence, shunt DC motor specification sheets often provide two rated voltage with each coil, sometimes with ranges. A shunt motor, for instance, could have an armature voltage of 450 V with a maximum of 600 V and a fields potential of 220 V with a maximum of 500 V. Keep in mind that these numbers depend on the motor's design and frame size. Also keep in mind that a DC motor's performance will be decreased and it may overheat if it is ever used with a power supply that is lower than its rated voltage.

Speed & Base Power

Because these motors are thought of as constant speed, a base speed and corresponding power are often mentioned on the spec sheet (in HP or kW). Although shunt DC motors can control their speed even with a complete guide, these numbers demonstrate what the motor is capable of moving and how quickly it can move it (within safe tolerances).

Frame dimensions & size

NEMA has established standard frame sizes to make it easier for buyers to switch between motor sellers, although typically, the motor's dimensions will constantly be provided if it is not standardized. The frame size will allow the specified a general concept of how the motor will fit into any specific application and offer an approximate estimate of the motor's power (though size can be misleading with electric motors, so use caution). Brush Life because a shunt DC motor connects the power supply to the rotating armature using brushes, these brushes will inevitably wear out over time. For operators to keep track of how long brushes have been in use and when they should replace them, the majority of DC motors include a brush life (in hours). These motors must be kept up with by changing the brushes as needed; otherwise, they risk damage or inefficiency.

Applications and Requirements

Shunt DC motors, as opposed to series DC motors, perform better in consistent speed applications because of their feedback architecture. They are ideal for woodworking machinery, grinders, and any other rotating heavy equipment where a user would be pushing against rotation since they can maintain a precise RPM as well as torque even under fluctuating load situations. Due to their low starting torque, these motors must wait before being utilized at rated speed. As a result, they cannot be immediately attached to a high load. Because no electric motor operates under perfect circumstances and all endure losses, their speed also marginally drops when they are fully loaded.

Series Wound DC Motor

Living without electronic gadgets in the world nowadays seems impossible. Everything people utilize on a daily basis, including our cars, homes, as well as the wall outlets that provide us with electricity, wouldn't exist if not for these mostly helpful gadgets [16]. Because of advancements made in the 19th and later centuries, we are now able to use electricity to create useful mechanical motion for a variety of great jobs. In this article, we'll talk about DC motors, one of the most common types of electric motors, and how they still have uses for humans. We will focus on the series wound DC motor (sometimes referred to as the "series DC motor"), which is essentially identical to other DC motor types in terms of features but differs in several significant ways.

Working Principle of a Series Wound DC Motor

The construction and performance of the series wound DC motor are generally comparable to those of other brushed DC motor types. The rotor and stator, two essential components, combine magnetically and electrically to produce rotation on an output shaft. A simplified circuit design for DC motors is shown in Figure 6.5, and their primary construction is rather straightforward:

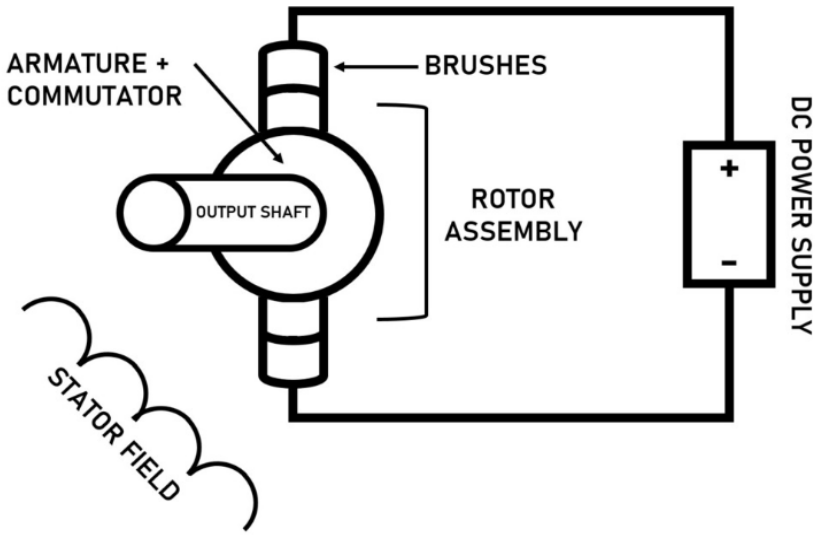

Figure 6.5 Represent the block diagram of series wound motor

This is also the schematic for a DC motor's fundamental circuit. The positioning of the stator in respect to the armature is intentionally left unclear in this figure. Consequently, the two main distinctions between different DC motors are its position and the power source. A permanent magnet or perhaps an electromagnet made of wire winding (referred to as a "field winding" in the figure) may provide the steady magnetic field that the stator field uses to operate on the complete rotor assembly. The revolving component that consists of the armature, stator windings rings, armature windings, as well as output shaft is known as the rotor, and it is powered by brushes that are connected to a DC power source. The primary shaft-encircling armature winding is housed inside metal laminations that make up the armature. This specific conductor coil is terminated there at commutator section after being wrapped over the armature windings. The armature functions as an electromagnet and produces its own magnetic field when powered by squeezing the brushes out on to the commutator section, exactly as the field winding does. The current flowing through the brushes, commutator loops, and armature coils when the operator applies the DC power source causes the armature's field to begin to resist the stator's fixed magnet field. When the rotor can only revolve in position, it "repels" itself magnetically from either the stator flux, yet this produces usable mechanical output upon that main shaft.

It is clear from this figure why these machines are referred regarded as "series wound" DC motors as their field coil is connected in series with both the armature winding and is driven by the DC power supply. This indicates that the field windings are powered by the same current that feeds the armature coils. The field winding must be able to withstand the whole armature current together with the current of the stator yet offer the least amount of resistance, thus it is wound with only a few turns of great copper wires to accomplish this. Shunt types, on the other hand, wire individual field coils into parallel arrangement with the armature, producing various effects. These devices were reversible if the leads of the field coils or even the rotor coils are switched, which may cause the device to reverse the rotational direction. Additionally, these devices are offered as universal brush motors and therefore can run on AC with a few small modifications.

Characteristics of Series Wound DC Motors

This document will quickly go over some of the fundamental parameters that consumers may use to choose the best series DC motor design. Note that this part only covers the primary values that are necessary to be aware of in the majority of applications; DC series devices offer more characteristics than what are described in this section.

Voltage (Rated (Nominal)

The DC power supply needed to run the motor is indicated by the rated voltage. This is the bare minimum that must be used, while a little higher figure is also feasible. Take care while reaching the nominal voltage since using a higher voltage may cause motor burnout or damage due to the high current inside the field coil.

Brush Life

The power supply throughout the armature coils is used by these devices via mechanical commutation; as a result, the carbon brushes that serve as the combining portions for this commutation eventually wear out and need to be changed on occasion. The operational life of the brushes is often provided by DC devices in terms of hours, and in order to avoid damage, it is crucial to keep a record of how long the brushes have been used for use.

Peak & Continuous Power

The output power delivered by the device is the power of a series wound DC motor, measured in kW or HP. A series wound DC motor's continuous power must be established for specific applications since the peak value should only be employed briefly, that often when starting a motor.

Speed Range

Once the output shaft of a series wound DC motor is unloaded, it will continue to accelerate until it obliterates itself. This is the most serious flaw in these systems and results from putting the field coil into series with the armature. Because of this, these devices should constantly be loaded and should never be employed without a load attached. Most specification documents include a safe/maximum RPM rate that won't damage these instruments, which should be taken into particular consideration when choosing a motor type.

Compound wound or compound machine

A shunt wound as well as a series wound DC motor are combined to produce a compound wound DC motor, which offers this same best of both worlds. The shunt wound DC motor does indeed have a higher starting torque than the DC series motor, but both have an incredibly effective variable speed capability. Basically, compound DC motors were constructed from a mix of shunt and series motors. They go by the name DC compound motors as well. The winding of an armature is linked towards both series and shunt field coils in this kind of motor. These field coils, which have been connected to the armature conductors, provide the appropriate level of magnetic flux and help to provide the torque required to facilitate the spinning of the armature at the proper speed level. With only a few turns with series winding at the top, the field is mostly wound as a shunt field. The purpose of this structural combination is to get the superior qualities of both of these kinds. A series motor provides a strong and high starting torque, whereas a shunt motor offers very effective speed control. As a result, a compound DC motor significantly compromises on these attributes. A self-excited motor that is composed of both series and shunt field coils linked to the armature winding is referred to as a compound wound DC motor (also referred as a DC compound motor). Combined field coils therefore provide necessary magnetic flux, which interacts with both the armature coil therefore produces the torque needed to enable rotation at the correct speed.

As one can see, a compound wound DC motor essentially results from the combination of a shunt wound DC motor and a series wound DC motor in order to attain the best of both of these kinds' characteristics. While a DC series motor has a large starting torque, a shunt wound DC motor offers an incredibly effective speed regulating feature.

Therefore, the compound wound DC motor achieves a balance between these two characteristics and has a nice mix of appropriate speed management and strong beginning torque. Although neither it's starting torque nor its speed control are as excellent as those of a shunt DC motor.

Types of Compound Wound DC Motor

On the basis of how the field winding connects to the armature winding, the compound wound DC motor may be further classified into two basic varieties, and they are:

Long Shunt Compound Wound DC Motor

As shown in Figure, the shunt field winding of a long-shunt compound wound DC motors is linked in parallel throughout the series combination of the armature and series field coil (Figure 6.6).

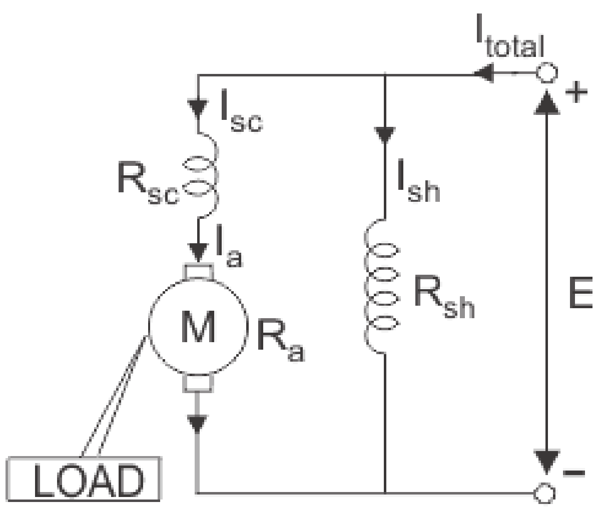

Figure 6.6Long shunt compound wound DC motor

Voltage and Current Equation of Long Shunt Compound Wound DC Motor

Let E and I total represent the total source current and voltage delivered to the motor's inverting input. The coefficients of the current flowing through into the armature resistance are Ia, Ise, and Ish. Resistance in series windings Resistance to shunt winding and Rse, respectively.

Now we know in shunt motor,

$$I_{total} = I_a + I_{sh}$$

And in series motor

$$I_a = I_{se}$$

Consequently, the current equation for a DC motor with compound winding is.

$$I_{total} = I_{se} + I_{sh}$$

And its voltage equation is,

$$E = E_b + I_a(R_a + R_{se})$$

Short Shunt Compound Wound DC Motor

The shunt field winding is merely linked in parallel throughout the armature winding in what seems like a short shunt compound wound DC motor. In addition, the series field coil is subjected to the whole supply current before ever being divided into shunt and armature field current, as shown in Figure 6.7.

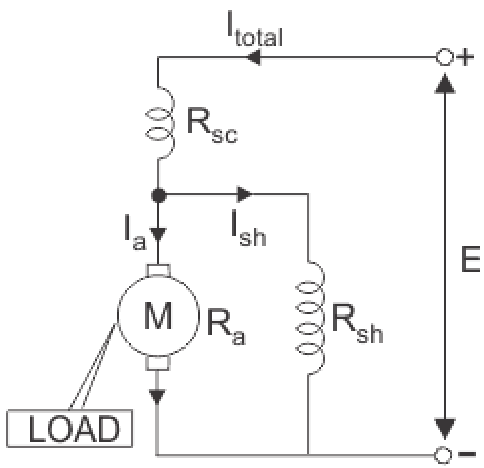

Figure 6.7 Short Shunt Compound Wound DC Motor

Cumulative Compounding of DC Motor

A compound wound DC motor is considered to be progressively compounded whenever the series winding's main field flux is aided or enhanced by the shunt winding's shunt field flux.

$$\emptyset_{total} = \emptyset_{series} + \emptyset_{shunt}$$

Types of Armature Winding

The armature winding is a crucial component of the spinning machine. By transforming mechanical power into electrical power and electrical energy onto mechanical energy in this winding, power may be conserved. Lap winding and wave winding are the two categories under which armature winding falls. In a DC machine, the armature is often wrapped using two approaches, which are sometimes referred to as forms of armature winding, including such Lap Winding and Wave Winding.

Lap Winding

The conductors are connected in this sort of winding and thus that their parallel poles and lanes are comparable. Every armature coil's final component may be linked to the commutator neighboring segment. The number of brushes throughout this winding is comparable to the number of parallel lanes, and in Figure 1 these brushes are equally divided into positive and negative polarity windings. Lap winding is mostly used in high current, reduced voltage machinery. The three categories of lap windings include the following. There are three types of lap winding: simplex, duplex, and triplex.

The formula yc = m, where m = 1, 2, 3, etc., yields the commutator pitch for the lap windings. The winding order is m, and yc seems to be the commutator pitch. Simple lap winding results from m = 1, duplex lap winding from m = 2, etc. yc = m results in an m-order multiplex lap winding. The indication relates to how the winding is supposed to develop. A "progressive" winding is one that moves forward, whereas a "retrogressive" winding moves backward. One coil, according to the configurations for progressive and retrogressive lap winding. A detailed image of a 12-slot basic lap winding for just a 4-pole armature. Additionally illustrated are the connections between the coils and the commutator segments. The conductors travel as illustrated from left to right, with the armature located below the poles. The brushes' location and polarity are also shown. Here, single-turn coils having yc = 1 are seen. The winding creates the same number of parallel pathways as there are poles. As a result, Z/2b becomes the number of conductors linked in series between the brushes. Consequently, the lap winding is a good choice for high current generators. The whole line current in such a symmetrical winding is shared by the parallel routes in Figure 12. An issue with circulating current arises as the number of parallel channels inside the armature winding increases. Because of the non-uniformities throughout the magnetic circuit, the induced emf's in the various routes often vary somewhat. With the machine's increased number of poles, this will rise. If this error is not fixed, circulating currents start to occur in these closed parallel channels. Under loaded circumstances, this circulating current overcharges the brushes and consumes energy while producing heat. The provision of equalization connections is one strategy often used in DC machines to mitigate this issue.

As the name implies, these connections find comparable potential sites along the several parallel lines and link them to make the potentials equal. Any potential difference produces a localized circulating current, bringing the voltages into balance. Additionally, the brushes are not loaded by the circulating current as it passes through them. The designer chooses the quantity of these equalization connections, the conductor's cross section, and other factors. With the aid of a 6-pole armature containing 150 commutator segments, an example of an equalization connection is presently given. Given that they are separated by one pole pair, the coils 1, 51, and 101 are all put beneath the poles of the same polarity. Like such, there are 50 groupings (Figure 6.8). The connections below are picked in order to keep the total number of links to 5 (let's say). Following that, the coils beneath the first pair of poles are 1, 11, 21, 31, and 41. These are joined to counterparts that are 50 and 100 degrees apart from one another to provide 5 equalizer connections. Between any two following links, a sequence of 10 coils is linked (Figure 6.9). The wave windings will then be inspected.

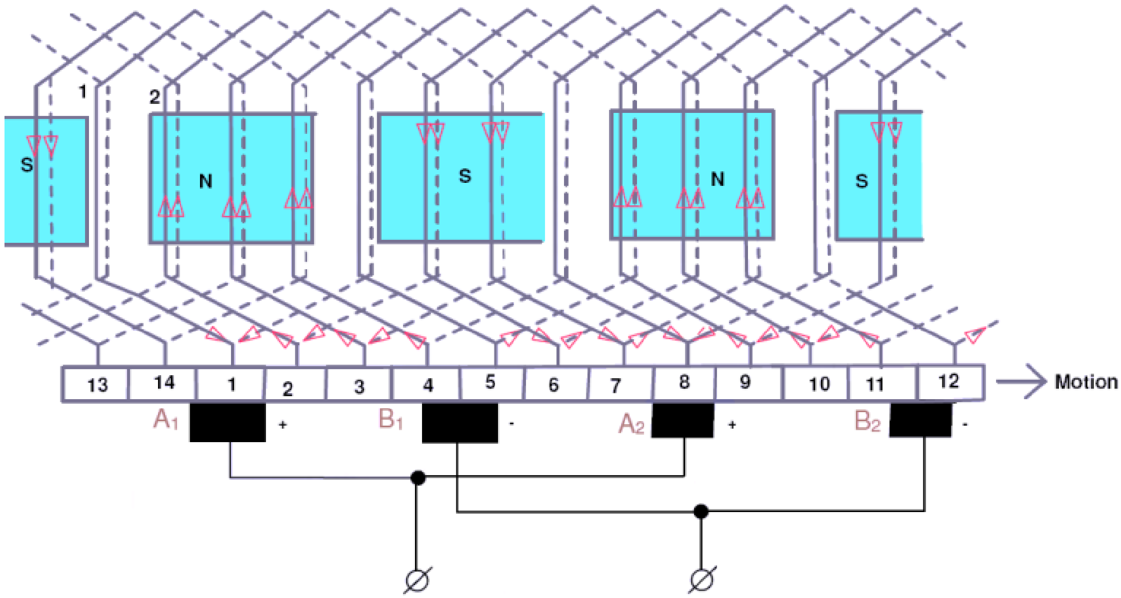

Figure 6.8 Illustrates the Developed view of a retrogressive Lap winding.

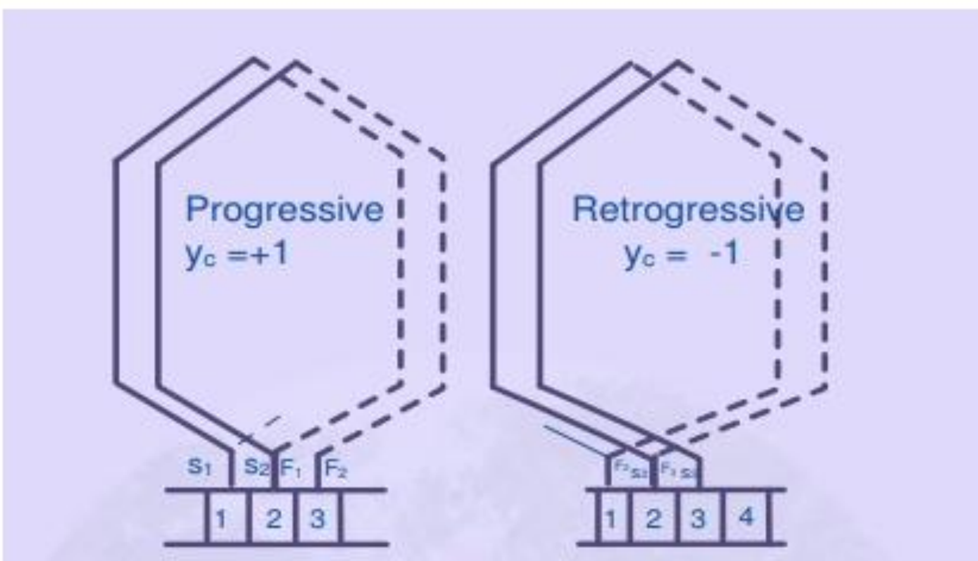

Figure 6.9 Illustrates the Lap Winding is one type of winding with two layers.

Simplex Type Lap

Winding the starting end of a secondary coil may be placed beneath a comparable pole to the beginning end of the first coil in this kind of winding, and the number of parallel lanes are equal to the number of poles of both the windings (Figure 6.10).

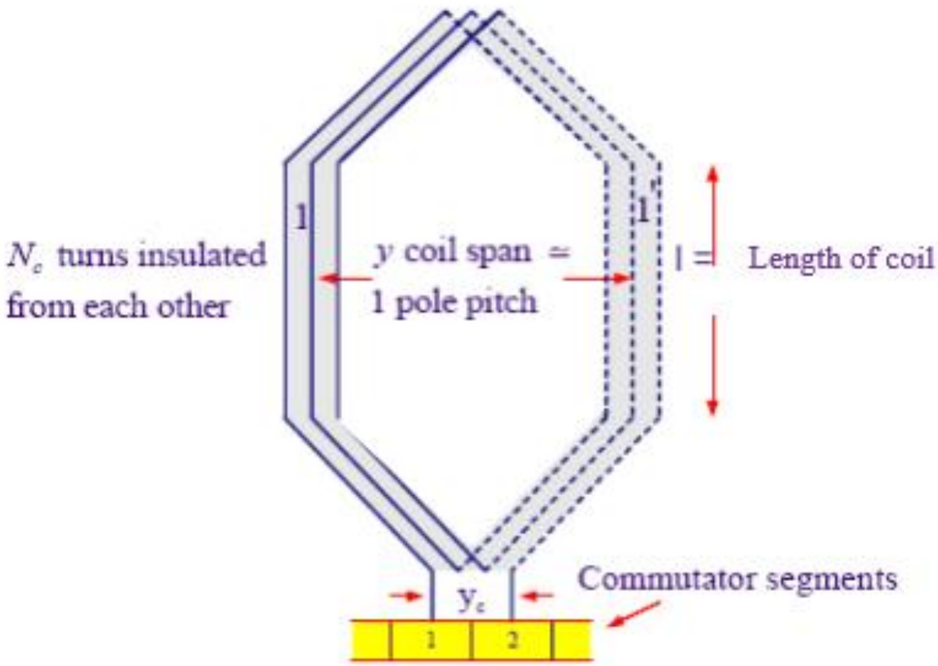

Figure 6.10 Shows the Simplex Type Lap

Duplex Type lap

Duplex Type lap the number of parallel lanes between the poles is twice the number of poles in this style of winding. Large current applications make up the majority of lap winding's applications. Such a winding is created by positioning two identical windings on an identical armature and connecting the even-numbered commutator bars to the main winding and the off-numbered commutator bars to the secondary winding.

Triplex type lap

Winding these windings of this sort of winding are connected to the bottom third of the commutator bars. Due to the many lanes and multiple lanes present, triplex type lap windings are often used in high current applications. The primary disadvantage of this winding is that it makes use of many conductors, raising the cost of the winding.

Waves winding

There are just two parallel lanes between the positive and negative brushes in this form of wave winding. The starting end of a second armature coil commutator segments is connected to the final end of the first armature coil at a fair distance. The conductors in this kind of winding correspond to the two parallel machine pole channels in Figure 2. The digit number brush is the same as the number of parallel ports. Machines that operate at low current and high voltage may use this kind of winding. When it completes one cycle, the armature winding falls into a slot to the left of where it started. Socially regressive windings is the term given to this kind of winding. Similar to this, progressive wrapping refers to when the eddy currents of an armature descend on one slot forward towards the right. Consider two winding layers and the requirement that perhaps the AB conductor be in the upper layer semi of a slot upon that right or left. Assume that the primary and back pitches are the YF and YB. These pitches' quantities are quite similar to the winding pole pitch. The winding average pitched is given by the following equation.

In wave windings, all of the coils that are simultaneously transporting emf in the same directions are gathered together and joined in series. As a result, there are merely two pathways between the brushes in a basic wave winding, with 50% of a total conductors within every path. The commutator pitch should be chosen as yc = C 1 p, where C is the total number of segments on the commutator, to perform a wave winding. C and p should appropriately meet this relation; yc must be an integer. Additionally, in this case, the positive sign denotes a progressive winding, whereas the negative sign results in a retrogressive winding. A multiplex wave winding with order m is produced using the equation yc = (C m)/p. a simple wave winding with slots on 4 poles. The diagram shows that after connecting p coils in series, the connection to the next (or prior) neighboring coil is made. Once all the coils were linked together in sequence, the winding automatically closes. The diagram shows where the brushes should be placed. As can be seen from the commutator pitch formula, there are only a limited number of commutator segments available for wave winding. Only one more or one less than a certain multiple of pole pairs may be used as the number of commutator segments. Simple wave windings are preferable in multi-polar machines with lower power levels because, regardless of the number of poles, there are always two parallel circuits per simple wave winding. Simple wave windings provide two parallel lines, as was previously described; duplex wave windings have 2*2=4; etc. One circuit has all of the coils that really are under all of the north poles, and the other circuit contains all of the coils that are under all of the south poles. Therefore, two brush sets were sufficient. Sometimes individuals may use brush sets that are equivalent to the number of poles. The amount of current that must be gathered by each brush set is decreased however the number of parallel circuits is not increased in this configuration. An example may be used to demonstrate this. It is decided to employ a 4-pole wave-connected winding having 21 commutator segments. $yc = (21-1)/2 = 10$. The outcome is a wave that is winding backward. The layout of the whole string of connections is seen below. The remaining neutral axis coils, such as coils 6, 11, and 16, are spaced apart by a pole pitch if coil number one is presumed to be located in the neutral axis.

The number of coils that fall under each circuit is reduced by almost half if the brushes are retained at commutator segments 1 and 6. The brushes' polarity alternates between positive and negative. Or, you might use any two nearby poles or two brushes at poles 11 and 16. Merely two parallel circuits may be created by connecting 1, 11, 6, and 16 and placing four brushes at positions 1, 6, and 11. But the brush currents have been cut in half. Due to the less amount of current that must be gathered by each brush when using this approach, a commutator may be used that is shorter in length and costs less. This brush configuration is shown in relation to a 21 slot, 4 pole machine. Similar to this, 2, 4, or 6 brush sets may well be utilized in a 6-pole winding. In comparison to a simplex winding, multiplex windings with order m contain m times as many circuits and, as a result, greater restrictions on the choice of slots, coil sides, commutator, and brushes. Because of this, windings beyond duplex are very rare while being theoretically conceivable. When it was necessary to double the number of simultaneous routes, the duplex windings were adopted (Figure 6.11).

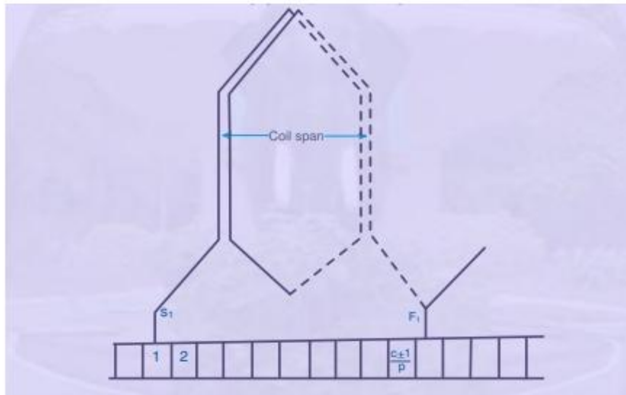

Figure 6.11 Shows the wave winding

The following equation provides the winding's standard pitch.

YA =YB + YF/2

If the whole no. of the conductor is ZA, then the normal pitch can be defined by the following equation:

YA =Z+2/p or YA =Z-2/p

The number of poles included in the aforementioned equation is indicated by the letter "P," and as it is always even, Z is always calculated as an even digit: Z = PYA 2. Therefore, both progressive windings and retrogressive windings are denoted by the marks + and -.

Applications of Lap and Wave Windings

A wave winding contains more conductors in series than a lap winding, which results in a larger terminal voltage. Because there are more parallel channels, a lap winding may carry more current than just a wave winding. In tiny machines, individual armature conductors' ability to transport current is not crucial, hence wave windings are utilized to generate the right voltages. Due to the abundance of armature conductors available in big machines, it is simple to get adequate voltages, as well as the current carrying capability is more important.

CHAPTER 7

Commutation in DC Machine

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A DC generator's armature, which is located in a revolving magnetic field, produces voltage that is alternating throughout nature. The process by which the produced alternating current inside the armature winding of the a DC machine is changed into direct current after passing through the commutator as well as the fixed brushes is known as commutation throughout DC machine, or more particularly commutation in DC generator.

Once more, commutation is used in DC motors to transform the input DC into an alternating form in the armature. The commutator segments as well as the brushes must always be in movement contact throughout this conversion of current from the spinning armature of a DC machine towards the stationary brushes. The coils located beneath one pole, let's say N pole, and spin here between positive brush as well as its subsequent negative brush as the armature begins to rotate. The current flowing through these coils is directed inward toward the commutator segments. The coil is then briefly short-circuited using a brush for something like a period of 1500 seconds. It's known as the commutation phase.

The armature coils revolve beneath the S pole and between the negative brush as well as its subsequent positive brush after this short-circuit duration. The direction is then switched to one that is away from commutator segments. Commutation procedure is the word used to describe this phenomenon of current reversal. The brush terminal supplies us with direct current. If somehow the commutation procedure, or the reversing of current, is finished by that of the conclusion of the short circuit time, or the commutation interval, the commutation is said to be perfect.

A DC generator's armature conductors were subjected to alternating currents. The Commutation process is used to switch from an administered direct current to an alternate current that was created. The generated current only travels in one direction when the armature's conductors are located beneath the North Pole. When they are below the South Pole, however, the current is flowing in the other way. If the current is reversed during the short circuit period, sparking will occur somewhere at brush contacts, the commutator surface will get damaged from overheating, as well as the machine will be referred to as being badly commutated.

Methods of Improving Commutation

There are three major ways to get sparkles or improve commute times. Resistance, voltage, and compensating winding are all components of commutation. As shown in Figure, Commutating poles or Interposes and Brushes Shifting are two more techniques utilized in voltage commutation to create the injected voltage (Figure 7.1).

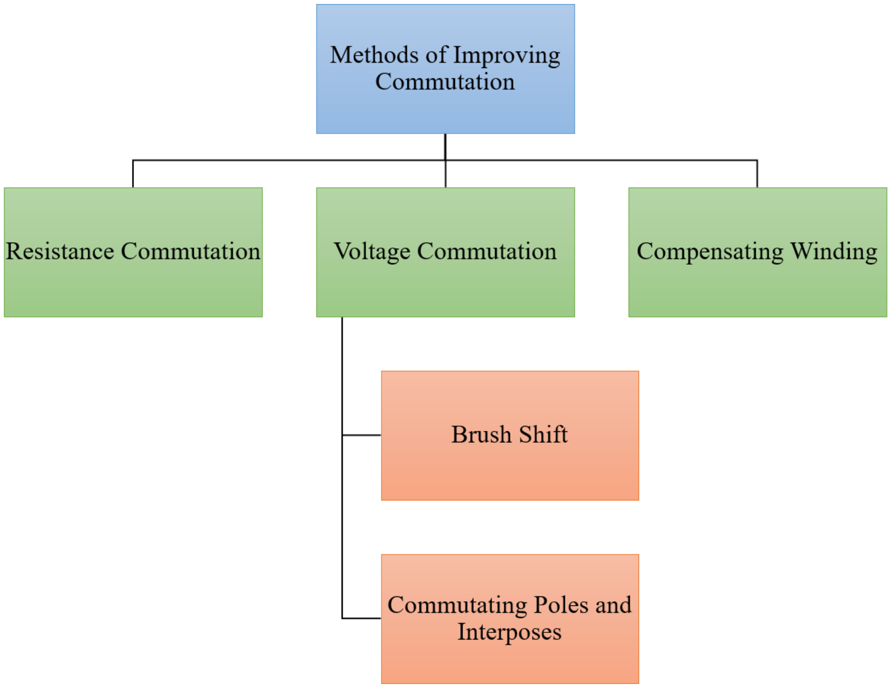

Figure 7.1 Methods to improve the commutation

Resistance Commutation

Carbon brushes are used in the Resistance Commutation technique to enhance commutation. The high contact resistance among both commutator segments and brushes is a result of the usage of carbon brushes. The propensity of this high contact impedance is to make the short circuited coil's current vary in response to the commutation requirement.

Voltage Commutation

The arrangement used in the voltage commutation technique is designed to create a voltage throughout the coil undergoing the commutation process, neutralizing the reactance voltage. The reactance voltage is opposed by the injected voltage. Sparkles Commutation will ensue from a fast reversing of current in the short-circuited coil if indeed the value of the injection voltage is set equal to the reactance potential.

The following are the two techniques utilized to generate the injected voltage in antagonism to the reactance voltage.

Brush Shift

Armature response causes the magnetic neutral axis (MNA) to move, with the generator's MNA moving in the rotational direction and the motor's MNA moving against it. A flux is created in the neutral zone by the armature current. The transformer coil induces a tiny voltage since it is decreasing the flux.

Commutating Poles

Interposes are short poles that are connected to the stator and are positioned between the main poles. Commutating poles and compiles are other names for interposes. Also because interposes must provide fluxes exactly proportional towards the armature current, the interposes secondary winding are linked in a series with the armature. The same armature current influences both the armature and then interposes MMFS simultaneously because the same time. As a result, a suitable interpose flux component cancels out the armature flux throughout the commutating zone, resulting in a tendency to alter the electromagnetic neutral axis. The neutral plane shifting and reactance potential must produce one voltage throughout the conductors conducting commutation, and then interposes must create a voltage opposite to that value.

When using a generator

The neutral plane moves in the rotational direction. As a result, the conductor undergoing commuting requires that then interposes polarity match that of the following main pole in the rotational direction. The interposes need to have the opposing flux, which corresponds to the flux of the primary pole in front according to the rotational direction in order to counteract this voltage.

In case of a motor

For a motor, the positive plane moves in the opposite direction of rotation, as well as the flux on the commutating conductors is identical to that of the main pole. Then interpose should be of the same polarity as the prior major pole in order to oppose this voltage. Inside the direction of rotation, and interpose as well as primary pole have opposing polarities (Figure 7.2).

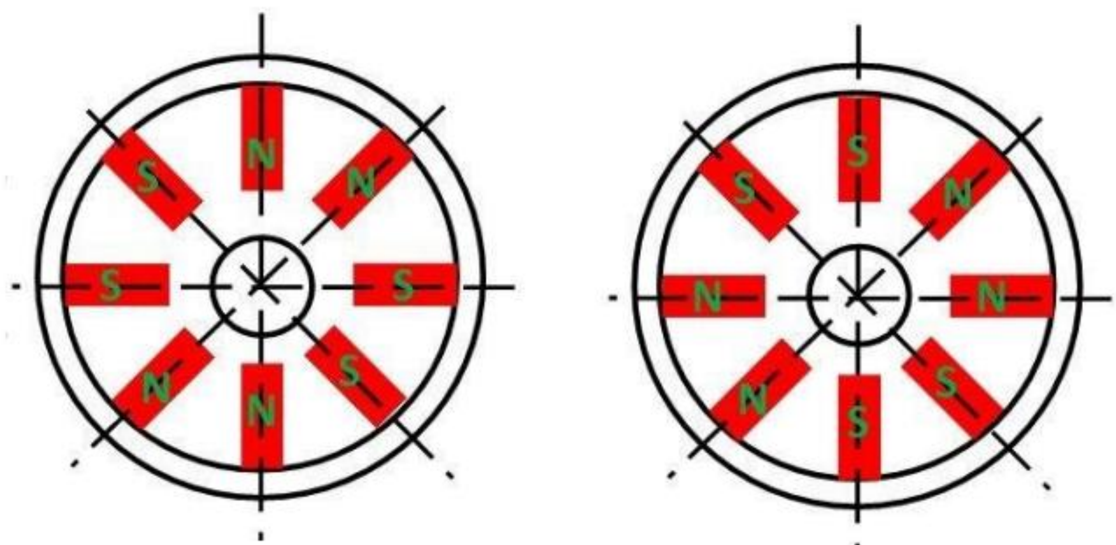

Figure 7. 2 Commutation in motor

Only enough flux is provided by the interpoles to ensure proper commutation. They are unable to eliminate the flux distortion brought on by the armature's cross-magnetizing MMF. The voltage between neighboring commutator segments may increase significantly during severe load variations or when loads are changing quickly. This enough ionizes the air surrounding the commutator to make it conductive. Brush to brush is formed as an arc. Flashover is the name given to this occurrence. The segments of the commutator will melt because of how hot this arc is. It has to be put out right away. Utilizing compensatory windings prevents flashover.

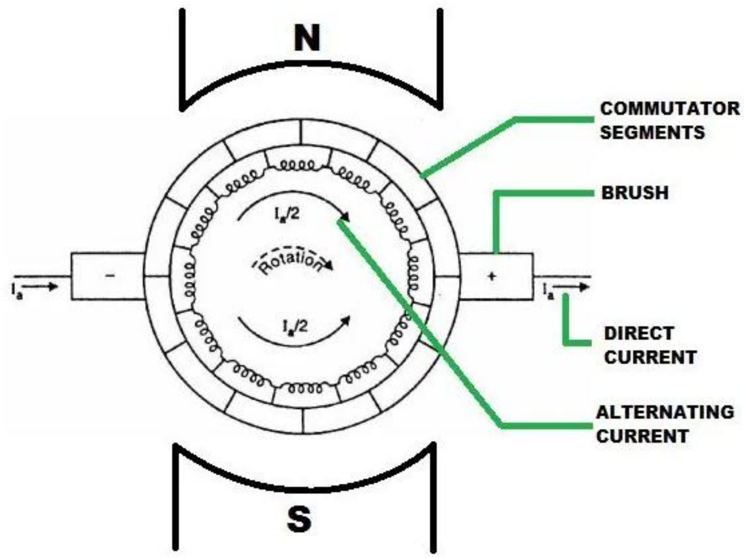

Figure 7.3 Compensatory windings prevents flashover

Commutation Process

Commutator, a gadget, aids in this process. To comprehend the commutation procedure in Figure, let's examine the operation of a DC motor. Electromagnetic induction is indeed the fundamental idea behind how a motor works. A conductor creates magnetic field lines all around it as current flows through it. Humans also know how magnetic flux lines go from a magnetic somewhere at North Pole to a magnet at the South Pole whenever a magnetic north as well as magnetic south face one another. These magnetic lines of attraction are blocked when a conductor with an externally applied magnetic field surrounding it is put in their path. Thus, dependent on the direction of a conductor's current, those magnetic lines attempt to shift this obstruction higher or downward. This results in a motor effect (Figure 7.4).

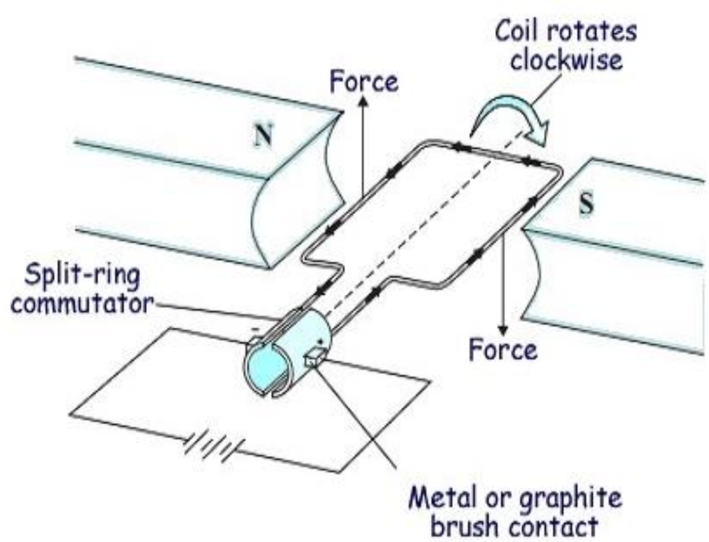

Figure 7.4 Process of commutation in motor

An electromagnet positioned between two magnets with one magnet's North Pole facing south will move the coil upwards while the coil's current is flowing in one direction as well as downward when the coil's current is flowing in the other direction. This same coil's rotatory motion is produced as a result. Two half-moon-shaped metal objects called commutator are connected to either end of the coil to alter the direction that the current travels in the coil. The commentators are linked to the opposite end of the metal brushes, which have one end hooked to the battery. In certain kinds of engines and generators, a commutator is indeed a rotating electrical switch that periodically flips the direction of current between both the rotor as well as the external circuit. It is comprised of a cylinder made up of several metal contact segments mounted on the machine's revolving armature. Additionally, the commutator, a component attached to the armature, allows for this current switching. The angle of a coil affects the lever arm that controls the torque applied to the armature (cos α).

EMF Equation of a DC Generator

A voltage is produced in the armature's coils as it spins. The rotational emf of a generator is designated as that of the Generated emf or Armature electromagnetic fields in Figure 7.5 and is written as Er = Eg. The rotational emf of a motor is often referred to as either the back emf or counter electromagnetic fields and is written as Er = Eb.

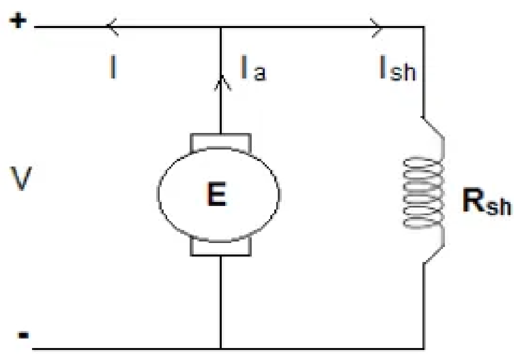

Figure 7.5 Shows the line diagram of DC generator

Derivation of EMF Equation of a DC Machine – Generator and Motor

Let,

P – Number of poles of the machine

ϕ – Flux per pole in Weber.

Z – Total number of armature conductors.

N – Speed of armature in revolution per minute (R.P.M).

A – Number of parallel paths in the armature winding.

Eg=Generated EMF=EMF per parallel path

The flux cut through one conductor during one armature rotation is expressed as:

Flux cut by one conductor=$p\varphi$…………….. (1)

One revolution's duration is specified as:

$$t = \frac{60}{N} seconds$$

Consequently, one conductor's average induced electromotive force will be:

$$e = \frac{P\varphi}{t} \dots\dots\dots\dots (3)$$

Equation (3) will result when the value of (t) from equation (2) is entered,

$$e = \frac{P\varphi}{\frac{60}{N}} = \frac{P\varphi N}{60} volt \dots\dots\dots\dots (4)$$

Z/A is the product of the number of series-connected conductors in each parallel route. As a result, the equation below provides the average generated electromotive force (emf. over each parallel route or the armature terminal:

$$E = \frac{P\varphi N}{60} * \frac{Z}{A}$$

$$E = \frac{P\varphi nZ}{A} \dots\dots\dots (5)$$

Where n is the speed in revolution per second (r.p.s) and given as:

$$n = \frac{N}{60}$$

The number many conductors per parallel route (Z/A) and the number of poles for a certain machine are both constant. Consequently, equation (5) may be written as:

$$E = K\varphi n$$

Where K is a constant and given as:

$$K = \frac{PZ}{A}$$

Consequently, the average induced electromagnetic field equation also has the following form:

$E \propto \varphi n$ Or

$$E = K_1 \varphi N$$

Where the angular speed in radians per second is denoted by:

$$\omega = \frac{2\pi N}{60}$$

Thus, it is evident that the speed as well as flux per pole strongly correlate with the induced emf. The orientation of a magnetic field and the direction the rotation both affect the polarities of the produced emf[37]. The polarity changes if any of the two is reversed, but still the polarity is unaffected if both are. [38]. All DC machines, irrespective of whether they're acting as a generator or a motor, are subject to this generated emf, which is a basic phenomenon [39]. The equation below gives the induced emf whenever the DC machine is acting as a generator:

$$E_g = \frac{P\varphi NZ}{60A}\ volts$$

Eg is the Generation Emf, in that case. The equation below gives the induced emf when the DC machine was acting as a motor:

$$E_b = \frac{P\varphi NZ}{60A}\ volts$$

The induced emf in some kind of a motor is known as the back emf (Eb) because it operates in opposition to the supplied voltage.

Armature Reaction in DC Machines

The carbon brushes have always been positioned just at magnetic neutral axis in some kind of a DC machine. The geometric neutral axis and the magnetic neutral axis meet in a no load state. Therefore, whenever the machine is charged, the armature flux has a triangle wave structure and is directed anywhere along inter-polar plane (the axis between both the magnetic poles). As a consequence, the main field is cross-magnetized and the armature current flow is redirected anywhere along brush axis. Due to this cross-magnetization action, flux is concentrated at the leading pole tips while a motor is operating and on the trailing pole tip when a generator is operating [40]. The impact of the armature flux mostly on main flux is known as the armature response. The resulting flux for a DC motor is stronger at the leading pole ends and weaker somewhere at trailing pole tips. When the lines of magnetic fields are broken, EMF is generated in the armature winding. Armature conductors travel perpendicular to the flux lines forward along axis (or, you might say, a plane), so as long as they are on that plane, those who do not cross the flux lines. The MNA (Magnetic Neutral Axis) is the axis that, when the armature conductors move parallel towards the eddy currents, produces no emf. Because current reversing with in armature conductors occurs along this axis in Figure 1, brushes always seem to be positioned along the MNA. Geometrical Neutral Axis (GNA) is the axis that is perpendicular to the axes of the stator poles. An equation for the induced emf somewhere at armature winding terminals caused by conductor motion in the field created by field poles was previously developed. But for the generator to be useful, a load must receive electrical output from it. In this scenario, the armature conductors simultaneously carry currents and generate a separate field. Therefore, it is essential to comprehend how the fields interact in order to comprehend how the loaded machine behaves. They mainly concentrate just on surface of the armature since the magnetic structure is intricate and they are interested in the flux that the conductors cut. Since the armature component field mmf are located on two distinct machine members, a signal convention is necessary for mmf.

The mmf acting from across air gap as well as the flux density inside the air gap are indicated as positive whenever they act in such a direction from of the major factor in determining to the armature, according to the convention adopted here. The magnitude of the contained current is calculated using a flux line. The field mmf and armature mmf are individually calculated and summed at each location on the surface of an armature since the magnetic circuit was non-linear. The presence and total mmf have a direct relationship with the actual flux generated. Only in the event of a linear magnetic circuit how can the flux created by the field as well as the flux produced by that of the armature be summed to obtain the total flux. Secondly, in order, the distribution of mmf caused by the poles and armature was studied (Figure 7.6).

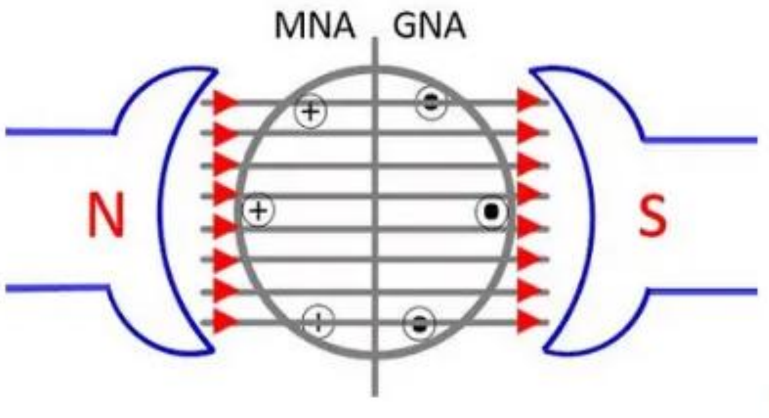

Figure 7.6 Armature reaction in DC generator

Take into account that just the field winding is powered and that the armature conductors are not carrying any current. In this instance, the electromagnetic flux lines at the field's extremes are symmetrical towards the polar axis and homogeneous. The "Magnetic Neutral Axis" (M.N.A.) and the "Geometric Neutral Axis" are congruent (G.N.A.). Armature flux lines caused by the armature current are seen in the following frame in the previous picture. De-energized field poles are used. Now, both fluxes flux resulting from the armature conductors plus flux resulting from the field winding will be present simultaneously while a DC machine is operating. The primary field flux is disturbed because the armature flux automatically creates over it. In DC machines, this phenomenon is known as the armature response.

Leading and Trailing Pole tip

The leading tip of a pole is the point where another armature conductors enter impact, and the trailing tip is the opposing tip in the opposite direction. Thus instance, if the motor turns counterclockwise in the image above, the lower point will be the leading tip for something like the North Pole while the higher tip will be the leading tip for such South Pole. The tips are switched if the motion is reversed (like with a generator). The magnetic neutral axis changes under load anywhere along rotational direction in a DC generator while changing in the opposite direction in a DC motor as a result of cross magnetization. If the brushes are left in their original placements, the generators or motors produced e.m.f. will decrease, causing significant sparking during commutation.

This is due to the fact that only the coils on the brushes undergo commutation, and the commuting coil is affected by the alternative pole (changes its location from north to south pole or vice versa). As a result, the direction that the current flows quickly switches from I to -i or conversely. This causes the coil to experience a very high reactance potential (L di/dt), which escapes inside the form of thermal energy and crackling and damages the brush and commutator section. The following techniques are used to lessen the negative impacts stated above as well as to enhance the functioning of the machine:

Total mmf and flux of a loaded machine

This demonstrates a pole's mmf decreasing at one tip while significantly increasing at the other. While the machine's pole arc per pole pitch ratio is 0.7, the tip adds 70% of an armature response mmf, causing a significant amount of saturation when the machine is operating at maximum capacity. In Figure 16, the flow distribution is also shown. Point by point in space multiplication of the mmf and permeance waves yields this result. Due to fringing, the actual flow distribution deviates somewhat from this. As can be observed from the picture, the high medium reluctance causes the flux in the intrapolar region to be much lower. To prevent oversaturation of this portion, the air spaces beneath the pole tips also are widened in practice. Thus, the salient pole field construction's benefit is clear. It significantly lessens the armature reaction's impact. Additionally, the coils that are undergoing commutation contain very little emf generated in them, which results in improved commutation. Despite the fact that armature response created a crossing magnetizing effect, excessive saturation beneath one pole tip causes the net flux each pole to slightly decrease under load. This is especially true for current DC machines, because the machine operates under considerable saturation due to the field's usual excitation (Figure 7.7).

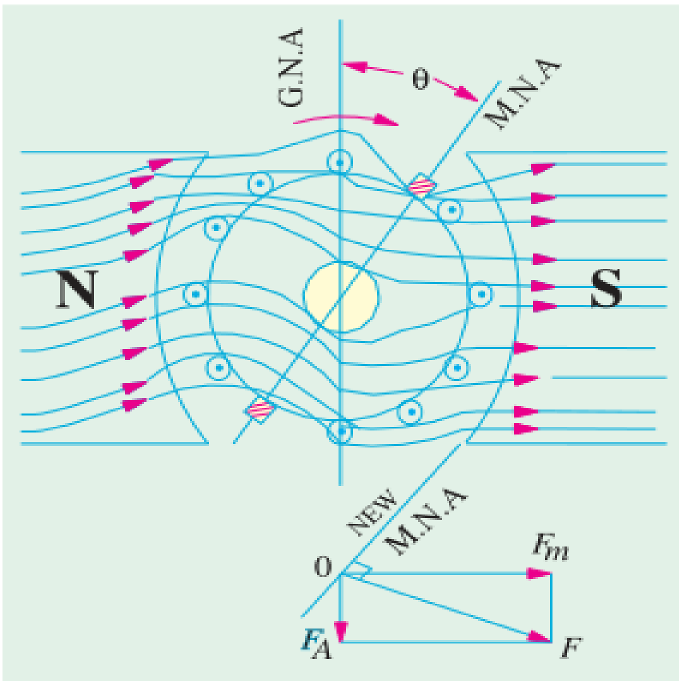

Figure 7.7 MMF and flux of a loaded machine

Effect of brush shift

The brushes might be moved in a way that reduces the air gap flux, such as anywhere along direction of the rotation for generator operation and opposed to the direction of the rotation for motor action. This will raise the speed of the motor and lower the electromotive force in the generator. Thus created was the demagnetizing mmf (magneto motive force). Brush shift is severely constrained, therefore the brushes must be moved to a new location if the load, the rotation's orientation, or the mode of change the fundamental. Due to this, only extremely tiny machines may use brush shift. The brushes are likewise fixed in this location at a position that corresponds to the regular load and mode of operation. Because of these drawbacks, this approach is often not favored. To increase commutation, the brushes in certain tiny D.C. machines are moved away from the magnetic neutral axis. This is particularly true of devices that operate in a single direction and in a single mode (either as a motor or a generator). Lead is the phrase used to describe such a change in rotational direction (or forward lead). Backward lead is the term for shifting brushes in the reverse direction from the direction of rotation. The electrical angle or the number of secondary winding are used to indicate this lead. A pole pitch is equivalent to a 180 degree electromagnetic angle.

Inter Pole

Just about all the medium and big sized DC equipment now utilize inter poles due to the brush shift's limitations. The inter polar axis has long, thin poles called inter poles. In the case of generator action, the succeeding pole is the one that will be rotated next, while in the case of motor action, the following pole is the one that will be rotated after the generator action. The inter pole's purpose is to balance the inter polar axis's armature response mmf. Inter poles are linked in series with the armature, thus as the armature's current direction changes, so does the inter pole's. This is as a result of the armature reaction's mmf direction being in the interpolar axis. The characteristic impedance voltage (L di/dt) is totally neutralized by the commutation voltage, which is also provided for the coil that is undergoing commutation. As a result, sparking is prevented. Since inter polar windings always are maintained in series with the armature, they carry the armature current and function properly regardless of load, rotational direction, or mode of operation. To guarantee that they exclusively affect the coil that is undergoing synchronization and that their impact does not extend to the other coils, inter poles were made smaller. Widening this same base of the inter poles will prevent saturation and enhance responsiveness.

Compensating Winding

The commutation difficulty with DC devices is not the sole issue. When operating with significant loads, this same cross magnetizing armature response may result in very high flux densities at the leading pole tip and trailing pole tip of the generation and motor, respectively. Because this coils is physically near to the commutation location (at the brushes), where the ambient temperature could be already high as a result of the commutation operation, it may create an induced voltage strong enough to trigger a flash over the span of related neighboring secondary winding.

Armature reaction in motors

As discussed earlier, for a given polarity of the field and sense of rotation, the motoring and generating modes differ only in the direction of the armature current. Alternatively, for a given sense of armature current, the direction of rotation would be opposite for the two modes. The leading and trailing edges of the poles change positions if direction of rotation is made opposite. Similarly when the brush leads are considered, a forward lead given to a generator gives rise to weakening of the generator field but strengthens the motor field and vice-versa. Hence it is highly desirable, even in the case of non-reversing drives, to keep the brush position at the geometrical neutral axis if the machine goes through both motoring and generating modes. The second effect of the armature reaction in the case of motors as well as generators is that the induced emf in the coils under the pole tips get increased when a pole tip has higher flux density (Figure 7.8)

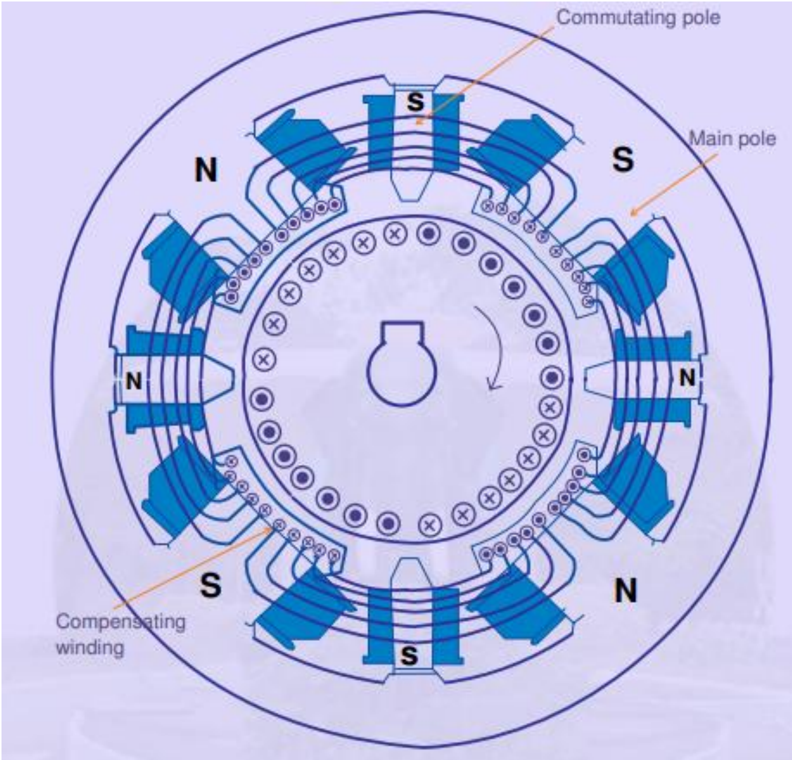

Figure 7.8 Armature reaction in motors

This increases the stress on the ‘mica’ (micanite) insulation used for the commutator, thus resulting in increased chance of breakdown of these insulating sheets. To avoid this effect the flux density distribution under the poles must be prevented from getting distorted and peaky. The third effect of the armature reaction mmf distorting the flux density is that the armature teeth experience a heavy degree of saturation in this region. This increases the iron losses occurring in the armature in that region. The saturation of the teeth may be too great as to have some flux lines to link the thick end plates used for strengthening the armature. The increase in iron loss could be as high as 50 percent more at full load compared to its no-load value. The above two effects can be reduced by providing a ’compensating’ mmf at the same spatial rate as the armature mmf. This is provided by having a compensating winding housed on the pole shoe which carries currents that are directly proportional to the armature current. The ampere conductors per unit length is maintained identical to that of the armature.

CHAPTER 8

Methods of Excitation

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As may already be shown, the cross-magnetic armature response makes the analogous circuit model of a D.C. machine relatively straightforward. Additionally, the main field's main field acts in quadrature to the axis of compensatory mmf and commutating pole mmf. As a result, the flux beneath the pole shoe is altered but not reduced (in case the field is not saturated). That whether machine is operating as a generator or a motor, with or without a load, the relative interconnections of the armature, compile, and compensatory winding remain unchanged. As a result, within the machine, all of them are permanently linked. Only the extra ohmic drops brought on by the compile and compensatory windings are reflected at the terminals. As a result, compensatory winding and commutating pole wrapping contribute to the armature circuit's resistance and may be regarded as components of it. A voltage source with internal resistance equivalent towards the armature resistance plus the compile resistance plus the compensatory winding resistance may be used to easily mimic the armature circuit. The impact of the brushes may be illustrated individually as an extra continuous voltage drop equal toward the brush drop since they behave like non-linear resistance.

Excitation circuit

There are two possible kinds of excitement for creating the necessary field. Excitation of permanent magnets (PM) and electromagnetic excitation. Only very tiny devices that make it impossible to provide a field coil use permanent magnet excitation. Additionally, it is impossible to change the excited fields of permanent magnets for control. For big machinery, permanent magnets are either prohibitively costly or unavailable.

However, a benefit of permanent magnets is that the development of the field does not result in any losses. Everyone uses electromagnetic excitation. Even if some energy is used in setting up the field, there are benefits including lower costs and simplicity of management. By doing the calculations for the magnetic circuit, it is possible to determine the number of ampere turns needed to provide the appropriate flux per pole. Calculated and additional MMF is needed for the poles, air gap, armature teeth, armature core, and stator yoke. Figure 18 depicts two 4-pole machine poles with the flux routes shown.

These equations allow for the computation and addition of the mmf needed for each and every component along the flux's path. To create two poles, you need this amount of mmf. It is useful to conceive about mmf per pole, which is just the number of ampere turns needed to create an electrical current by a coil coiled around a single pole. For tiny devices, a coil coiled around a single pole generates all of this mmf. Induction is used to obtain the second pole. This process saves money since only one coil has to be coiled in order to generate two poles. Larger machines do not employ this since it results in an asymmetrical flux distribution inside the machine. In big machines, each pole is given anmmf per pole equal to half of the total mmf. A coil with a lot of turns but little current used may generate the whole mmf needed. Such a winding has a high resistance value, which causes a significant ohmic drop. It may be used to link across a source of power, hence the name "shunt winding." Shunt excitation is the name given to this kind of excitation. On the other hand, to generate the necessary ampere turns, one may use a few turns of wire with a big cross section conveying a strong current. These windings may be linked in series with such a big current path, like an armature, since they have a very low resistance. Series winding and series excitation are terms used to describe this kind of winding and excitation. Either of these forms of excitation, or perhaps both of them, may be present in a DC machine (Figure 8.1).

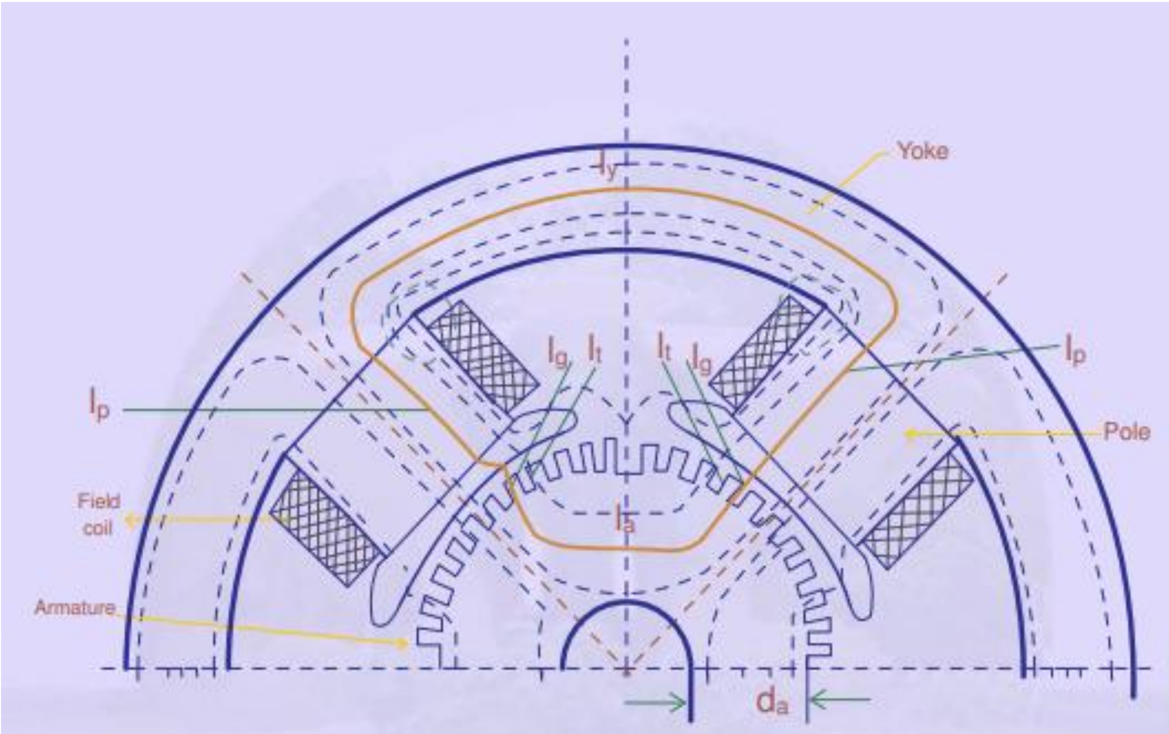

Figure 8.1 illustrating the Excitation circuit

Types of Generator

MMF is necessary for a DC generator to create flux through its magnetic circuit. By using field excitation as shown in Figure, the MMF required to create flux in a dc generator's electromagnetic circuit is achieved. Current is flowing through the primary winding of a DC generator when a DC power is increased, creating a constant magnetic field. The term for this is field excitation. The DC generator transforms the electrical energy into energy. These field coils carrying electricity in a DC machine generate the machine's magnetic energy (Figure 8.2). Excitation is a phenomena where a magnetic flux is produced by a circulating current throughout the field windings. The techniques used for field excitation are used to categorize DC generators. The DC generators are divided into two categories based on excitation: independently excited DC generators as well as self-excited DC generators. DC generators of the permanent magnet type are also available. Shunt wound, series wound, as well as compound wound DC generators are further categories for self-excited DC generators. Long shunt wound and short shunt wound compound wound DC generators were subcategories of these devices. The armature conductor of a DC generator spins, while the field's poll are motionless. With the aid of the commutator, the electromotive force created in the armature conductor is transformed through into direct voltage at the brushes.

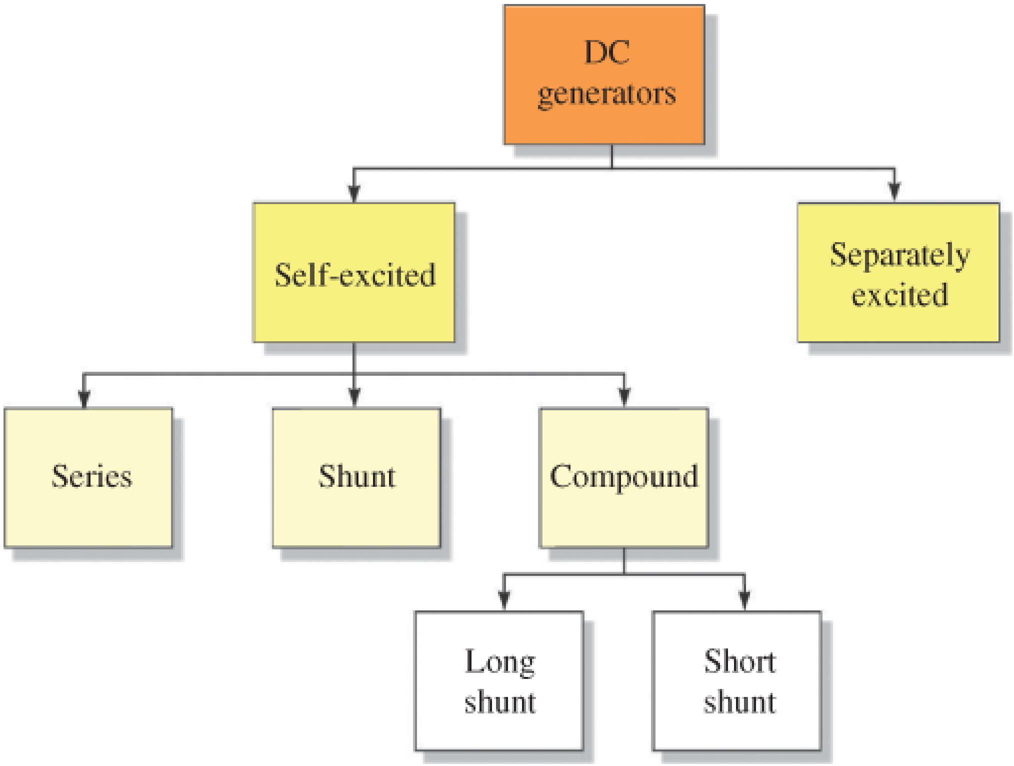

Figure 8.2 Types of Generator

<u>Permanent Magnet DC Generators</u>

The most basic sort of generator is referred to as a permanent magnet DC generator because it uses permanent magnets tp produce flux in the armature winding. A permanent magnet multiple magnets are positioned all around an armature. According to the generator's design, this kind cannot produce a lot of power and is not used in industrial applications. Like dynamos in bikes, permanent magnet DC generator are often utilized in tiny applications.

Figure below shows the fundamental design of a permanent magnet DC generator. As is well known, voltage is produced when a wire crosses a magnetic field, and the quantity depends on the wire's loops as well as the field's rotational speed.

Additionally, the angle here between magnetic force as well as the moving surface affects how much voltage is present. The voltage fluctuates with each loop's rotation from zero to its maximum amount as a function of angle, creating an absolute number of sinusoidal waveform. The voltage becomes constant at its highest value as the number of loops at various angles increases (Figure 8.3).

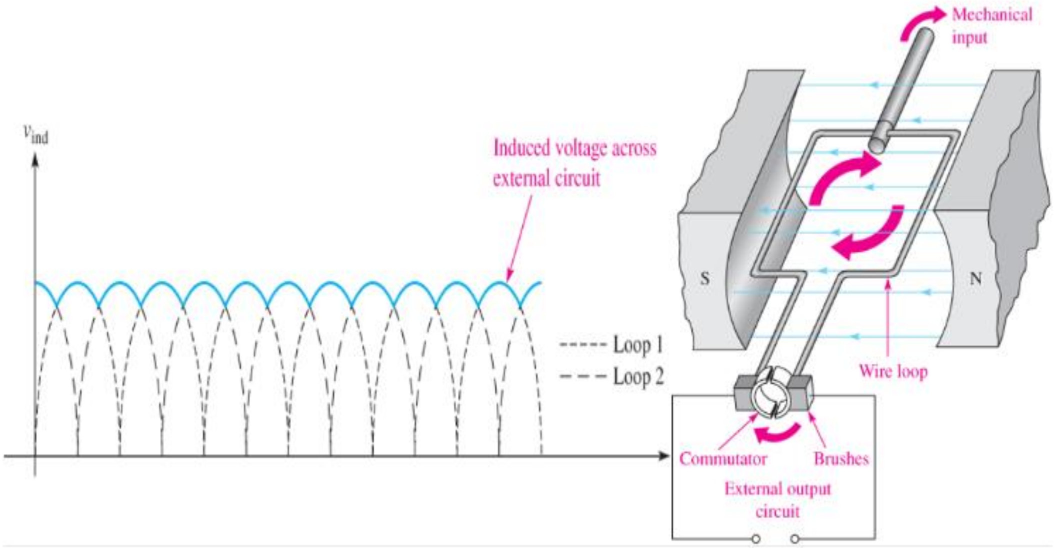

Figure 8.3 Permanent Magnet DC Generators

The induced voltage is calculated as:

$$V_{ind} = Blv$$

Where:

V_{ind} = induced voltage, in V

B = flux density that is perpendicular to the motion, in Wb/m2

l = length of the conductor, in m

v = velocity of the conductor, in m/s.

Advantages of PMDC Motors

The following are some of the benefits that PMDC motors offer over traditional DC shunt motors: PMDC motors don't need field winding, hence they don't have field circuits copper loss.

The efficiency of PMDC motors is better than that of traditional DC motors.

Since PMDC motors don't need field winding, they are smaller than standard DC motors in size.

In the case of PMDC engines, a field excitation setup is not necessary since the magnetic field is produced by permanent magnets.

PMDC motors are cheaper and economical for fractional kW rated applications.

Separately Excited DC Generators

The field magnets in this technique are powered by an external DC source, one such battery. As the rotating velocity increases, the EMF and voltage within the output may increase. The circuit design and symbols for the independently stimulated DC generators are shown in Figure 1: A shunt generator with a potential divider-shaped regulating resistor connecting the generator's field to the voltage source V_f. The field winding's current draw may be controlled between zero and its maximum value. A field controlling resistance may be connected simply in series if the desired change in excitation is modest. In each of these scenarios, a prime mover spinning the armature is presumptively present. D.C. generators are often tested to ascertain their open circuit output magnetization characteristic using a different excitation. The armature's terminal voltage is noted while the excitation current was monotonically raised to a maximum value and subsequently lowered in the same way.

A zero load current is maintained. The generator's speed is maintained at a set value. The open circuit characteristic (occ), also known as the no-load magnetization curve or the no-load saturation characteristic, is the graph that depicts the induced emf's behavior as a function of an excitation current. At high excitation current levels, the magnetization characteristic shows saturation in Figure 8.4.

The induced emf does not reach zero whenever the excitation current is decreased to zero because of the hysteresis that the iron inside the magnetic structure exhibits. The residual field inside the iron is to blame for this. In contemporary machinery, this residual voltage ranges from 2 to 5 percent. Separate excitation is desirable because it allows for good functioning over the machine's whole voltage range, beginning at zero, and is independently of the terminal voltage the load current (Figure 8.5).

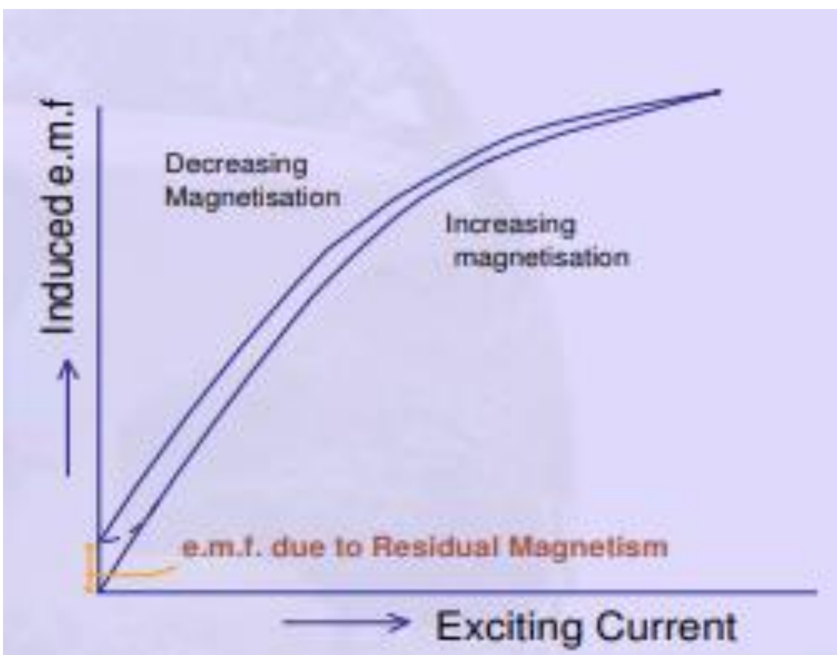

Figure 8.4 Relation between the exciting current and induced emf

IL is equal to Load current

Ia is equal to Armature current

Eg is equal to Generated EMF (Electromagnetic Force)

V is equal to Terminal voltage

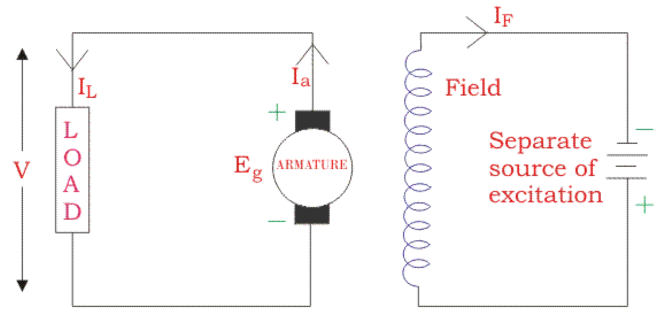

Figure 8.5 Illustrates the circuit diagram of Separately Excited DC Generators.

$$I_a = I_l = I$$

$$V = IR_a$$

$$P_g = E_g * I$$

$$P_l = VI$$

Self-Excited DC Generators

In self-excited DC generators, the field circuits are internally connected to the armature, and the field magnetic are driven through their own internal current. There is always some flux in the poles due to the remaining magnetic [48]. Whenever the armature rotates, a small amount of electrical energy is created, and this current passes through into the armature winding with both the load to increase the pole flux. As even the pole flux increases, both current as well as EMF increase, and so this exponentially increasing process continues until stimulating is necessary. In accordance with the field coils and their placement, self-excited DC generators are divided into the following categories:

Shunt Wound DC Generators

Those field windings are parallel-connected to the armature wires to turn on the generator. The required magnetic field for both the generator's activation is provided by the insulating current-carrying loops known called armature winding. Due to residual magnetization throughout the poles, the field windings of an apparatus akin to a shunt generator produce voltages equal to those of the generator's terminals, but somehow the voltage's actual value changes with the consumption and its pace. The circuit diagram for this type is as in Figure 8.6:

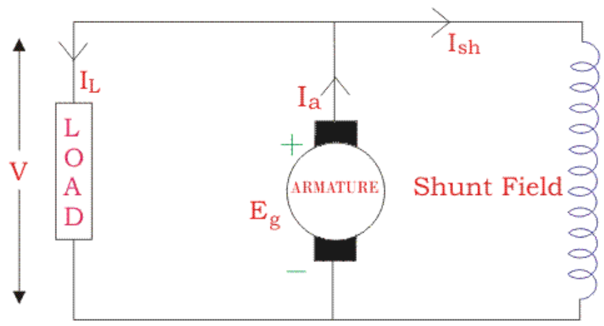

Figure 8.6 Shunt Wound DC Generators

Where:

V is equal to Terminal voltage

Eg is equal to Generated EMF

Ish is equal to current flowing through the shunt field

Ia is equal to Armature current

IL is equal to Load current

Rsh is equal to shunt winding resistance

Ra is equal to Armature resistance

Shunt field current Ish and load current IL are the two components that make up armature current Ia.

$$I_a = I_{sh} + I_l$$

The IL would be at its maximum value when the most efficient electricity for the loading would indeed be available. Therefore, it is advisable to keep the shunt current as low as possible. Consequently, it is desirable to maintain a high amount of shunt resistance.

$$I_{sh} = \frac{V}{R_{sh}}$$

$$V = E_a - I_a R_a$$

Electricity generated and power sent to the load are:

$$P_g = E_g * I_g$$

$$P_l = V * I_l$$

Series wound generators

In series-wound generators, the field winding is coupled to the armature wires in series. The generator's wiring schematic. The load and the fields coil's current flow at the same rate. For low electrical susceptibility, field windings are made with few turns and thick wires. Figure 8.7 shows the schematic diagram for this kind:

$$I_a = I_l = I_{sc} = I$$

$$V = E_g - I^2 * R_a$$

Generated power and power delivered to the load are:

$$P_g = \frac{I}{timesE_g}$$

$$P_l = \frac{I}{timesV}$$

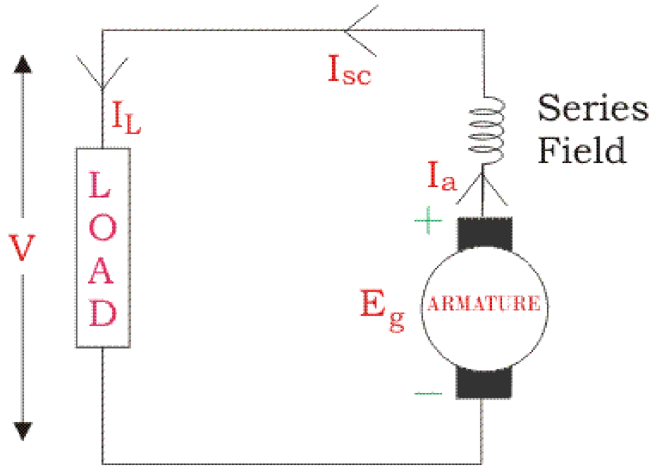

Figure 8. 7 schematic diagram for Series wound generators

<u>Compound Wound DC Generators</u>

In the series wound type, the voltage output and EMF are dependent on the grid voltage, whereas with the shunt type, the output is proportional to the magnitude of the load current. Compound wound generators, which combine both series and shunt, are available to get around both kinds' drawbacks. The compound wound generators' circuit combines shunt and series fields wounding. With the armature, there seem to be two different kinds of short shunt compound wound generators and long shunt compound wound generators, as well as series and parallel windings.

<u>Long Shunt Compound DC Generators</u>

The shunt windings are parallel as well as the series field and armature in long shunt compound DC generators. This sort of circuit design is shown in Figure 8.8:

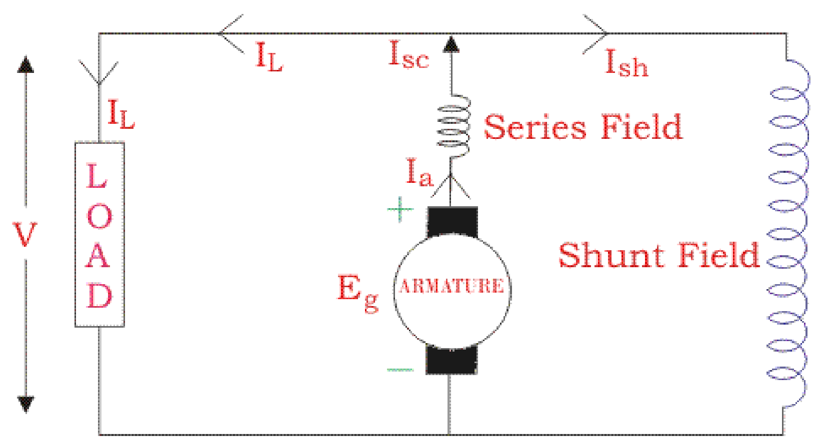

Figure 8.8 diagram of Long Shunt Compound DC Generators

The currents in the circuit are:

$$I_{sh} = \frac{V}{R_{sh}}$$

$$I_{cs} = I_l + I_{sh}$$

$$I_{cs} = I_a$$

The load voltage is equal to:

$$V = E_g - I_a(R_a - R_{sc})$$

Generated power and the delivered power to the load are:

$$P_g = I_G * E_g$$

$$P_l = I_G * V$$

Short Shunt Compound Wound Generator

The shunt field winding and the armature winding are only linked in parallel in some kind of a short shunt compound wound generator. An illustration of a short shunt-wound generator's connections. The value of series armature current is:

$$I_{se} = I_L$$

The shunt field current is given as:

$$I_{sh} = \frac{V + I_L R_{se}}{R_{sh}} = \frac{E_g + I_a R_a}{R_{sh}}$$

$$I_a = I_l + I_{sh}$$

Terminal voltage is given as:

$$V = E_g - I_a R_a - I_L R_{se}$$

Self-excitation

There really is no external source of excitation current in a self-excited machine. The armature is linked across by the shunt field. There has been no change in connectivity for machines in a series. The series field and armature remain connected in series. Now used to describe self-excitation. In a shunt generator, self-excitation happens in the way that is described below. Depending on the rotation speed and residual magnetism that really is present, a weak induced emf approximately 2 to 5 percent manifests across the brushes when the armature is turned. A modest mmf is generated when this voltage is put from across shunt field winding. This residual field is enhanced and creates more voltage from across brushes if this mmf is designed to help it. It resembles positive reinforcement. When the voltage produced in the armature is really just sufficient to overcome the ohmic drop within the field circuit, the induced emf progressively rises. In such a scenario, neither the field mmf nor the emf accumulation continue to rise. The term "self-excited" refers to the machine when there has been a "significant" voltage buildup.

A fresh, unexcited machine will not have a residual field. In these circumstances, the field may be briefly linked to a battery to produce a residual field. It is necessary to correct the connections' polarity. Reversed connections or the improper rotational orientation might cause the polarity to change. Change the polarity of the connections of both the field with regard to the armature to solve this issue if the generator had been operating with the armature revolving in the clockwise direction before halting and if one attempts to self-excite the identical with the counterclockwise direction. All resistances connected in series with both the field winding, such as regulating resistance, contact pressure, drop at the brushes, and armature resistance, are collectively referred to as field circuit resistance. At low currents, brush contact resistance is typically significant. The overall circuit resistance may be greatly increased by dust buildup on the commutator or by a mica insulator that has worn out. It is possible that the speed will be too low, causing the normal field opposition to be much higher than the critical value. Therefore, maintaining solid connections, clean commutators, and speed should often be enough to solve this issue. In order to exceed the crucial speed, speed must be raised to a high value. If the load switch is closed, the load resistance will be very high.

Self-excitation of series generators

A series generator's self-excitation requirements are nevertheless quite comparable to those of a shunt machine. Since the field circuit resistance in this instance is identical to the load circuit resistance, it must be kept as low as possible to promote self-excitation. A tiny resistance known as a diverter is often attached from across series field to adjust the field mmf. Any field diverter, if present, must always be open circuited in order to aid in the generation of the greatest mmf possible during self-excitation. In a series generator, the self-excitation characteristic of the load current and the field current of the machine are identical.

Self-excitation of compound generators

The majority of compound machines are essentially shunt machines, with the series winding acting to increase or decrease the field depending on the connections and the load. The two fields' mmf cooperate in cumulatively compounded machines while they compete in differentially compounded machines. It is possible for the self-excitation to continue as in a shunt machine since the shunt winding is present. However, there is a little variation depending upon how the shunt winding was attached to the armature. There are two types of shunt connections: short and long. The series winding also receives the shunt field current in lengthy shunt connections. However, because of the little mmf contribution from of the series field, it has no impact on the process of self-excitation. The primary poles are wound using both series field winding but also shunt field winding. If additional excitation windings with one sort or another are required for any control reasons, they will also find a home on the main poles. The intended field windings should support the machine's whole operating range at nominal armature current. Due to the armature current's cross-magnetization, the demagnetization mmf caused just by pole tip saturation must be offset by the field's production of extra mmf.

External characteristics of a shunt generator

As the load is raised, a self-excited machine will experience a greater voltage drop at the terminals for something like a given no-load voltage than a separately excited machine. This is because the excitation current directly depends somewhat on terminal voltage. Regardless of whether the load impedance is lowered, the terminal voltage quickly declines after a certain load current. When it becomes unstable, the terminal voltage. Additionally, in a self-excited generator, the conjunction of both the magnetizing characteristics but also field resistance line has a significant impact on the no-load terminal voltage. An intriguing topic is the identification of a shunt generator's exterior features. The external properties may be readily established by calculating the load magnetization curves at various load currents. The fluctuation of the terminal voltage as a result of an excitation current, while holding the speed and armature current constant, is shown on the load magnetization curve. If similar curves are established for various load currents, the external characteristics of the shunt generator may be obtained by locating the locations at which these curves cross the field resistance line. By deducting the armature drop through each excitation point, the loaded saturation curve may be created from the no-load saturation curve/OCC. Thus, it can be observed that this family of curves is nothing more than an OCC with the armature drop relocated lower. We get the required result by calculating their intercepts along the field resistance line. In order to account for the dips at the various currents, the x axis and the field resistance line were adjusted "upwards," and their intercepts with the OCC are discovered.

Load characteristics of compound generators

The exterior properties of compound generators under low loads mimic those of shunt generators. Depending about whether cumulative and otherwise differential compounding is employed, the load current passing through into the series winding either supports or opposes generating shunt field ampere turns. The flux per pole and indeed the induced emf E are increased or decreased as a result. This results in a distinctive fluctuation that is load current dependent. If the armature drop is offset by this higher emf, the terminal voltage is nearly unchanged under both light and heavy loads. The term "level compounding" refers to this. Under compounding and above compounding were terms used to describe cumulative compounding that falls below and over this number, respectively. The Figure depicts them. Because the series field mmf opposes the properties of the shunt field, the characteristics correlating to all degrees of differential compounded are inferior to those of a pure shunt machine (Figure 8.9).

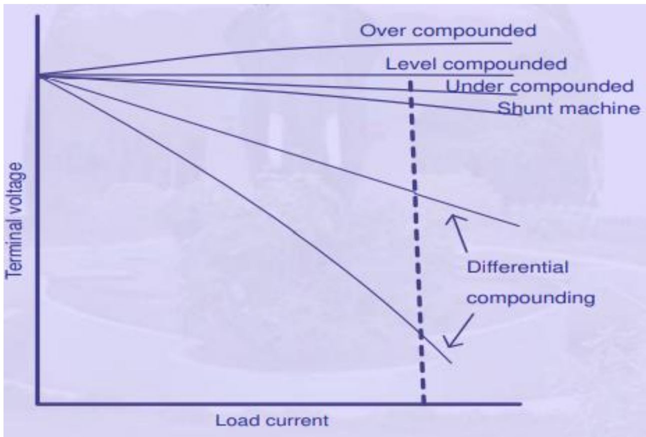

Figure 8.9 Load characteristics of compound generators

Parallel operation of generators

When the load exceeds the capability of any one machine, D.C. generators must run concurrently to provide a shared load. It could be a good idea to only put a second machine into service when demand rises in circumstances where the load is often low but sometimes high. The need for spare capacity and its cost are reduced by this strategy. When one machine has to be removed for repair or maintenance, some other machine may continue to work with less burden. In each of these instances, many machines are linked together to work in tandem.

Shunt Generators

Similar to how parallel operation of double storage batteries works, parallel operation with two shunt generators does as well. While it is not feasible with batteries, we may simply change the outward properties of generators. The voltages of a two machines were made equal and in opposition within the loop that the two machines make before they are connected. This prevents a current from flowing between the devices. Even without a connected load, power loss is still caused by the circulating current. The discrepancy in the induced emf in the loaded machine renders the load sharing unfair. Two generators are linked in parallel in Figure 30. The current provided by each machine is zero, and the no load emfs are set equal to E1 = E2 = E on no load. A total load current of I ampere being drawn by that of the load as it is progressively applied. Under these circumstances, the load voltage is V volts. Each machine will give currents between I1 and I2 ampere, and so that I1 + I2 = I, to share equal total current.

CHAPTER 9

D.C. Motor

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D.C. motors have a special position in the world of electrical drives. They are favored machines with precision drives due to their simplicity and linearity of control approach. These devices are still in demand by the industries despite significant developments in A.C. drives. They are favored in independent battery-powered systems and high-speed drives off constant voltage main supply in addition to applications requiring great accuracy. If they run a current through into the armature once the field is excited, the rotor will start spinning due to the torque it will encounter. The law of interaction makes it simple to determine the torque's direction (Figure 9.1). Thus according Lenz's law, these moving conductors generate emf and decrease the field, which is often referred to as the "back emf" and serves as a sink for electrical energy from the electrical component. The power that is absorbed manifests as mechanical power. Even before mechanical power could be put to use, the frictional but also iron losses had to be overcome. Figure 30 shows the connections to something like a D.C. shunt motor's supply.

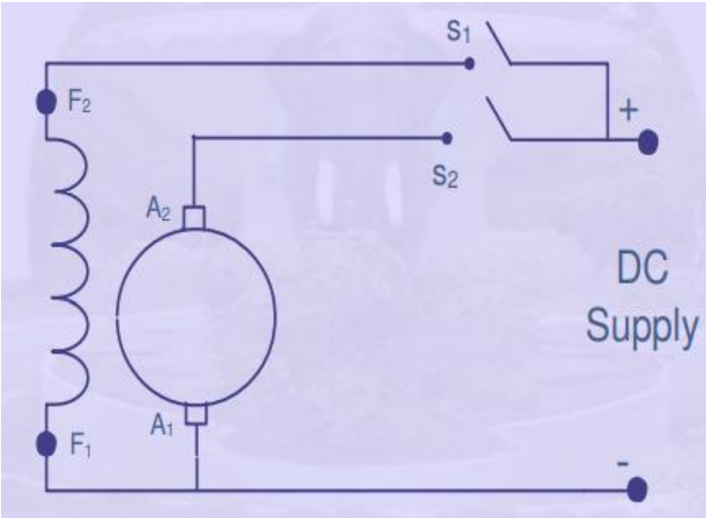

Figure 9.1 schematic diagram of DC motor

<u>Load characteristics of a series motor</u>

The method outlined under "shunt motor" may also be used to calculate a series motor's torque and speed characteristics. The flux variation matches the machine's magnetization curve because the armature current simultaneously serves as the series field's excitation current. The usable flux would be smaller than the machine's no-load magnetization curve at high armature current values. Similar to how the torque fluctuates for tiny values of both the load currents, overall flux in this area is inversely proportional to the armature current. The torque grows proportional with Ia as the flux fluctuation becomes smaller as the magnetic circuit is becoming more and more saturated Figure 9.2.

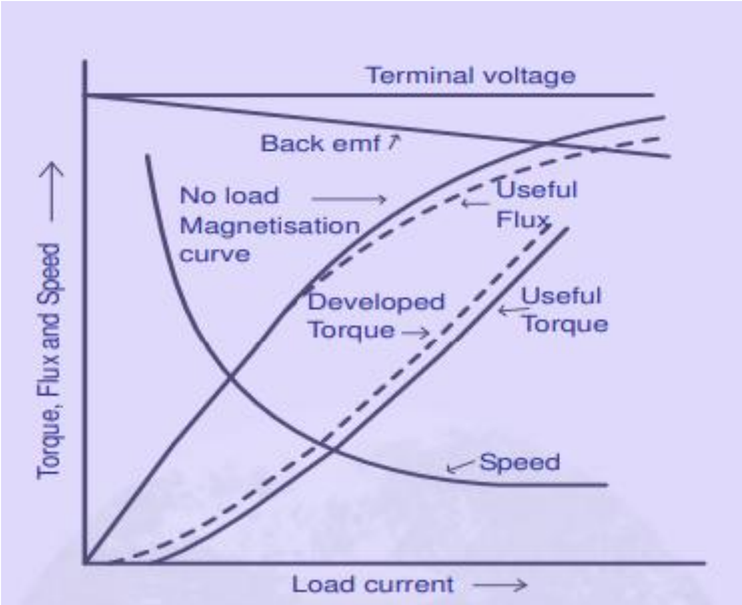

Figure 9.2 Load characteristics of a series motor

Following the aforementioned technique, it displays the fluctuation of E1, flux, torque, and speed through which the torque-speed characteristics of the series motor for a certain applied voltage V may be shown, as seen in Figure. This torque-speed curve appears seen to have a rectangular hyperbola-like starting section and a virtually straight line-like ending portion. The speed is much higher than the motor's rated speed under low load situations. Such high speeds are dangerous because the armature and commutator might be destroyed by the centrifugal forces acting around them, leading to a catastrophic breakdown. As a result, it is not advised to utilize series motors in situations where the load may eventually become zero. In contemporary machines, a "weak" shunt field is given on series motors to provide a distinct, if modest, value of flux even though the armature current is now almost nil. This is done to protect the motor and people. This limits the no-load speed to a safe maximum velocity. It goes without saying that this field has to be linked in order to help the series field.

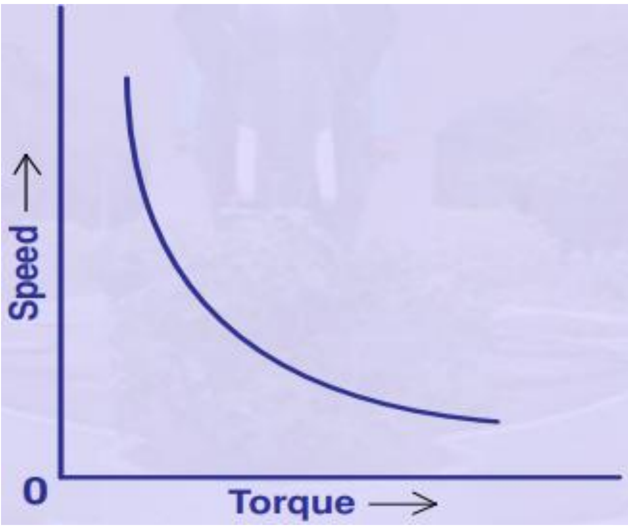

Figure 9.3 speed torque characteristics of DC series motor

Load characteristics of a compound motor

Compound motors give rise to two circumstances. Shunt field and series field mmfs may work against or in favor of one another. Differential compounding is the name of the first configuration, which is hardly employed. Unless the armature mmf sufficiently low and there isn't any magnetic saturation, they result in unstable machine operation. This mode could occasionally be caused by the driving operation of the level-compound generator, such as when the prime mover fails. Additionally, differential compounding may provide a significant negative mmf at overload or startup conditions, which might cause the machine to start in the other way. The amount of compounding is very low in motors designed for constant speed operation so as to not present any issues.

Industrial drives employ cumulatively compounded motors extremely often. A machine with a high degree that compounding will resemble a series machine in terms of attributes, but now with safe no-load speed. The field is reinforced under stress as a result of the compounding. As a result, the armature current's torque per amp is increased. A cumulatively compounded machine is particularly suited for intermittent peak demands because of this property. A fly wheel may be advantageously employed with such motors because of the significant speed fluctuation between low load and high load circumstances. All contemporary machines are compound machines, as can be seen from the justifications given under shunt and series engines for the inclusion of an extra series/shunt winding. The sole difference between them is the amount of compounding.

Parallel operation of D.C. motors

Similar to how generators must run in parallel to drive a shared load, motors may likewise be needed to do so. In both situations, there are identical advantages and drawbacks. The speed of the load, which the two machines are attached to, is the shared parameter throughout the torque speed plane. The intersection of a torque speed curves determines the shared torque between each machine.

The point of intersection of torque speed lines that are drooping stays largely unaffected by slight changes in the characteristics brought on by temperature and stimulation effects. The torque shared by each machine, however, varies significantly if these curves are flat. The torque requirement is distributed more widely throughout the machine with the flatter slope. As a result, operating two shunt motors throughout parallel is far more challenging than operating the identical machines as generators.

When compared to the identical equipment operating as cumulative compounded motors, the operating of level compounded generators is significantly more challenging. Similar to shunt motors, cumulative compounded motors operate more easily in parallel. In terms of parallel operation, series motors are suitable due to their rapidly decreasing speed increasing load torque. Even if they have significant disparities in their properties, their simultaneous functioning is nonetheless unaffected.

Electric locomotives are one application where many series motors run in parallel. The rotational speeds of these motors may vary in order to maintain the same common linear velocity of a train due to the unequal wear and tear of the locomotive's wheels. There is no propensity for derailment since the torque generated by one machine stays close to the other. Figure9.4 shows the torque speed curves for series motors operating in parallel.

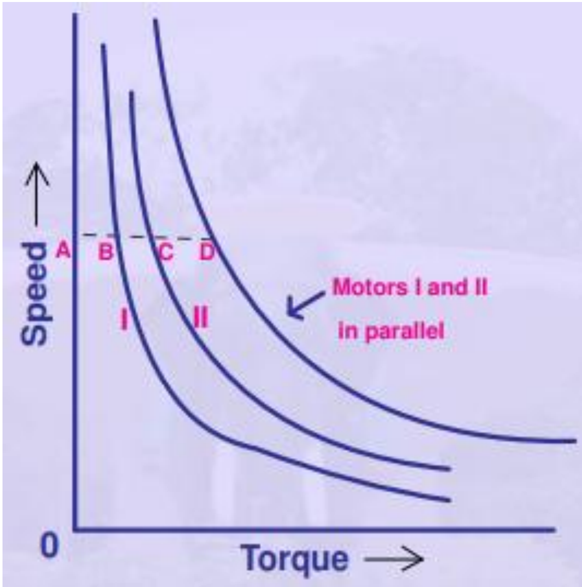

Figure 9.4 speed torque characteristics of Parallel operation of D.C. motors

Application of D.C. motors

Here, basic application ideas are covered on their own. The mechanical equation of dynamics, which is reiterated here, is the main concern.

$$T_m - T_L = J\frac{dw}{dt}$$

Therefore, TM and TL are the motor and load torques, which are given as functions of, respectively. When operating in a steady state, d/dt will be zero. Three key operational facets are examined while applying motors. Starting, limiting speed, and braking it is necessary to boost the machine's speed from zero to its operational speed. The motor is beginning at this point. According to the demands of the load, the operating speed itself ought to be changed. Speed control is the term for this. The running machine must finally be stopped by decelerating the same. This process is braking. It is considered that the change in the load's characteristics is either not practical or not desired, thus the torque speed characteristics of a machine are adjusted to accomplish this. Therefore, the techniques that may be used to alter the torque speed characteristics as well as the actual changes in performance that these techniques produce are quite significant. Other factors, such as initial cost, ongoing cost, efficiency, and simplicity of operation are also employed when more than one approach is available to accomplish the same goal. The functioning of D.C. machines is often thought of as operating off a constant voltage because of the absence of apparatus like transformers. D.C. provides.

Starting of D.C. machines

The torque that the motor generates at zero speed must've been more than what the load requires for the machine to turn on. When TM > TL is positive, the machine accelerates because d/dt is likewise positive. The armature current with the maximum applied voltage is determined by V/Ra where Ra is the armature circuit impedance since the induced emf at the beginning point is zero as the = 0. A D.C. machine's armature resistance often results in a 1 to 5 percent reduction in current under full load. As a result, the beginning current often increases to many times the current at full load. If complete flux has previously been established, the torque may be explained in the same way. The speed of the machine immediately increases. As the speed rises, an induced emf countering the applied voltage emerges across the terminals. Thus, when less current is pulled from the mains, less torque is generated. This keeps on until the motor torque as well as the load torque are equal. Since there is no acceleration at this stage of operation, this same machine tends to operate constantly at this speed.

DC shunt motor

When a D.C. shunt motor's armature and field are turned on simultaneously, a significant amount of current is consumed at first, but as the field flux progressively rises, torque steadily increases. It is desirable to energize the field first in order to increase the torque produced per amp of line current drawn. Since the beginning current is determined by V/Ra, the voltage V may be decreased or the armature circuit resistance Ra could be raised to lower the starting current to something like a safe amount. A motor generator set may produce variable voltage V. Ward-Leonard arrangement is the name of this configuration. Figure is a schematic representation of the Ward-Leonard setup. The Ward-Leonard generator's field may be adjusted to produce a variable voltage was at its terminals, which is employed to start a motor. You may achieve the second approach of beginning with higher armature circuit resistance by first connecting more resistances in the series with the armature. Reduced torque and current are the results. Torque speed curve under certain circumstances. This graph clearly shows that the empty machine achieves its maximum speed, whereas a loaded machine could creep at a pace much slower than the typical speed. The initial resistance also consumes a lot of energy. Thus, at the conclusion of the beginning phase, the initial resistance must be decreased to zero. To prevent the current from abruptly rising to high levels, this must be done gradually. Series motors and compound motors both start similarly to shunt motors. For compound motors, better starting torques were generated since the torque per ampere is higher (Figure 9.5).

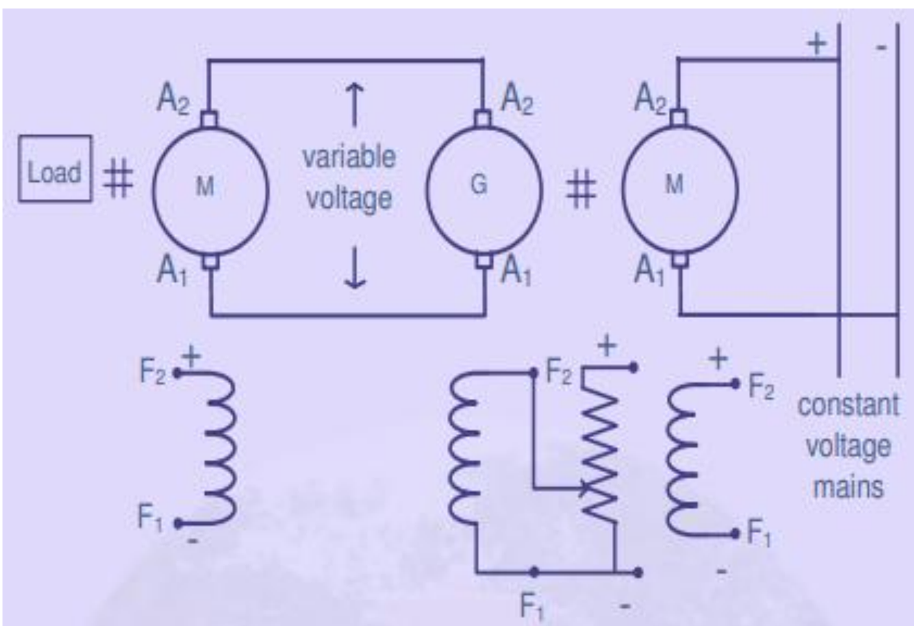

Figure 9.5 schematics diagram of DC shunt motor

Speed control of D.C. motors

Armature voltage control and flux control techniques are offered for speed control. The Ward-Leonard arrangement or series armature resistance may be used as a variable voltage source for the voltage control. In the case of speed control, the series resistance must remain in the circuit the whole time, unlike the beginning circumstances. This implies that these resistors lose a significant amount of energy. Furthermore, for continuous functioning, these resistors need to be appropriately cooled. On the other hand, the motor receives the exact voltage it needs from the variable voltage source, and the control gear's losses are kept to a minimum. When a high speed ratio and/or power rating are needed, this approach is often utilized. Speed control also involves the use of flux or field control. Field weakening is often used. Operating at speeds faster than the normal speed is the result of this. Because the machines have already been saturated and a big field mmf is required for a modest increase in flux, strengthening that field has limited potential for controlling speed. Flux weakening increases operating speeds, but it also decreases the torque the machine produces at a given armature current, thus the power provided remains constant regardless of armature current. The machine is stated to be in field-weakening mode of constant power mode. Constant flux mode without higher applied voltage may be employed beyond the nominal rate of operation, however this is never done since the stress mostly on commutator insulation rises.

Because of this, voltage control is used for operating below nominal speed. Field weakening is used above the normal speed. Both shunt and compound motors employ series resistances to diminish the field. However, in the case of series motors, field weakening is accomplished by the employment of "diverters." Diverters were resistances attached in parallel towards the series winding in order to lower the field current while impacting the armature current.

Braking the D.C. motors

A motor "coasts" to rest when it is turned off due to frictional forces. When a quick halt is necessary, braking is used. Mechanical braking is used often. There are several reasons to use electric brakes, some of which are listed below: to increase the mechanical brakes' stopping ability. To extend the mechanical brakes' life. To increase energy efficiency and renew electrical power. To immediately step the machine in an emergency to decrease the stopping time in numerous industrial processes in order to increase throughput. In many instances, electronic braking increases the amount of brake power that is available for use during the application of mechanical brakes. As a result, there is less wear and tear on the mechanical brakes and less need for frequent replacement of these components. The total energy efficiency is raised by recovering the mechanical energy trapped in the spinning components and injecting it into the supply lines. The term for this is regeneration. If the safety of the workers or the machinery is in danger, the machine may need to stop immediately. Such conditions call for a very significant braking force. Electric brakes are also effective in certain situations. Procedures requiring frequent starting and stopping may well be finished faster if braking time is reduced. Whenever the process time is shortened, the throughput rises. In general, the electronic braking procedure is rather simple. The electric motor may be designed to produce power and absorb mechanical energy by applying the proper terminal conditions. This translated mechanical power was efficiently used and dissipated by the electrical network. Several broad types of brakes exist: The electronic braking process is, in general, rather straightforward. By using the right terminal conditions, the electric motor may be made to generate power and absorb mechanical energy. The electrical network effectively dissipates and uses this translated mechanical power. Regenerative, reverse voltage, and dynamic braking are the three main categories of braking.

Dynamic braking

In different DC machine dynamic braking are:

Shunt machine

The motor is attached to a dynamically braking resistance RDB during dynamic braking and is cut off from the supply. To do this, flip the switch from position 1 to position 2. It should not be necessary to cut off the field's supply. The armature continues to spin because of the inertia and rotation that occurs during driving mode. The existence of the field as well as the rotation cause an emf to be generated. The braking resistance is current-driven by this voltage. This current is moving inside the opposite direction to that of the one that existed prior to the connection alteration. As a result, the torque that was created is likewise reversed. The device functions as a brake. For a certain value of RDB, overall torque speed characteristics of the machine operating in dynamic braking mode are depicted. The driving action is consistent with the positive torque. Both torque-speed curve with dynamic braking of the shunt stimulated motor. In this case, the device acts as a self-excited generator. The self-excitation collapses as well as the braking effect is zero below a particular speed.

Series machine

When the armature of a series machine is removed from the mains, the excitation current goes to zero and, as a result, the induced emf likewise disappears. Dynamic braking has to be accomplished by isolating the series field and connecting it to a low voltage, high current source. Instead, the motor is designed to operate like a machine that is individually activated. Dynamic braking is possible when many machines are present at all times, such as in locomotives for trains. In such situation, a single dynamic brake resistor that has all of the series fields linked in series and all of the armatures connected in parallel was employed.

Compound generators

The situation with a compound machine is similar to that of a shunt machine. The armature is linked across the braking resistance and just a separately excited shunt field is employed. A differentially compounded generator transforms a cumulatively coupled motor into a braking torque generator. Therefore, if high braking torques have been required, the series field must be reversed.

Regenerative Braking

Regenerative braking involves feeding energy recovered from spinning masses back through into D.C. power source, even as name indicates. As a result, this kind of braking increases the machine's energy efficiency. By increasing speed or excitement alone, the armature current may be forced to reverse for just a constant voltage operation. Increased speed does not cause braking, and it is only possible to raise excitation across a very narrow range, maybe between 10% and 15%. Therefore, running the machine on a variable voltage source is the ideal way to achieve regenerative braking. The speed gradually decreases as the voltage is persistently pushed below the induced emf value. Separate excitation is used to maintain the field current's constant value. The Ward-Leonard setup, which is schematically shown, may be used to provide the variable D.C. supply voltage. Right up to zero speed, braking torque may be acquired. The static Ward-Leonard approach is still used today to get changeable D.C. voltage. In comparison to a spinning machine, this offers several benefits. Although static sets are small, more efficient, take up less room, and operate quietly, they have limitations such as significant ripple at low voltage levels, bidirectional voltage regulation, and poor overload capacity. If regenerative braking is necessary, bidirectional power flow capability is a need. Because the characteristics do not apply to the second quadrant of series motors, they cannot be regenerative braked.

Plugging

The third braking technique is plugging. Hookup technique for plugging in a shunt motor. When the machine is first linked to the supply, the switch S is in the first position. A reverse voltage is already supplied from across armature if the switch is now in position 2. A significant amount of reverse current flows through into the armature as a result of the induced armature voltage E and supply voltage V cooperating. This generates a substantial braking torque, or negative torque. Plugging is sometimes known as reverse voltage braking as a result. The device immediately comes to a stop.

The direction of rotation will reverse and the motor will begin to rotate in the other direction if the motor is not turned off at this moment. Therefore, there are two options for this form of braking: plug to reverse versus plug for stop. To activate the switch S with zero speed, people must simply require the plugging to bring the speed to zero. If nothing is done, the plug will operate in reverse. In reversible drives, plugging is a practical way for swiftly changing the direction of rotation. As with beginning, it's important to restrict the current and, therefore, the torque during plugging in order to lessen the strain on the mechanical system as well as the commutator. To do this, more resistance is added in conjunction with the armature before plugging.

Series motors

Plugging is not an option for series motors because when reverse voltage is provided across the equipment, the field current also reverses. This maintains the generated torque's direction. When running a D.C. series motor on a D.C. or a.c. source, this feature is advantageous. Series motors may thus be referred to as universal motors.

Compound motors

Similar to how shunt motors are plugged in, compound motors are also plugged in. Due to the existence of series field winding, various safety measures must be taken. When plugged in, a motor that was cumulatively compounded became differentially compounded. The flux may be forced to low levels or even reversed by the series field's mmf, which can "overpower" the shunt field.

As a result, the huge braking current lasts longer and the braking torque is reduced. It could be wise to short circuit this series field at the moment of braking to prevent this by deactivating it. In these circumstances, the brakes works just like a shunt motor. In order to get the correct mmf, the series field must be switched around and linked if plugging is used to run the motor in both the positive and negative directions of rotation. Plugging causes the motor to operate in reverse driving mode, as opposed to dynamic and regenerative braking, which turn the motor into a generator even during braking time.

Application of D.C motors and generators

It is clear from the prior sections that dependent on the circuit circumstances, a DC machine is capable of having a range of torque-speed characteristics. Only when these features are viewed in conjunction with the characteristics of the loads which they function with will the requirement for creating them become apparent. Even though it is beyond the scope of this article to examine motor load systems in depth, it could be helpful to look at the usual torque-speed properties of several of the common loads. Passive loads and Active loads are the two main categories of loads. They may operate unidirectional or in both directions (Reversible loads). While active loads may serve as both sources and sinks producing mechanical energy, passive loads just absorb the energy produced by the motors. It is possible to assume that the revolution is going either clockwise or counterclockwise. The positive orientation of the rotation is often assumed to be the direction within which the load works the majority of the time. A positive toque is any torque that accelerates its motor load system inside the direction of rotation. The rotational torques of motors, generators, or loads may be visually depicted on a four-quadrantile using this. Using the x-axis to express the torque as just an independent variable.

CHAPTER 10

Testing of D.C. Machines

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It is necessary to test a D.C. machine to ensure appropriate construction and trouble-free operation. The exterior qualities required for use of these machines may be found through the testing. Additionally, the machine's rating, efficiency, and temperature increase are available. Now that some of the tests have been mentioned in order.

Measurement of armature resistance

The v-i technique is used to measure the winding resistances between field windings and armature windings. At the time of the exam, Field is not enthused. Although any applied voltage value is possible, the greatest permitted voltage and current are selected during in the test to reduce mistakes. Two resistances are connected in series to form the armature circuit. They are resistance for armature winding and resistance brought on by brushes and brushing drop. A non-linear resistance is how the brush contact drop works.

A number of v-i measurements are made to distinguish this from both the armature circuit impedance and brush resistance. These test points, which are shown graphically, are fitted by an equation of the type V = Vb + IRa. The comparable armature resistance is assumed to equal V/I ohm for high values of I. The armature resistance Ra = V/I ohm is the result if the brush drop value Vb may be disregarded.

Open Circuit Characteristic (OCC)

The OCC is very valuable since it displays the mmf and, therefore, the field current needed to produce a certain voltage anywhere at speed, with no load. It is a graph that displays the variation of both the induced emf as both a function of excitation current, with both the load current set to zero and the speed remained constant.

The no-load saturation curve or even no load magnetization characteristic are other names for it. This is established experimentally by operating the device at a steady speed while being independently energized and monitoring the terminal voltage as just a function of an excitation current. Whenever the machine functions as a shunt generator, the self-excited voltage and OCC may both be determined using this curve.

Short circuit characteristics (SCC)

The armature is maintained short circuited throughout the short circuit test using an ammeter. A very little field current is sent across the field while the machine is demagnetized. The SCC represents the fluctuation of the short circuit current as a proportion of excitation current. Additionally, the speed must remain consistent throughout the test. The armature drop anywhere at load current may be estimated using the short circuit test.

Load test

It is necessary to do a load test in order to determine a machine's rating. When the machine is loaded, a portion of the input is lost inside and converts to heat, raising the machine's temperature. Excessive temperature increase harms the insulations, which eventually causes the insulation and the machine to fail. The results of a load test reveal a machine's effectiveness under any load scenario. Additionally, it displays the machine's temperature increase. The machine may be run safely at such load if the temperature increase is less than the insulation's allowable value; otherwise, the load must be decreased. The continuous rating of both the machine is the greatest continuous load that may be given by it without causing the insulation being employed to overheat. As a result, the load test by itself can provide us with accurate rating information and aid in the accurate evaluation of efficiency.

10.2 Measurement of rotor inertia

It is necessary to do a load test in order to determine a machine's rating. Whenever the machine is loaded, a portion of the input gets lost inside and converts to heat, raising the machine's temperature. Excessive temperature increase harms the insulations, which eventually causes the insulation and the machine to fail. The results of a load test reveal a machine's effectiveness under any load scenario. Additionally, it displays the machine's temperature increase. The machine may be run safely at such load if the temperature increase is less than the insulation's allowable value; otherwise, the load must be decreased. The continuous ratings of both the machine is the greatest continuous load that may be given by it without causing the insulation being employed to overheat. As a result, the load test by itself can provide us with accurate rating information and aid in the accurate evaluation of efficiency.

Swinburne Test of DC Machine

A DC machine may be tested using this indirect technique. It bears Sir James Swinburne's name. The most popular and straightforward technique for assessing shunt as well as compound wound DC devices that have constant flux is Swinburne's test. The machine's efficiency under any load is predetermined for this test. The device may be used as a generator or a motor. With this testing approach, no load losses were evaluated independently, allowing us to finally calculate efficiency.The diagram below depicts the circuit connection for Swinburne's test. With the aid of a shunt regulator R, as shown in figure, the machine's speed is adjusted to its rated speed (Figure 10.1).

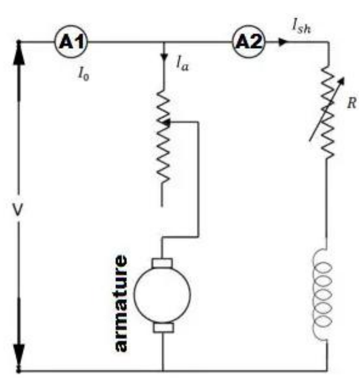

Figure 10.1 Swinburne Test of DC Machine

Calculation of Efficiency

I0, the no-load current, should (it can be measured by ammeter A1)

Ish stands for shunt armature current (it can be measured by ammeter A2)

Then, no load armature current = $(I_0 - I_{sh})$

Let V serve as the supply voltage as well. No load power input is thus equal to VI0 watts.

Swinburne's test has no load and simply requires power input to cover losses. Iron losses inside the machine's core, losses from friction and windings, and copper losses from the armature are indeed the principal losses. In Swinburne's test, this same machine's mechanical output at no load is zero, therefore the no load input power is simply utilized to cover losses.

The value of armature copper loss = $(I_0 - I_{sh})^2 R_a$

In this case, Ra stands for armature resistance.

The armature copper loss must now be subtracted from the no load power input in order to get the constant losses.

The efficiency at any load may now be determined once we have calculated the continuous losses at no load.

Let I be the load current at which we need to determine the machine's efficiency.

When the machine is running, the armature current (Ia) will be equal to (I - Ish).

Additionally, while the machine is producing.

Calculation of Efficiency When the Machine is motoring on Load

Power input = VI

Armature copper loss,

$$P_{CU} = I^2 R_a = (I - I_{sh})^2 R_a$$

Constant losses,

$$W_C = VI_0 - (I_0 - I_{sh})^2 R_a$$

$$Total\ losses = P_{CU} + W_C$$

Efficiency of the motor=

$$\eta_m = \frac{output}{input} = \frac{input - losses}{input} = \frac{VI - (P_CU + W_C)}{VI}$$

Calculation of Efficiency When the Machine is Generating on Load:

Power input = VI

Armature copper loss,

$$P_{CU} = I_2 R_a = (I + I_{sh})^2 R_a$$

Constant losses,

$$W_C = VI_0 - (I_0 - I_{sh})^2 R_a$$

$$Total\ losses = P_{CU} + W_C$$

Efficiency of the generator=

$$\eta_g = \frac{output}{input} = \frac{input - losses}{input} = \frac{VI - (P_C U + W_C)}{VI}$$

Advantages of Swinburne's Test

The key benefits of this test include: This test is highly practical and cost-effective since it uses very little power from the supply to carry out the test. Since continuous losses are known, Swinburne's test efficiency can be predicted for any load.

Disadvantages of Swinburne's Test

The following are this test's key drawbacks: Iron loss is ignored even when it changes from no load to full load as a result of armature response. Because the test was conducted with no load, humans cannot be certain that the commutation performed well under loaded conditions.

Whenever the machine is loaded, we are unable to monitor the temperature increase. Temperature may affect power losses. Since the Swinburne's test is a no load test, it cannot be used to determine the efficiency of DC series motors.

Hopkinson's Test or the DC machine's Regenerative Test

Regenerative Testing is another name for Hopkinson's DC Machine Test. This test is one of the most effective techniques to assess a DC machine's efficiency and losses. Two identical DC equipment are mechanically coupled together to conduct the test. Where one device serves as a motor and the other as a generator.

As a result, the generators electrical output powers the motor, which is coupled to the generator via a shaft. This test is also known as the "back-to-back test" because the motor as well as generator may operate back-to-back.

Hopkinson's Test: Performance and Circuit Diagram

Below is a circuit schematic that has two identical DC shunt machines having mechanically connected shafts. In this test, two machines that are electrically linked in parallel by a switch S are made to operate as a motor and a generator, respectively. In reality, the generator's output of electrical energy is insufficient to power the motor because of the decline caused by the existence of losses. An external dc supply was connected to the motor in order to offset these losses. Therefore, the power used from the external source is solely used to account for machine loss (Figure 10.2).

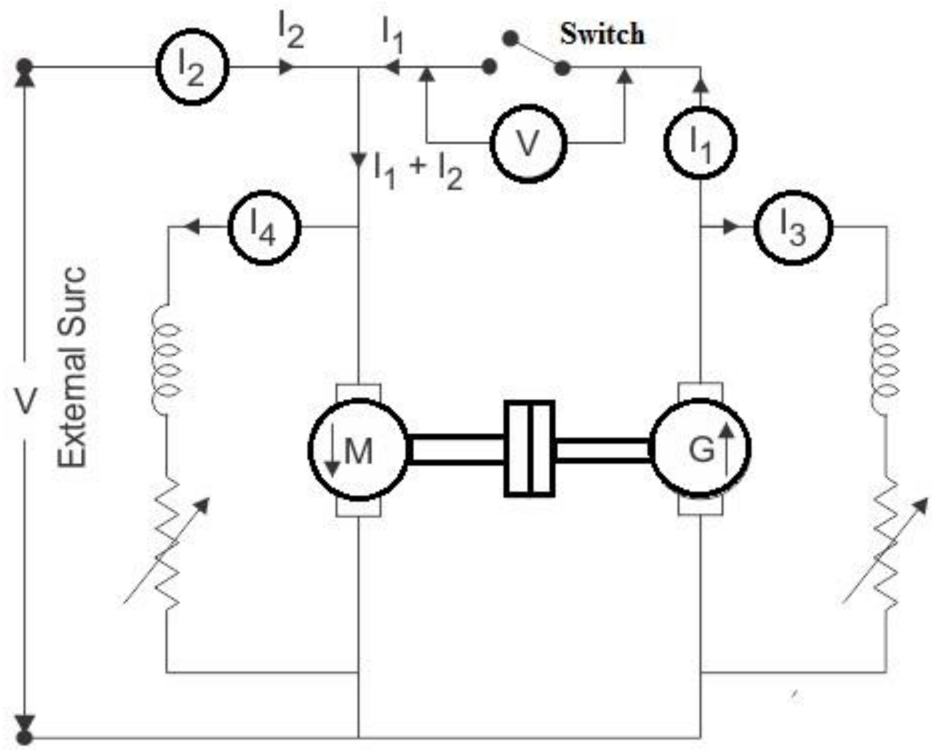

Figure 10.2 Circuit Diagram of Hopkinson's Test

The output with one machine is sent to the the others and vice versa, preventing waste and allowing for full load testing. The switch S is initially left open, and power is supplied to machine M, which functions as a motor. By regulating the shunt field resistance with both the aid of a rheostat attached to the field circuit, the motor's speed is brought up to its rated value. As a result, a generator, G, is operated by another machine, motor. Now, the rheostat linked to the generator field winding adjusts the generator voltage until the voltmeter V placed across the switches S reads zero. This shows that the generator voltage is identical to the supply voltage in terms of both magnitude and polarity. The switch is turned off when the voltmeter displays zero. Therefore, the machines may be placed into any desired load by adjusting the excitation intensity of the fields using rheostats.

Calculation of Efficiency by Hopkinson's Test:

If V is the supply voltage,

Supply current = I_1

I_2 is the amount of generator-supplied current.

I_3 = Shunt field current of the generator

I_4 = Current in the motor shunt field

Ra is the generator and motor's armature resistance.

= The combined generator and motor's efficiency

Here, we can see that the input to the motor is the total of the output from the generator and the external power source, adjusted for losses. The mechanical production of the motor serves as the input towards the generator in a similar manner.

The output power of the generator is equal to V I2 if V is indeed the supply voltage.

(1) The motor's input power is V (I1 + I2), and its output power is V (I1 + I2).

Consequently, from calculations (1) and (2), the generator's input power (and the motor's output power) are equal to V (I1 + I2) and V (I2 + I2), respectively (2),

$$\eta^2 \, V(I_1 + I_2) = V \, I_2$$

$$or$$

$$\eta = \sqrt{\frac{I_2}{I_1 + I_2}}$$

When the losses of the generator as well as the motor are assumed to be equal, the resultant efficiency equation is used. Because the armature current is greater than that of a generator in actuality, the copper loss of the motor armature is greater. Additionally, since a generator's excitation current is higher than a motor's, the generator's shunt field copper losses and iron loss are increased.

The efficiency of something like the two machines differs due to these variations in losses. if the constant inefficiencies for both machines are considered to be equivalent (losses due to iron, friction, and windage). The two machines are then equally responsible for sharing the continual losses. We were aware that the total losses including both machines were equal to the power they drew from the outside, or V I1. Therefore, the constant losses Wc were calculated by deducting the external power taken from the motor and generator's armature as well as shunt field copper losses.

Constant losses of the motor and generator are given by Wc = V I1 - armature and shunt field core losses.

The efficiency of the machines may be estimated independently by knowing the constant inefficiencies as,

Efficiency of the Motor

Let,

Motor power input is equal to V (I1 + I2).

Motor constant losses equal Wc/2 Motor copper loss equals (I1 + I2 - I4)

Motor loss due to 2 Ra Shunt field copper = V I4

Hence, the motor's efficiency is,

$$\eta_m = \frac{output}{input} = \frac{input - losses}{input}$$

$$= \frac{V(I_1 + I_2) - \left[(I_1 + I_2 - I_4)^2 R_a + VI_4 + \frac{W_c}{2}\right]}{V(I_1 + I_2)}$$

Efficiency of the Generator:

Let,

The generator's power output is equal to V I2.

Generator constant losses equal Wc/2.

Generator armature copper loss equals (I2 + I3)

Generator copper loss at 2 Ra Shunt field = V I3

Consequently, the generator's effectiveness is,

$$\eta_g = \frac{output}{input} = \frac{output}{output + losses}$$

$$= \frac{VI_2}{VI_2 + \left[(I_2 + I_3)^2 R_a + VI_3 + \frac{W_c}{2}\right]}$$

Benefits of the Hopkinson's Test

Only enough electricity is needed to cover the machines' losses, which is a very modest amount. It is simple to assess the temperature increase and commutation of both machines since the test is performed at full load. Without actually loading the equipment with a full range of loads, the test is conducted. Due to the fact that huge equipment can be evaluated at full load using little electricity, the testing approach is particularly cost-effective. The disadvantage of changing iron losses when machines are loaded owing to armature response in Swinburne's Test is eliminated since the test is conducted at full load.

Problems with Hopkinson's Test

Practically speaking, having two identical machines and doing an analysis while testing tiny DC machines are both challenging.

Motor Field Test for DC Series

The most widely used test for dc machines to identify losses and efficiency is the Swinburne test. It is an indirect technique used to test a DC machine without actually loading it. Since it is a no-load test, a series motor reaches an extremely high speed when there is no load. Swinburne's test is thus challenging to do on large series motors. Therefore, only dc shunt and small series devices may be used with Swinburne's test. Field tests may be used to get around this problem. Let's examine in this post how a field test may be used to assess the efficacy of dc series motors.

Motor Field Test for DC Series

Two comparable dc series motors, which are often used for electric traction tasks, are employed in a field test. In a field test, the efficiency and losses of two comparable dc series motors with their field windings coupled in series are assessed. The two machines are mechanically connected such that one operates as a motor while the other is a generator that is powered by the motor. The variable load resistance R allows the generator's electrical output to flow through while dissipating it as heat. Below is a circuit schematic for a dc series motor's fields test (Figure 10.3).

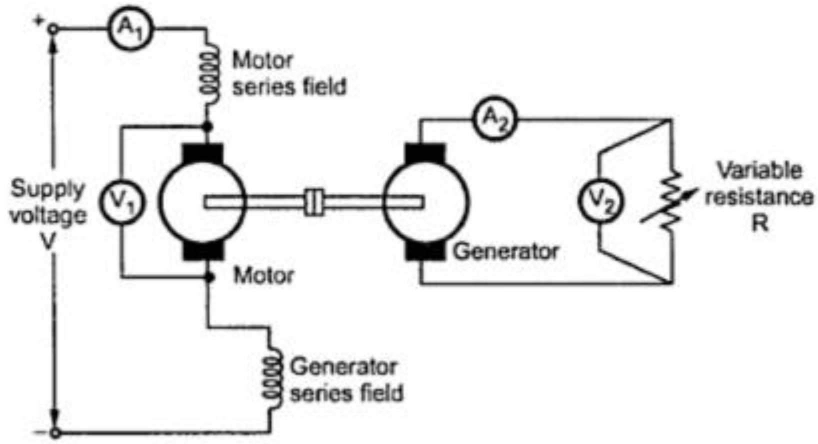

Figure 10.3 Illustrate the circuit diagram for Motor Field Test for DC Series

They experience frictional losses and ongoing losses as they rotate. By connecting the series field winding of the generator with both the motor armature circuit, it is possible to equalize the iron and frictional losses of the two machines. Running the machines at the same pace will synchronize them.

Losses of copper and iron are influenced by Bm and frequency, which in turn are influenced by Bm flux and speed. By meeting the aforementioned two requirements, the iron losses may be kept constant. Until the armature attached to the motor armature circuit receives the full-load value, the load resistance R is modified. Following this adjustment, various voltmeter and ammeter measurements are recorded.

Let,

Voltmeter reading equals supply voltage, where V = V1 volts.

Motor input current = ammeter reading, A1 = I1 Generator terminal voltage equals voltmeter readings, V2 = V2.

Generator loading current equals ammeter reading A2 = I2

Each machine's armor resistance is equal to Ra.

Each machine's series field is equal to Rse.

V1 I1 is the input to the complete set.

The whole set's output is V2 I2.

Set losses as a whole are equal to P1 = V1 I1 - V2 I2.

Motor copper loss due to series field and armature = (Ra + Rse) armature and field of the I12 Series generator copper loss = I22 Ra + I12 Rse

Pcu, or the set's total copper losses, is equal to I12 Ra plus I12 Rse plus I22 Ra plus I12 Rse.

Pcu = (Ra + 2Rse) + (I12 Ra + I22 Ra)

Set stray losses equal PT - Pcu Stray losses for each device are calculated as (PT - Pcu) / 2 = Ps.

Field Testing of a DC Series Motor: Benefits and Drawbacks

The most widely used test for dc machines to identify losses and efficiency is the Swinburne test. It is an indirect technique used to test a DC machine without actually loading it. Since it is a no-load test, a series motor reaches an extremely high speed when there is no load. Swinburne's test is thus challenging to do on large series motors. Therefore, only dc shunt and small series devices may be used with Swinburne's test. Field tests may be used to get around this problem. Let's examine in this post how a field test may be used to assess the efficacy of dc series motors.

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Motor Field Test for DC Series

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Running the machines at the same pace will synchronize them.

Losses of copper and iron are influenced by Bm and frequency, which in turn are influenced by Bm flux and speed. By meeting the aforementioned two requirements, the iron losses may be kept constant. Until the armature attached to the motor armature circuit reads the full-load value, the load resistance R is modified. Following this adjustment, various voltmeter and ammeter measurements are recorded.

Let,

Voltmeter reading equals supply voltage, where V = V1 volts.

Motor input current equals ammeter reading (A1 = I1), generator terminal voltage equals voltmeter readings (V2 = V2), and generator loading current equals ammeter reading (A2 = I2).

Each machine's armor resistance is equal to Ra.

Each machine's series field is equal to Rse.

V1 I1 is the input to the complete set.

The whole set's output is V2 I2.

Motor field and armature copper loss = (Ra + Rse) Total losses of the set = P1 = V1 I1 - V2 I2 Generator copper loss in the I12 Series field and the armature is equal to I22 Ra plus I12 Rse.

Pcu, or the set's total copper losses, is equal to I12 Ra plus I12 Rse plus I22 Ra plus I12 Rse.

Pcu = (Ra + 2Rse) + (I12 Ra + I22 Ra)

Set stray losses equal PT - Pcu Stray losses for each device are calculated as (PT - Pcu) / 2 = Ps.

Motor Efficiency

Motor input equals V1 I1.

Motor losses are equal to I12(Ra + Rse) + Ps.

Motor output is calculated as V1 I1 - [I12 (Ra + Rse) + Ps]

Consequently, the motor's efficiency is,

$$\eta_m = \frac{V_1 I_1 - \ [I_1^2(R_a + R_{se}) + P_S]}{V_1 I_1}$$

Generator Efficiency

Generator losses equal I22 Ra + I12 Rse + Ps. Generator input equals V2 I2.

Output of the generator is V2 I2 + I22 Ra + I12 Rse + Ps.

Consequently, the generator's efficiency is,

$$\eta_g = \frac{V_2 I_2}{V_2 I_2 + I_2^2 R_a + I_1^2 R_{se} + P_S}$$

Benefits of Field Testing

Calculating stray losses is simple since the two machines have the same excitation and speed. To prevent the load from being unintentionally thrown off, the generator armature is directly linked to load resistance R without the need of a switch.

The iron losses including both machines are the same since the fields of the generator and the generator are connected in series.

Benefits of Field Test

The arrangement is large and takes up a lot of room. Due to the utilization of two machines, there's going to be an increase in energy consumption. Through load resistance, the generator's electrical output is converted to heat and dissipated. Hopkinson's Test uses it to provide input to the motor.

Running down Test or Retardation Test on DC Machines

We'll talk about the retardation test for DC machines. Running down test is another name for the retardation test. This is a very effective method for determining stray losses in three - phase induction motors. In this test, we only measure the total stray losses due to the machine's mechanical (friction and windage) and demagnetization. Below is a circuit schematic for a retardation experiment on DC machines. Armature terminals A1, A2 (Figure 10.4).

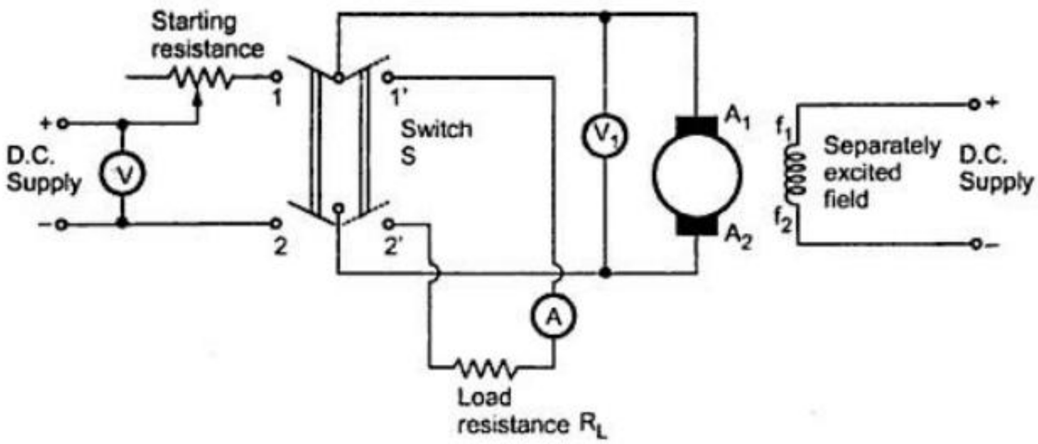

Figure 10.4 Schematic diagram for Retardation Test on DC Machines

The procedure of Retardation Test on D.C Machines

The key components of the running down or retardation test are outlined below. 1. Start the DC machine now normally, and by varying the resistance, run it a little faster than it is rated to go. 2. Just switch off the power supply to the armature after reaching the desired speed while keeping the field excited normally. 3. Next, wait for the speed to drop below the rated level for a while, and then, using the tachometer, record the values for speed (in rpm) and time (in the sec). As a result, the armature slows down and uses its stored kinetic energy to compensate for rotational or incidental losses such iron, friction, and winding loss. If I am the armature's inertia as well as the angular velocity, then Armature kinetic energy equals 0.5 I2. Rotational losses, W = Kinetic energy change rate.

$$W = \frac{d}{dt}\left(\frac{1}{2}I\omega^2\right) = I\omega\frac{d\omega}{dt}$$

I=Moment of inertia of the armature. In retardation test of dc machines, the rotational losses are given by,

Let N = normal speed in r.p.m.

ω = normal angular velocity in rad/s = 2π N/60

∴ Rotational losses, W = Rate of loss of K.E. of armature

or $$W = \frac{d}{dt}\left(\frac{1}{2}I\omega^2\right) = I\omega\frac{d\omega}{dt}$$

Here I is the moment of inertia of the armature. As ω = 2π N/60,

$$\therefore \quad W = I \times \frac{2\pi N}{60} \times \frac{d}{dt}\left(\frac{2\pi N}{60}\right) = \left(\frac{2\pi}{60}\right)^2 IN\frac{dN}{dt}$$

or $$W = 0.011\, IN\frac{dN}{dt}$$

Swinburne's Test

The variation in speed from no load to full load is rather minor for a d.c. shunt motor. Therefore, it is reasonable to expect that mechanical loss will not change as the load increases. Additionally, the core loss may be considered to stay the same provided field current is maintained constant throughout loading. In this test, the motor is operated at rated voltage and speed with no load. Both the field current When and the current obtained from the supply IL0 are noted. The motor's net mechanical power generated is 0 since it is not under load. Therefore, the core loss, frictional losses, and windage losses of the motor must be covered by the gross power generated by the armature. Therefore,

$$P_{core} + P_{friction} = (V - I_{a0}r_a)I_{a0} = E_{b0}I_{a0}$$

From no load to complete load, a shunt motor's Pcore and Pfriction stay essentially constant, hence the total of these losses is known as constant rotational loss.

$$\text{constant rotational loss, } P_{rot} = P_{core} + P_{friction}$$

The continuous rotational loss in the Swinburne's test, which consists of core and friction loss, is determined using the equation above. We can accurately predict the motor's efficiency under any loading scenario once we know the value of Prot from the Swinburne's test. Let's assume that the motor is loaded such that the new supply current is IL as well as the new armature current is Ia. The main benefit of Swinburne's test would be that the shunt machine may be operated as a motor with low power consumption from the supply, and efficiency can be anticipated for any load current based on the no load result. However, such test is insufficient if we would like to learn more about how it will function under real load (including the impact of armature response, temperature increase, and commutation). The obvious approach is to load the machine, either directly on the motor shaft for a motor, or across the terminals for a generator, depending on the application. For high rating machines (let's say over 20 kW), this may seem straightforward, but it might be challenging to apply in the lab. As a result, the laboratory has to have enough supply to provide such a huge power in accordance with the machine's rating. Second, one has to have a lot of weight to absorb this power.

Calculation of efficiency

Let's say the machines' field currents are adjusted such that the initial machine acts as a motor with nothing but an armature winding of Iam and the second machine acts as a generator with or without an armature current of Iag. Let's also suppose that I1 is the current pulled from the supply. Total power taken from the source is VI1, which is used to power both machines' rotational and Cu losses inside the armature and field.

$$\begin{aligned}
\text{Power drawn from supply} &= VI_1 \\
\text{Field Cu loss for motor} &= VI_{fm} \\
\text{Field Cu loss for generator} &= VI_{fg} \\
\text{Armature Cu loss for motor} &= I_{am}^2 r_{am} \\
\text{Armature Cu loss for generator} &= I_{ag}^2 r_{ag} \\
\therefore \text{Rotational losses of both the machines} &= VI_1 - \left(VI_{fm} + VI_{fg} + I_{am}^2 r_{am} + I_{ag}^2 r_{ag}\right)
\end{aligned}$$

Since the speed of both machines is the same, it is reasonable to assume that their rotational losses are also equal. However, this assumption is incorrect because the field current of something like the generator will be slightly greater than the field current of something like the motor. As a result, once Prot is guesstimated for each machine, researchers can proceed to calculate the machines' efficiency as follows,

$$\text{Rotational loss of each machine, } P_{rot} = \frac{VI_1 - \left(VI_{fm} + VI_{fg} + I_{am}^2 r_{am} + I_{ag}^2 r_{ag}\right)}{2}$$

CHAPTER 11

Working Principle of Transformer

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Electricity is transferred from one circuit to another through electrical transformers, which modify the voltage level but don't change the frequency.They were designed to use an AC supply, therefore differences in the supply voltage must effect variations throughout the current. As a consequence, an increase in voltage and vice versa will happen as current increases. Transformers contribute to the reliability and efficiency of energy networks by altering voltage levels as needed. Although they are used in a variety of domestic and professional contexts, the long-distance distribution and regulation of electricity may be their most significant usage. Transformer: Transformer functioning is based on the idea of mutual induction. An iron core connects the transformer's windings.

A voltage is produced in the windings as a result of the permeability in the core, which links the primary and secondary windings. The workings of the transformer are explained in the paragraphs that follow. An alternating voltage is applied to the main winding, where causes magnetizing potential to flow through it. As a result, magnetizing flux is generated and concentrated in the contained low reluctance permanent magnets path. This flux links the primary and secondary windings together. Voltage is self-induced throughout the main winding and the secondary winding, accordingly. Each turn, the voltage output is the same in the primary and the secondary windings. The temperature throughout the windings is influenced by the winding's number of turns. Depending on the voltage level, there are two different kinds of transformers: step up transformers and step down transformers. Its electrical voltage is increased by using step-up transformers. Transformers called step downs are used to reduce electrical voltage. Instrumentation transformers, distribution lines, and power generating equipment make up the three types of transformers (Figure 11.1).

A transformer is made up of a laminated steel core and two inductive windings.The coils and steel core are separated from one another. An oil regulator that can provide oil to cool its transformer tank, suitable bushings for connecting terminals, a tank-like container for both the winding and cores assembly, and other parts may also be found in a transformer on the left depicts a transformer's basic structure. The cores of all types of transformers are constructed by stacking or combining laminated steel sheets with little to no gap separating them (to achieve continuous magnetic path). The steel used does have a high silicon content and is occasionally heat treated to provide high permeability and minimum hysteresis loss. Eddy current losses are minimized by using laminated steel sheets. E, I, while L are formed from the sheets. To avoid excessive impedance at joints, laminations are layered by flipping the sides of joints. In those other words, if the joints of the first sheet construction are located on the front face, the joints of the next assembly will be located on the back face.

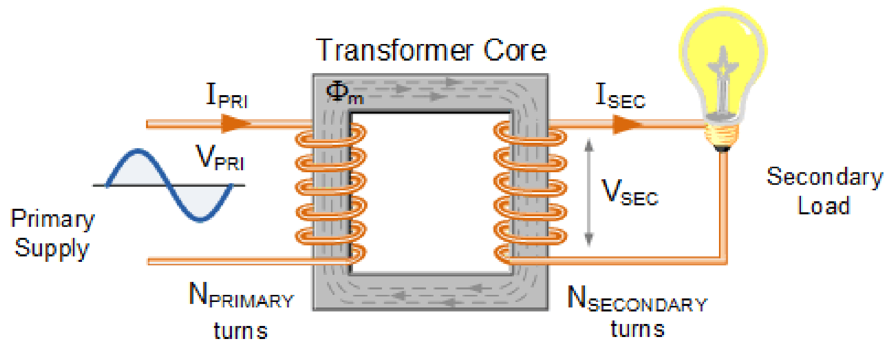

Figure 11.1 Construction of transformer

Transformer Construction (single-phase):

Keep in mind that perhaps the two coil windings are just magnetically coupled and not electrically connected. A single-phase transformer may be used to alter the voltage provided to the primary winding shown Figure by either raising or lowering it.When a transformer is used to "increase" the voltage within its own secondary winding in relation to the primary, it is referenced to as a step-up transformer. To "decrease" the voltage on a certain secondary winding in relation to the main, step-down transformers were utilized (Figure 11.2).

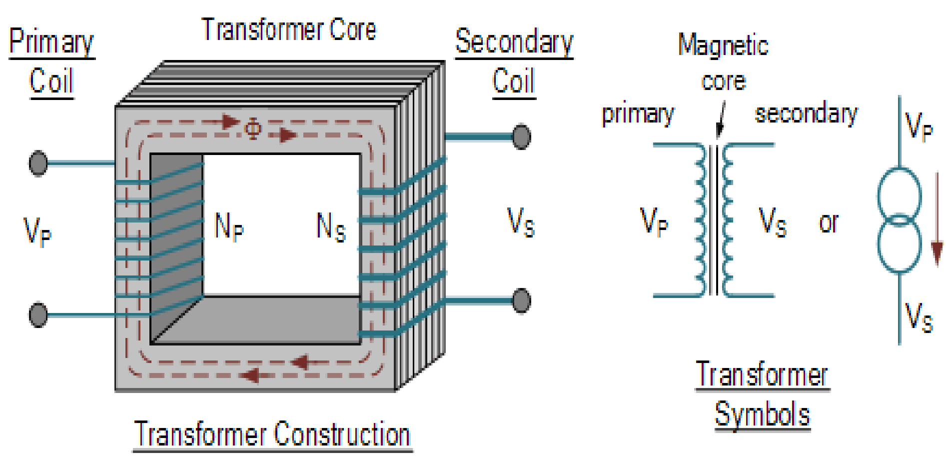

Figure 11.2 Construction of single phase transformer

Where:

VP is equal to the Primary Voltage

VS is equal to the Secondary Voltage

NP is equal to the Number of Primary Windings

NS is equal to the Number of Secondary Windings

Φ (phase) is equal to the Flux Linkage.

Remember that the two coil windings really aren't electrically linked, but merely magnetically related. A single-phase transformer could alter the voltage provided to the main winding while it is in operation. When a transformer is used to "increase" the voltage its own secondary winding in relation to the primary, it is called to as a step-up transformer. To "decrease" the voltage upon that secondary coil in relation to the main, step-down transformers are utilized. Furthermore, there is a third situation that takes place whenever a transformer's secondary voltage is equal to the main winding's voltage differential. In other terms, the output's voltages, current, and power are exactly the same. These transformers, also known as impedance transformers, are often used for resonant frequency or even when separating neighboring electrical circuits.

A Transformers Turns Ratio

By adjusting the number of coil rounds in the primary winding (NP) in relation to the number of coils turns upon that secondary winding, the voltage differential between both the primary and secondary windings may be produced (NS). There is now a ratio between the main coil's turns divided by that of the secondary coil's turns since the transformer is essentially a linear device [1]. This ratio, sometimes known as a transformer's "turns ratio" or the ratio of transformation (TR). The transformer's functioning and the accompanying voltage present just on secondary winding are determined by the ratio value of the turn. The proportion of wire turns on the main winding to those on the secondary winding must be understood. The turn's ratio, which compares both two windings in sequence and has no measures, is expressed with a colon, for example, 3:1. (3-to-1). According to this example, 3 volts on the main winding will result in 1 volt here on secondary winding, or a 3 volts-to-1 volt ratio. The resultant voltages must vary in the same ratio if the proportion between the numbers of turns varies, and this is true. The theme of Transformers is "ratios." Any particular transformer's primary to secondary ratio, inputs to ratio of output, and turn ratio will all be equal to that transformer's reference voltage. In other terms, "turns ratio = voltage ratio" for something like a transformer. Just the turn’s ratio matters, not really the actual number of cable turns on any particular winding, and this correlation is represented as: Formula for ratio transformation.

$$\frac{N_P}{N_S} = \frac{V_P}{V_S} = n = turn\, ratio$$

Considering the phase angles and a perfect transformer: $\Phi P \equiv \Phi S$ Because the turns ratio 3:1 represents a completely different transformer relationships and output voltage from a situation in which the turns ratio is presented as: 1:3, it is vital to note that perhaps the order of the numbers is crucial when describing a transformer's turns ratio value.

Transformer Action

As people’ve seen, the turn ratio, or the ratio of secondary winding to primary winding coils turns, influences the voltage output of the secondary coil. However, how does this secondary voltage created if the two windings remain electronically insulated from one another. A transformer, as shown in Figure, essentially consists of two coils twisted around a single soft iron core.

The main coil receives current whenever an alternating voltage (VP) is provided, which causes the coil to create a magnetism around itself. Faraday's Law of electromagnetic induction refers to this phenomenon as mutual inductance. As even the current flow increases from zero to its optimum amount, denoted as d/dt, the magnetic field becomes stronger. The soft inner core of the this electromagnet creates a route for and focuses the magnetic flux as that of the magnetic field and the direction it has created extend outward from the coil. Under the effect of the AC supply, that magnetic flux rises and decreases in opposing directions, connecting the turns of the both windings.

The amount of current as well as the number of turns throughout the winding, however, determine the intensity of the magnetic field that is induced into to the soft core of iron. The magnetic field intensity decreases when current is decreased. A voltage is induced into in the secondary coil whenever the magnetic streams of flux travel around the core and pass through to the turns of a secondary winding. N*d/dt (Faraday's Law), where N represents the number many coil turns, will determine how much voltage is generated. Additionally, the main winding voltage and this induced voltage have the same frequency.

As a result of the identical magnetic flux connecting the turns of both windings, we can observe that the same potential is generated in each coils turn of both windings. As a consequence, each winding's overall induced voltage is inversely proportional to the number of revolutions in that winding. However, if the magnetic inefficiencies of the core are considerable, the peak magnitude of the output voltage accessible upon that secondary winding will indeed be decreased.

They may either transmit more current through the primary coil or maintain the same flow of current while enhancing the number the coil turns (NP) of the wrapping in order to boost the primary coil's ability to generate a magnetic field strong enough to overcome the core's magnetic losses. The "ampere-turns," a product of amperes and turns, is what defines the coil's magnetizing power. So let's assume we have a transformer with something like a single main turn and a single secondary turn. If there are no losses and one volt is delivered to the primary coil's one turn, enough power must flow and magnetic flux must be produced to induce one voltage in the secondary coil's one turn. In other words, each winding can handle the same amount of volts every turn. The fundamental connection between the induced emf, (E) in a coil winding with N turns being given by when the magnetic flux fluctuates sinusoid ally = max, sint:

Emf = turns x rate of change:

$$E = N\frac{d\emptyset}{dt}$$

$$E = N * \omega * \emptyset_{max} * \cos\omega t$$

$$E_{max} = N\omega\emptyset_{max}$$

$$E_{rms} = \frac{N\omega}{\sqrt{2}}\emptyset_{max} = \frac{2\pi}{\sqrt{2}} * f * N * \emptyset_{max}$$

Where:

f= is the flux frequency in Hertz, = ω/2π

N= is the number of coil windings.

Φ=is the amount of flux in Webbers$E_{rms} = 4.44\ fN\emptyset_{max}$

Electrical Power in a Transformer

The power rating of the transformer is yet another of its fundamental characteristics. Simply calculating the current even by voltage to get a rating in Volt-amperes gives you the power rating of a transformer (VA). Larger power transformers were rated in Kilo volt-amperes (kVA), where 1 kilo volt-ampere is equivalent to 1,000 volt-amperes, or Mega volt-amperes (MVA), wherein 1 mega volt-ampere is equivalent to 1 million volt-amperes. Single small component transformers may simply be measured in volt-amperes. Since transformers are constant-wattage devices and only vary the voltages to current ratio, the power available inside the secondary coil and the primary winding will be equal in a perfect transformer (again, disregarding any losses). In a perfect transformer, total voltage, V, multiplied by that of the current, I, will always stay constant, making the Power Ratio equal to just one (unity). In other words, electricity generation on the primary side place at a single voltage/current level is "converted" into electric power on the secondary side using the same frequency and voltage/current level. The transformer may increase (or decrease) voltage, but it cannot increase power. The output current always seems to be equal to the input power since a transformer steps up a voltages while stepping down a current and vice versa. When primary power matches secondary power, we may say that (PP = PS).

Power in a Transformer

$$Power_{Primary} = Power_{Secondary}$$

$$Power_{Primary} = Power_{Secondary} = V_P I_P \cos \emptyset_P = V_S I_S \cos \emptyset_S$$

The main phase angle is P, while the secondary phase angle is S.

Keep in mind that because power loss is inversely proportional to the square of both the transmitted current, that is: I2R, doubling the voltage, for example, would reduce the current by exactly the same amount while providing the same quantity of electricity to the load, resulting in a 4x reduction in losses. The total losses would be decreased by an amount of 100 if the voltage were raised by a ratio of 10, and the current would fall by the same amount.

Transformer Basics – Efficiency

A transformer may transmit energy without the need of any moving components. This indicates that no losses due to friction and wind age are present in other electrical equipment. Transformers do experience additional kinds of losses, referred to as "copper losses" and "iron losses," although these are often fairly minor. The electrical power that is lost in heat as a consequence of the currents flowing through the copper windings of a transformers is known as copper losses, also known simply I2R loss. The biggest loss in a transformer's functioning is due to copper losses. By square the amperes then multiplying by the winding's resistance in ohms, it is possible to calculate the actual watts of power lost (in each winding) (I2R). The lagging of the magnetic molecules throughout the core in proportion to the switching magnetic flux is known called iron losses, also referred as hysteresis. The reason for this trailing (or out-of-phase) state is because magnetic molecules need power to reverse; they don't do so until the flux has enough force to do so. Their reversal causes friction, and heat is created in the core as a consequence of friction, which is a sort of power loss. By using particular steel alloys for the core, hysteresis within in the transformers may be reduced. The amount of electricity lost by a transformer affects how efficient it is. Power (wattage) loss between both the main (input) and secondary (output) field winding of a transformers is a measure of its efficiency. As a consequence, a transformer's efficiency is high and equal towards the proportion of the input power toward the primary winding (PP) and output (PS) of both the secondary winding.

An ideal transformer should transfer all of the electricity generated it receives on one of its primary side to its own secondary side with a 100% efficiency rate. Real transformers, however, are not always as effective.

Their greatest efficiency while working at full maximum load is closer to 94% and 96%, which is nonetheless pretty respectable for an electrical equipment. A transformer's efficiency may reach up to 98% when it is running at a steady AC voltage and frequency. A transformer's efficiency is stated as:

<u>Transformer Efficiency</u>

Where: Power units are used to represent input, output, and losses.

$$Efficiency, \eta = \frac{output\ power}{input\ power} * 100\%$$

$$= \frac{input\ power - Losses}{input\ power} * 100\%$$

$$= \frac{1 - Losses}{input\ power} * 100\%$$

When discussing transformers, the main watts are often referred to as "volt-amps," or VA, to distinguish them from either the secondary watts. The efficiency equation may then be changed to:

$$Efficiency, \eta = \frac{secondary\ watts\ (output)}{Primary\ VA\ (Input)}$$

When studying about the fundamentals of transformers, utilizing images may help students retain the connection between the input, output, and efficiency of the transformer. Here, the three values of VA, W, and have been stacked to form a triangle, with the top representing power in megawatts and the bottom representing volt-amps and efficiency. This configuration accurately reflects where each number really sits in the efficiency formulae. I'll then wrap up my primer on transformer fundamentals.

A magnetic field is used by a transformer to convert one value on its own output winding to a different amount of voltage (or current) on its input winding. A transformer is made up of two electrically separate coils and works on the Faraday principle of "faraday's law of induction," according to which the magnetic flux produced by the currents and voltages passing in the main coil winding induces an EMF in the transformer's second winding.

To minimize eddy current and power inefficiencies, the main and secondary coil secondary winding are both wrapped around a single, individually laminated soft iron core. The secondary winding of the transformer distributes electricity to the load, whereas the stator windings of the transformer is linked to the AC power source that must be sinusoidal in nature. However, if the voltage and current ratings are followed, a transformer may be utilized in reversal with both the slightly greater to the secondary coil.

Transformer Construction

A magnetic circuit, more generally referred to as the "transformer core," is part of the architecture of a transformer and is intended to provide a channel for the magnetic field to travel around. The voltage induction between both the two input and output windings requires this magnetic route.

However, because the primary and secondary windings are so far apart from one another, this style of transformer design, in which the two windings are coiled on different limbs, is not particularly effective. Low magnetic connection between both the two windings and significant magnetic flux leakage from either the transformer itself are the effects of this. But in addition to this "O" shape structure, there are many "transformer construction" kinds and designs that may be employed to get around these shortcomings and create a smaller, more condensed transformer.

By putting the two windings into close proximity to one another and enhancing the magnetic coupling, it is possible to increase the efficiency of a straightforward transformer design. The magnetic coupling between the secondary winding may be improved by enlarging and intensifying the magnetic circuit surrounding the coils, but doing so also results in an increase in the magnetic cores of the transformer core.

The cores is designed to avoid flowing electric currents only within iron core itself in addition to providing a low resistance route for the magnetic field. Eddy currents, which circulate and produce energy losses and core heating, reduce the transformer's effectiveness. The iron circuit, which would be continually exposed to the opposing magnetic fields created by the external sinusoidal voltage supply, is the principal cause of these losses. Voltages produced in the iron circuit are what cause these voltages. Making the transformer core out of thin steel laminations is one technique to cut down on these undesired power losses.

The center iron core of the majority of transformer designs is formed of a high permeability material, often from thin silicon strong materials. These thin reinforcements are put together in an assembly to provide the necessary magnetic route with the least amount of magnetic loss. Because the steel sheet itself has a high resistivity, potential eddy current loss may be minimized by using thin laminations. Those steel transformer couplers range in thickness from 0.25 mm to 0.5 mm, and since steel conducts electricity, they are electrically isolated from any fastening studs, rivets, or bolts by a very thin layer of insulating varnishes or through the application of a corrosion products to the surface.

Transformer Construction of the Core

Generally, the name associated with the construction of a transformer is dependent upon how the primary and secondary windings are wound around the central laminated steel core. The two most common and basic designs of transformer construction are the Closed-core Transformer and the Shell-core Transformer.

In the “closed-core” type (core form) transformer, the primary and secondary windings are wound outside and surround the core ring. In the “shell type” (shell form) transformer, the primary and secondary windings pass inside the steel magnetic circuit (core) which forms a shell around the windings as shown in Figure 11.3.

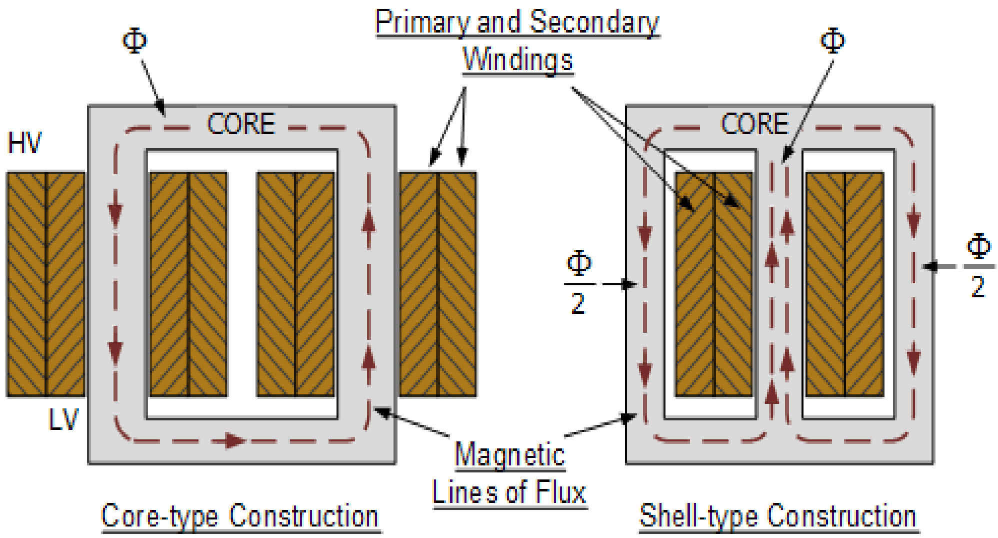

Figure 11.3 Construction of transformer core

The magnetic flux between the main and secondary windings flows wholly inside the core in both kinds of transformer core designs, with no dissipation of magnetic flux via air. Approximately half of the winding is wrapped around every leg (or limb) of a transformer's magnetic circuit when it is constructed using a core type transformer. In order to increase permanent magnets and allow virtually all magnetic lines of force to pass across both the primary and secondary windings while simultaneously time, the coils are not set up with the primary winding on one leg as well as the secondary winding on the opposite. Instead, half of a primary winding as well as half of both the secondary winding are stacked circumferentially on each leg. The term "leakage flux" refers to the tiny amount of magnetic force lines that flow beyond the core of this kind of transformer.

The primary and secondary windings of shell type power transformers are wrapped on the same central leg, which has double the cross-sectional surface of the two outer limbs, therefore preventing leakage flux. The magnetic flux maintains two intense magnetic routes outside the coils upon that left and right without recovering to the core coils, which is advantageous in this situation. As a result, the magnetic flux flowing from around outer extremities of this particular transformer design is equal to /2. Due to the closed route that the magnetic flux takes around the coils, core losses are reduced and overall efficiency is improved.

<u>Transformer Laminations</u>

However, one may be asking how the main and secondary windings for these sorts of transformer structures are twisted around these laminated iron or stainless steel cores. The coils are initially coiled on a former with a cross section of a kind that is cylinder, rectangular, or oval to fit the construction of both the laminated core. Within both the shell and core type transformers designs, the individual reinforcements are punched out or pressed from larger steel sheets forming thin steel strips that resemble the characters "E"s, "L"s, "U"s, and "I" as needed to install the coil field winding.

Transformer Core Types

When joined, these lamination stampings provide the necessary core shape. One component of a typical shell-type transformer core shown Figure is an E-I core, which is made up of two "E" stampings and two end closing "I" stampings. In order to decrease the resistance of the air gap there at connections during construction, these separate laminations are closely butted together, creating a highly saturated density of magnetic flux. In order to create an overlapped junction and the proper core thickness, equipment and other facilities laminations are often stacked alternatively one on top of the other. Reduced flux leakage reduced demagnetization are further advantages of this alternative stacking of something like the laminate again for transformer. Most isolation transformers, step-up and step-down transformers, in addition to auto transformers, employ an E-I core laminated transformer architecture

Transformer Winding Arrangements

Transformer windings, which are the primary current-carrying conductors coiled around the laminated portions of the core, are another crucial component of a transformer's design. Two windings would be included in a single-phase, two-winding transformer, as depicted. The main winding is the one that is linked to the voltage source, generates the magnetic flux, and induces a voltage by mutual induction throughout the secondary winding. A transformer is referred to as a "Step-down Transformer" if indeed the secondary output voltage is less than the main input power. A "Step-up Transformer" is referred to as such if this same secondary output voltage is higher than that of the main input voltage.

Either copper or aluminum wire is utilized as the primary current-carrying component in some kind of a transformer winding. Although aluminum wire is lighter and often less costly than copper wire, it is primarily employed in bigger power transformer operations because a higher cross-sectional area of conductors is required to convey the same amount of electricity as with copper. Copper conductors are often utilized in low voltage electronic and electronic circuits because they have a better mechanical strength as well as a smaller connector size than corresponding aluminum kinds. This is especially true for tiny kVA acceptable voltage transformers. The drawback is that these transformers may be rather heavy when they are fully assembled with their cores.

Concentric coils and sandwiched circuits are two major categories for transformer windings and circuits. The windings are often placed concentrically around at the core limbs in core-type method is implemented, as illustrated above, with both the higher voltage secondary conducting being coiled above the lower voltage secondary winding. Sandwiched or "pancake" coils are made out of flat conductors twisted in a spiral shape; the term comes from the way the conductors are arranged into discs. Individual coils are piled together and kept apart by insulation material like paper or plastic sheet, while alternate discs are designed to spiral around the outside towards to the center in an interleaved manner. With a core architecture of the shell type, sandwich coils intermediate windings are much more prevalent.

Figure shows another typical cylindrical coil configuration used in low voltage, high current transformer applications: helical windings, commonly known as screw windings. Large cross-section rectangular conductors are used to make the windings, which are then wound on their sides with insulated strands running continuously parallel along the duration of the cylinder. Appropriate spacers are implanted between adjacent did turn or diskettes to reduce turbulent flows between both the parallel strands. The coil advances in the shape of a corkscrew as it spirals outward. In an air-cooled transformers, a thin coating of varnish or enamel serves as the insulation to preventing the conductors from short - circuiting to one another. The wire is coated with this thin coat of varnish or enameled painting before being looped around the core. Larger transmission and distribution equipment use oil-impregnated sheets or cloth to insulation the conductors from one another. The whole cores and field winding are submerged and enclosed in a tank of transformer oil for protection. The transformer oil functions as a coolant as well as an insulator.

Transformer Dot Orientation

A laminated core cannot simply include one of the coil configurations wrapped around it. The secondary current and voltage may not be in phase with the main voltage and current, however that is a possibility. The orientation of each of the two current coil in relation to the other is unique. To maintain track of their respective orientations and since each coil might be coiled around the core in either the clockwise or an anticlockwise direction, "dots" are employed to designate a specific end of the each winding. The "dot convention" is the name given to this technique for determining a transformer's orientation or winding direction. The transformer's polarity is then defined by the relative polarity of something like the secondary winding with regard to the primary voltage, after which the windings of a transformers were wound such that the right phase relationships exist between the winding energies.

Transformer Construction using Dot Orientation

In Figure, the first transformer's two "dots" are shown next to one another on its two windings. The current approaching the main side dot and the current exiting the secondary dot are "in-phase." Because of this, the polarities of something like the voltages there at dotted ends are also in phase, however when the voltage is positive there at dotted end of the main coil, it is likewise positive there at dotted extremity of the secondary coil (Figure 11.4).

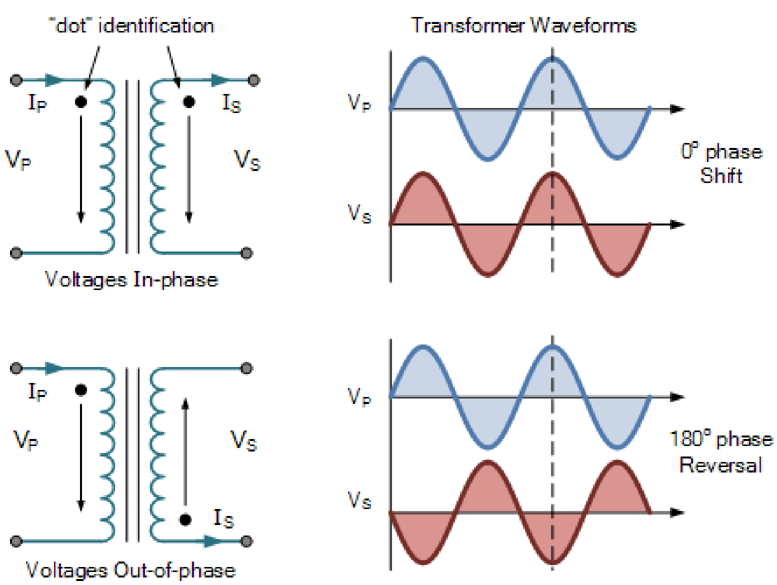

Figure 11.4 Transformer Construction using Dot Orientation

The secondary and primary coil secondary winding of a second transformer are coiled in the opposite directions, as shown by the two dots at the windings' opposing ends. Because of this, the current approaching the main dot and the current exiting the secondary dot are 180o "out-of-phase." As a result, the polarity of the energies at the dotted endpoints are also out of phase, thus while the main coil's dotted end is positive, the voltage from across corresponding second winding will be negative. The power transfer may then be built into a transformer in such a way that it is either "in-phase" with the main voltage or "out-of-phase" with that as well. To communicate transformers throughout series-aiding (secondary voltage is summed) or series-opposing (secondary voltage is the difference) configurations, which require a number of distinct secondary windings that were already electrically separated from one another, it is crucial to understand the dot polarity of each secondary winding. It is often useful to have the option of adjusting a transformer's turn ratio to counteract the impacts of changes in the main supply voltage, the transformer's regulation, or shifting load circumstances. The transformer's voltage is often controlled by adjusting the turn ratio, which affects the voltage ratio. To facilitate this modification, a portion of the main winding here on high voltage side usually tapped off. Due to the lower voltages per revolution upon that high voltage side compared to the low frequency secondary side, tapping is favored there.

Transformer Primary Tap Changes

In this simple example, the principal tap changes are computed for a 5% change in supply voltage, although any value may be used. As shown in Figure, certain transformers with a single core may include two or even more secondary windings or multiple or more main windings to be utilized in various applications (Figure 11.5).

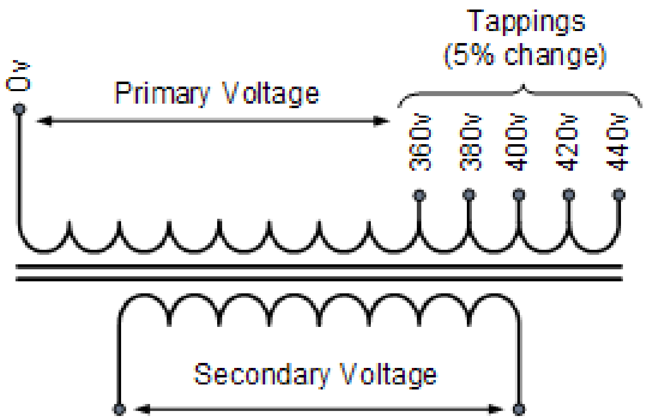

Figure 11.5 Diagrammatic representation of tap changes transformer

Transformer Construction – Core Losses

The capacity to enable magnetic flux to circulate is known as permeability, and it is significantly larger in steel or iron compared to that of air. The majority of transformer cores are made of low carbon steel, which has a susceptibility of up to 1500 as opposed to merely 1.0 for air. This indicates that a steel laminated cores is capable of carrying a magnetic flux 1500 percent stronger than air. Nevertheless, two different forms of losses throughout the steel happen when a magnetic flux runs in the core material of a transformers. Eddy current losses on the one hand, and hysteresis effects on the other hand".

Hysteresis Losses

Hysteresis of the Transformer Because to such sinusoidal supply voltage's impact, magnetic lines of force that are necessary to magnetize the core regularly change in value and direction, first in one direction before switching to the other, therefore results in losses. Heat is produced as a result of this molecular friction, which costs the transformer energy. The lifespan of the insulating materials used for the construction of the windings and structures might be shortened over time by extreme heat loss.

As a result, a transformer's cooling is crucial. Transformers are also built to function at a certain supply frequency. Decreasing the supply frequency will enhance hysteresis and raise the iron core's temperature. Therefore, dropping the supply frequency between 60 Hertz to 50 Hertz will elevate the amount of hysteresis occurring and lower the transformer's VA capacity.

Eddy Current Losses

On the other hand, circulating currents that are induced into steel as a result of the passage of the magnetic flux from around core are what lead to transformer eddy current losses. Continuous circulating currents are produced as a result of the core behaving like a single wire loop throughout the magnetic flux. The eddy currents produced by a solid iron core will have to be substantial since iron is an excellent conductor. Instead of enhancing the utility of the transformer, eddy currents serve as a negative force that causes the core of the transformer to heat up and lose power as they fight the flow of induced emf.

Laminating the Iron Core

Although eddy current losses inside a transformer core can indeed be totally avoided, they may be significantly decreased and managed by reducing this same steel core's thickness. The magnetic path of the transformers or coil is divided up into several thin pressed steel forms known as "laminations" rather than having one large solid iron core.As we saw above, the laminations employed in the building of a transformer are made of very small slices of insulated metal linked together to create a solid yet laminated core.

To improve the effective resistivity of a core and hence raise the overall resistance to restrict the passage of the eddy currents, those laminations are separated from one another by a layer of varnish of paper. All of this insulation has the effect of significantly reducing the unwelcome generated eddy current power loss in the core, which is why every magnetic iron circuit in every transformers as well as other electro-magnetic equipment is laminated. Eddy current inefficiencies in method is implemented are decreased by using reinforcement bars.

Transformer Construction – Copper Losses

The term "transformer core losses" refers to the energy losses, which manifest as heat owing to hysteresis as well as eddy currents throughout the magnetic path. Because alternating magnetic fields cause these losses throughout all magnetic materials, Even if there is no load attached to the secondary winding, a transformers will always have core losses anytime the main winding is activated.

As the magnetic flux generating these losses was constant at any and all loads, the conjunction of hysteresis and electrical resistance losses is sometimes known to as "transformer iron losses.

Copper Losses

However, the transformer is also responsible for a different kind of energy loss known as "copper losses." Transformer The resistance value of the secondary and primary windings is the major cause of copper losses. The majority of transformer coils are wrapped using copper wire, which has a resistance value in Ohms.

According to Ohms Law, any magnetic currents passing through copper wire will be resisted by the copper string's resistance. Large electrical currents begin to flow between the main and secondary windings of a transformer when an excess electricity is attached to the secondary winding, and electrical power and energy losses (the I2 R) happen as heat. Copper losses often change with both the load current, ranging from practically nil at no load to a maximum during full load whenever current flow is at its greatest.

To decrease these core and copper losses, a transformer's volt-amperes (VA) rating may be raised by improved design and construction. Conductors having a wide cross-section are needed for a transformer having high rating of voltage and current in order to reduce copper losses. By enhancing its insulation to tolerate greater temperatures or by boosting the rate at which heat drainage (better cooling) using pressurized air or oil, the transformer's VA rating may be raised. Thus, a perfect transformer would have the following characteristics:

Hysteresis losses and loops are both zero.

Zero Electromotive Force Losses due to Core Material's Infinite Resistivity 0

Zero winding impedance results in zero I2*R copper losses, which equals zero.

Transformer Loading

In the earlier lessons on transformers, they used the assumption that the transformer was perfect, meaning it had no core losses and no copper losses inside the transformer's windings. However, losses related to transformer overloading will always occur when a transformer is placed "on-load" in the actual world. Let's first examine what happened to a transformers when it is in this "no-load" state, which is in which there is no electrical load attached to the transformer's secondary winding and no secondary current will flow as a result. When a transformer's secondary side winding completely open circuited, meaning that nothing is connected as well as the transformer loading is zero, such transformer is described as being "on no-load." A minor current, IOPEN, will flow through into the primary coil winding of a transformer whenever an AC sinusoidal power source is connected to the primary winding because the standard power voltage is present. This primary current's flow is limited by a back EMF and the primary winding impedance while the secondary circuit is unconnected and open. Clearly, this no-load primary current (Io) should be enough to sustain a sufficient gravitational flux in order to generate the necessary back emf.

Transformer "No-load" Condition

Despite the fact that secondary circuit in Figure is open circuited, the ammeter above should show a modest current that flows through the primary winding. The following two elements make up this no-load main current (Figure 11.6):

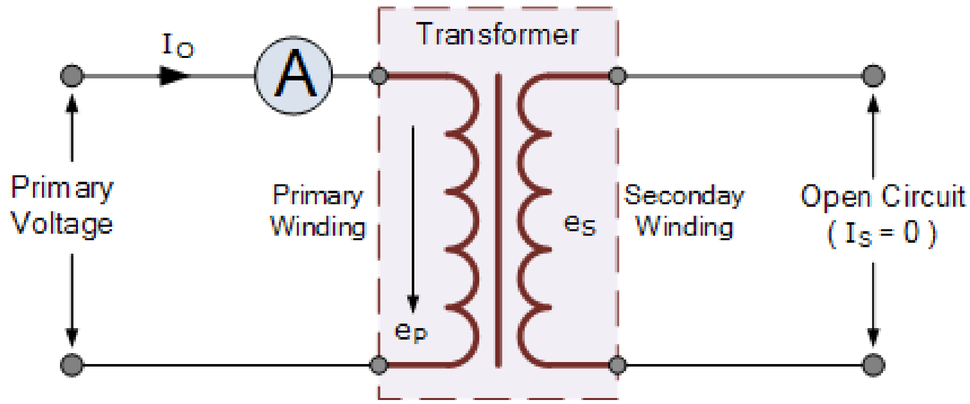

Figure 11.6 Schematic diagram of Transformer at "No-load" Condition

A current that is in phase and provides the core losses (eddy current and hysteresis).

A little current, IM at 90 degrees to the voltage that creates the magnetic flux.

Transformer "On-load"

A current flows throughout the secondary winding and to the load whenever an excess electricity is attached to a transformer's secondary winding and the transformer overloading is therefore higher than zero. The magnetic flux generated in the core by the main current is what causes the carried out effectively, which is caused by the induced voltage supply. In the transformer core, the secondary winding, IS, which depends on the load's characteristic, induces a secondary magnetic field, S, which moves in the absolute reverse direction of the main primary field, P. Due to the opposition between these two electromagnetic fields, the combined magnetic field is less than the single magnetic field generated by that of the primary winding by itself when the supplementary circuit is open circuited (Figure 11.7).

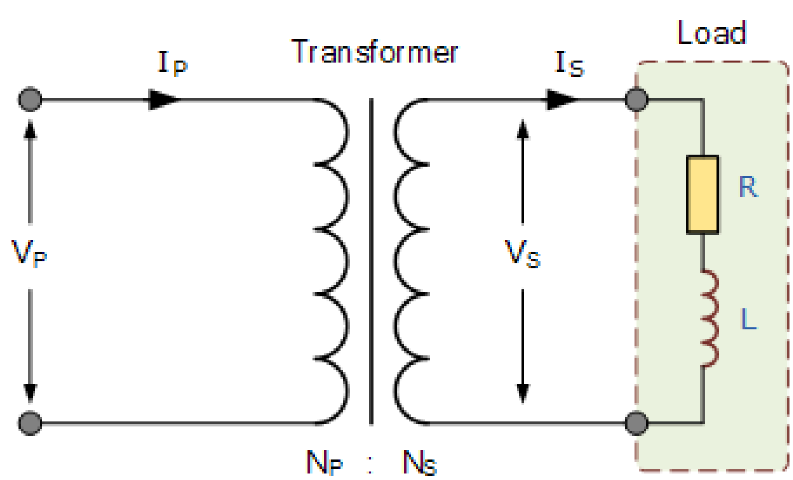

Figure 11.7 Schematic diagram of Transformer at load Condition

The primary current, IP, marginally increases as a result of the combined magnetic field's reduction of the primary winding's inductances. A balanced situation between the main and secondary earth's magnetic field must constantly be present for a transformers to function properly.

The primary current increases until the magnetic field of the core is returned to its original intensity. As a consequence, both the main and secondary sides of the power are equal and balanced.

Users are aware that a transformer's turns ratios specifies that each winding's total electromotive force is proportional to the number of turns in the that winding that a transformer's energy input and output are equal to volts equals amperes (V x I). Therefore:

$$power_{prim} = power_{sec}$$

$$V_P * I_P = V_s * I_S$$

Then $\frac{V_P * I_P}{V_s} = I_S$

$$\frac{V_P * I_P}{V_s} = \frac{I_S}{I_P}$$

But as previously stated, "voltage ratio = turns ratio" means that a transformer's amperage ratio is equal to its turn ratio. So that they may be connected, the connection between a transformer's voltage, current, and the number of turns is provided as:

Transformer Ratio

Keep in mind that the relationship between the current and the voltage and the number of rotations is inverse. This indicates that when a transformer is loaded here on secondary winding, if somehow the voltage is increased, the current must decrease, and vice versa, in in order to keep a balanced power rating throughout the transformer's windings. Or, "lower voltage, greater current" or "higher voltage, lower current".

When the voltage ratio is represented by NP/NS = VP/VS.

The current ratio is represented as NP/NS = IS/IP.

Combining Transformer Impedances

One must multiply or reduce by the square root of the turn ratio to relate a resistance or characteristic impedance through one side of the transformer to the other (Turns Ratio2). In order to refer (or reflect) the impedances (resistivity and characteristic impedance) from the secondary towards the primary aspect of the transformer, one must multiply by both the turns ratio square, N2, and we need to divide by the turns ratio squared while referring electrical primary characteristic impedance towards the secondary winding.

Therefore, primary to secondary reflection decreases R and X by an amount defined by N2, but secondary to primary sources raises R and X. The linked load impedance and characteristic impedance are also subject to this referring to or reflection of both the impedances in Figure 11.8.

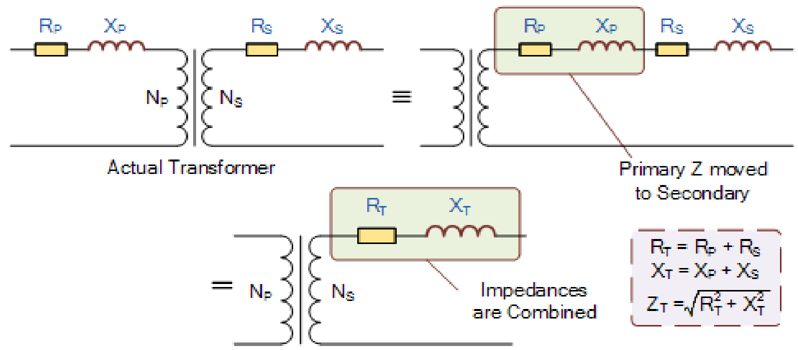

Figure 11.8 Combining Impedances of Transformer

For instance, if a secondary resistant of 2 ohms is referred to the primary side with an 8:1 turns ratio, the second permanent resistive value will be 2 x 82 = 128 ohms, whereas a primary resistance of 2 ohms will produce a secondary resistance value of 0.03125 ohms.

Transformer Voltage Regulation

The variation in secondary voltage magnitude during full load, or when the main supply voltage is kept constant, whereas the transformer loading is reaching its maximum, is referred to as voltage regulation. Regulation controls the voltage decrease (or rise) that takes place within the transformers when the voltage output drops too low due to the overloading, which impacts the transformer's efficiency and performance. A voltage regulation's proportion (or per unit) of the no-load potential is used to represent it. The percentage regulating of a transformers is thus provided if E symbolizes the secondary voltage at no loading while V represents this same secondary voltage at full load:

$$\frac{no\ load - full\ load}{no\ load} = \frac{E - V}{E}\%100$$

Therefore, the regulation would've been 5% if, for instance, a transformer produces 100 volts when it is not loaded but only 95 volts when it is fully loaded. The internal impedance of a winding, which comprises its resistance, R, and more critically its AC reactance, X, the current, as well as the phase angle, will determine the value of E-V.

Additionally, voltage regulation often rises as the load's maximum power gets more lagging (inductive). When it comes to transformer loading, voltage regulation can be either positively or negatively in value, using the no-load voltage as both a reference and changing down in regulatory oversight as the loads are applied, or using the full-load voltage as a reference and changing up in regulation even as load is decreased or eliminated.

In general, the core type transformer does not regulate as effectively as the shell type transformer whenever the transformer consumption is large. This happens because the frame interpolation of the armature winding in the shells type transformer results in improved flux distribution.

Multiple Winding Transformers

Various combinations of current and voltages are possible with multiple main or secondary windings in multiple winding transformers. Transformers with multiple main windings often have two or even more secondary windings. The main or secondary side of the transformer may contain more than one winding, which is one of its wonderful features. Transformers with many windings are often referred to as multiple wrapping transformers. A transformer with numerous windings operates on the same principles as a regular transformer. The calculations for primary and secondary voltages, current flow, and turns ratios are identical this time; however, we must pay close attention to the voltage magnetic poles of each winding because once connecting them together because the dot convention indicates the winding's favorable (or negative) polarization.

Transformers with multiple windings, sometimes referred to as multi-coils or numerous winding transformers, have much more than one secondary or primary coil on such a single laminated core, thus their name. The functioning is the same whether they are multi-winding, multi-phase single-phase transformers or three-phase transformers. In order to give a step-up, step-down, or a mix of the two between the different windings, multiple winding transformers may also be employed. In actuality, a multiple winding transformer is capable of having numerous secondary field winding within the same core, each of which may produce a different degree of voltage or current. The volt-ampere merchandise in each winding of a multiple winding transmitter is the same because transformers work on the mutual induction principle and each individual twisty can support the same number of volts per turn. Accordingly, NP/NS = VP/VS, if any turns ratio between both the individual armature winding becoming relative towards the primary supply. Single transformer is frequently employed in electronic circuits to give a range of lower voltages for various components. Power supply and triac switching conversions are two common applications for multiple winding transformers. Therefore, a transformer may contain a variety of secondary windings that are all electrically separated from one another and from the primary, just as they are from each other. The voltage produced by every one of the secondary coils will thus be proportionate to the number of coil spins, for instance.

An illustration of a typical "many winding transformer in Figure" is shown above. This transformer contains several separate secondary windings that provide different voltage levels. To run the transformer from greater supply voltages, these primary windings may be utilized alone or coupled together (Figure 11.9).

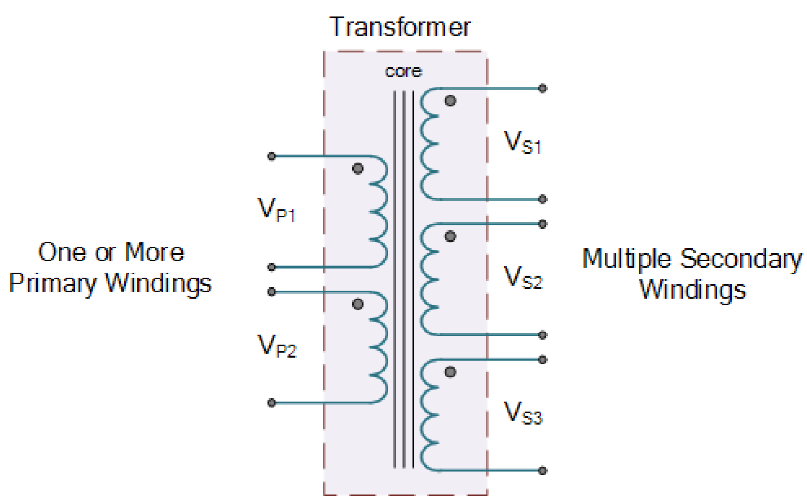

Figure 11.9 Multiple Winding Transformers

Different connections between the secondary windings might provide a greater voltage and current supply. It should be noted that electrical equivalence between the two power transformers is a requirement for connecting them in parallel. They have identical current and voltage ratings.

Dual Voltage Transformers

There are a variety of transformers with multiple windings that feature two main windings with similar ratings for voltage and current and two secondary field winding with the same specifications. With the windings coupled together either in a parallel or series arrangement configuration for larger primary voltage or secondary current flow, these transformer are made to be employed in a number of applications. Dual Converts the mechanical energy is a more popular name for these double winding transformers.

Dual Primary & Dual Secondary Transformer

The transformer comprises 4 windings in total—two primary and two secondary. With dual distribution transformer, as shown in Figure, the connections to the main or secondary windings must always be done appropriately. When a transformer is powered, a dead short that's been caused by faulty connection will often cause the transformer to fail. Dual voltage transformers, as we previously said, may be linked to run from power supply of several voltage levels, therefore their name. Let's take an example where the primary winding has a voltage rating of 12/24V on the secondary as well as 240/120V on the primary. This is accomplished by rating each of the two main windings at 120V so each secondary winding at 12V. It is necessary to connect the transformer to ensure that every primary winding gets the appropriate voltage (Figure 11.10).

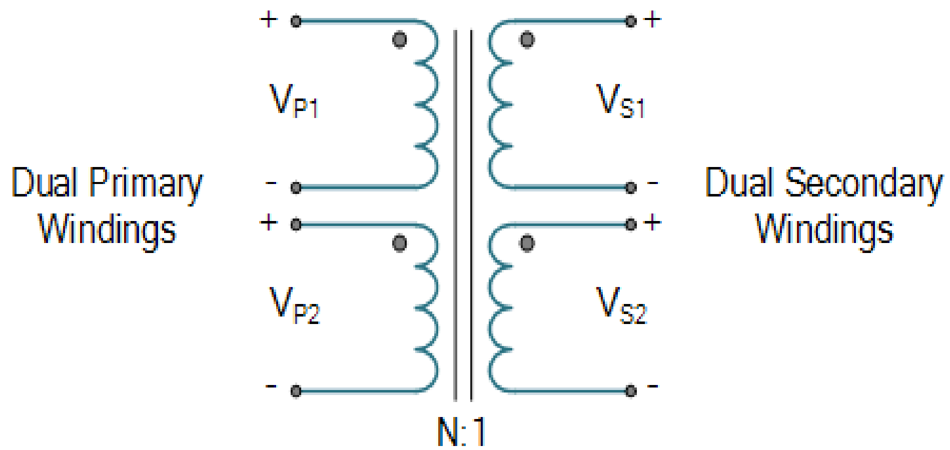

Figure 11.10 Dual Primary & Dual Secondary Transformer

Series Connected Secondary Transformer

Due to the fact that the two primary windings, each rated at 120V, are similar, half of the 240V supply voltage, or 120V, is dropped throughout each winding, ensuring that the same primary current can flow through both when the two windings are connected in parallel across the 240V supply. The secondary voltage output in Figure is equal to the total of the voltages of a two secondary windings, each of which has a rating of 12V and 2.5A (Figure 11.11).

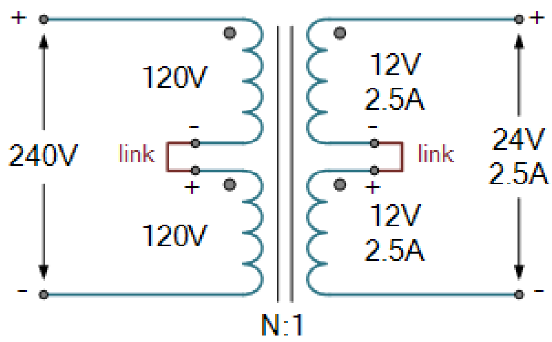

Figure 11.11 Series Connected Secondary Transformer

The secondary current is exactly the same at 2.5 Amps because the two windings are linked in series, causing the same amount of electricity to flow throughout every winding. Therefore, the output in our example above is regulated at 24 Volts, 2.5 Amps for just a secondary connected in series. Take the parallel-connected transformers, for example.

Parallel Connected Secondary Transformer

The two primary windings have remained unchanged in this instance, but really the two secondary windings have been combined in a parallel manner with regard to respective dot orientation. The secondary terminal voltage would remain the same at 12 Volts, but the current increases since the two secondary field winding, as previously, are each rated at 12V, 2.5A. In our previous example, the output is thus rated at 12 Volts, 5.0 Audio amplifiers for a secondary that is connected in parallel. Although the secondary and current voltages produced by various dual voltage transformers may vary, the basic idea remains the same. For coils to output the necessary voltage or current, their connections must be right.

On the windings, the terminals with the same phase shift are shown by dots. For instance, connecting two secondary field winding in opposite dot orientation will result in minimum waste or destruction to the transformers in Figure 11.12because the two magnetic fluxes will cancel each other out.

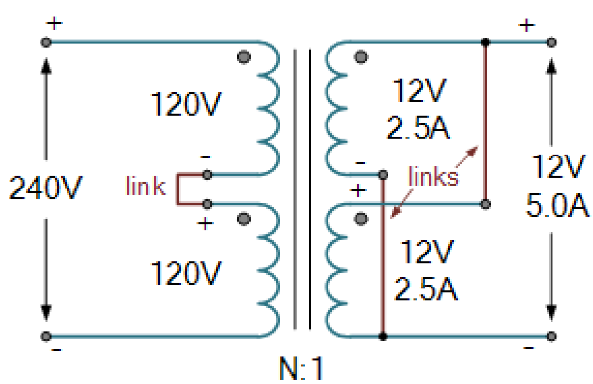

Figure 11.12 Parallel Connected Secondary Transformer

The Center-tap Transformer is a different kind of dual voltage transformer that has just one stator winding that is "tapped" at its electromagnetic center point. Two or even more transformers may well be linked in parallel with both the existing transformer to deliver a load greater than the rating of a existing converter. Whenever the load on any of the transformers exceeds its capacity, the other transformers are linked in parallel. Parallel operation is more reliable than using a single, bigger unit. Whenever two transformers are linked in parallel, the expense of maintaining the replacements is reduced. Instead of upgrading the present transformer with a single, bigger unit, it is often more cost-effective to install a second transformer in parallel. In the event of two simultaneous transformers with identical ratings, the cost of a replacement unit is likewise less expensive than the cost of a single transformer.

Center Tapped Multi Winding Transformers

A center-tap transformer is made to link two different secondary voltages, VA and VB, via a single point. This particular transformer set-up results in a two-phase, three-wire supply. The energy in each winding remains the same because the secondary voltages were same and proportionate to the supply voltage, VP. The turn's ratio, as indicated in Figure, determines the voltages generated across each secondary winding.

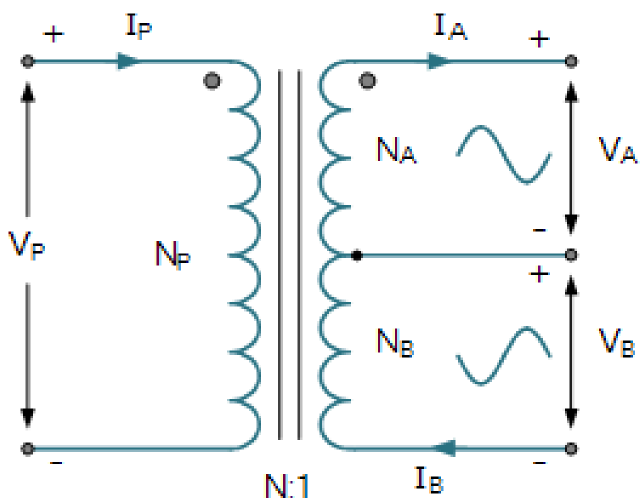

Figure 11.13 Center Tapped Multi Winding Transformers

A typical center-tap transformer is seen above. The secondary winding's precise center, where the tapping point is located, provides a common connection between two secondary voltages that are equal but opposing. The output VA will be positively charged with regard to the ground when the center-tap is grounding, however the voltage at the additional secondary, VB, will be negatives and opposed in nature, meaning they are 180o electrically out of phase with one another. The usage of an unsubstantiated center tapped transformer does have one drawback, however, that is the possibility of unbalanced voltages in the two secondary windings as a result of asymmetrical currents flowing in the common middle connector due to unbalanced loads. Using the dual power electronics converters mentioned before, we can also create a center-tap transformer. One may utilize the middle link as the tap as indicated by stringing together the secondary windings. The secondary winding's overall output voltage will equal 2V if indeed the output from each supplementary is V, as illustrated.

Center-tap Transformer using Multiple Winding Transformers

Several Windings In electrical and electronic circuits, transformers are used in a variety of ways. They may be used to provide various secondary voltages to various loads. Having their secondary windings linked together in succession to create a center-tapped transformer in Figure, or have their field winding coupled together within series or parallel configurations to generate larger voltages or currents (Figure 11.14).

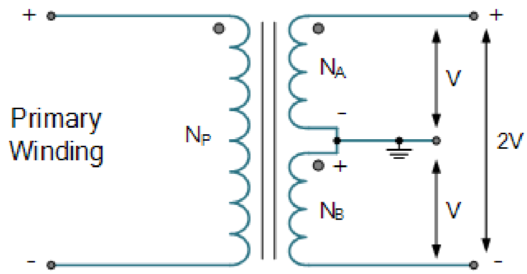

Figure 11.14 Center Tapped Multi Winding Transformers

The Autotransformer

An autotransformer costs less than conventional transformers because its primary and secondary windings seem to be electrically and magnetically connected. In contrast to a previous voltage transformer, which had two electrically separate windings called the primary and secondary, an automatic transfer switch has only had one single voltage winding that is shared by both sides. At different places along its length, this single wrapping is "tapped" to deliver a portion of the main voltage supply throughout its secondary load. Additionally, the autotransformer has a single winding that is shared by both the main and secondary circuits, although it still has the standard magnetic core.

As a result, the main and secondary windings of an autotransformer are connected magnetically and electronically. An autotransformer lacks the primary/secondary winding separation of a typical double wound transformer, which is its largest drawback. The main benefit of this kind of transformer architecture is that it can be produced much more cheaply for the same VA rating. The secondary is a portion of the section of the winding referred to as the main part of the winding, which is linked to the AC power source. By flipping the connections, an autotransformer can also be employed to scale the supply voltage up or down. The secondary voltage is "stepped-down" as illustrated if the primary is the whole winding, is linked to a source, as well as the secondary circuits is attached across just a piece of the winding. The secondary winding, IS, travels throughout the opposite direction while the main current, IP, is moving through into the single wrapping as shown by the arrow. As a result, the current flowing through the winding at the section of the winding that produces the secondary voltage, VS, seems to be the difference between IP and IS.

Additionally, the Autotransformer may be built using several tapping points. Auto-transformers may be used to raise supply voltage relative to supply voltage VP or to give various voltage points along a winding, as illustrated. A single winding of an autotransformer has two end terminals one and or more endpoints at the intermediate tap points. It is a transformers with shared turns between the main and secondary coils. The common part of the winding is the area that both the main and secondary share. The series part of the winding is the area that is not shared by the main and secondary. Two of something like the terminals get the principal voltage. Two terminals are used to provide the voltage level, one of which is often shared with a main voltage terminal.

Since both windings have the same volts-per-turn, each produces a voltage proportional to the number of turns. It is possible to utilize a smaller, smaller, simpler core and only one winding in an autotransformer because some of the outgoing current travels directly from the source to destination (via the series section) and only some of it is transmitted inductively (through into the common section). However, autotransformers' the voltage and current proportion may be calculated using the same method as conventional two-winding transformer.

Multiple Tapping Points of autotransformer

An auto-transformer winding is often marked by using capital (upper case) characters on the label. For instance, to designate the supply end, use A, B, Z, etc. Commonly, the common neutral connector is denoted by the letters N or n. All tapping locations along the main winding of the auto-transformer are designated with suffix numbers for the secondary tapings. As seen in Figure, these numbers typically begin at "1" and continue in order of increasing for any and all tapping locations (Figure 11.15).

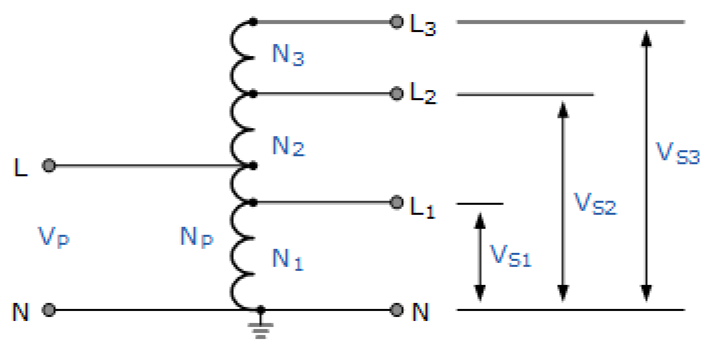

Figure 11.15 Multiple Tapping Points of autotransformer

Autotransformer Terminal Markings

An autotransformer is mostly used to modify line voltages in order to either change or maintain their value. The transformer proportion is modest if the voltage change is quite little, whether up or down, since VP and VS are virtually equal. IS and IP at this time are almost equal. Since the currents are significantly lower, the section of the winding that transports the difference between the currents may be produced from a substantially smaller conductor size, saving money compared to a double wrapped transformers of equal size. However, for a given VA or KVA ratings, an autotransformer's regulating, leakage inductance, and physical size because there is no second winding) are lower than for a twin wound transformers. In comparison to traditional double wound transformers with the same VA rating, autotransformers are obviously far less expensive. It is customary to weigh an autotransformer's price against a comparable double wound kind when selecting whether to use one. Comparing the quantity of silver saved in the unwinding allows for this. It is possible to demonstrate that the reduction in copper is equal to n*100% if the ratio "n" is defined as the proportion of the dropout wattage to the greater voltage. As an example, consider the copper savings for the four autotransformers.

Disadvantages of an Autotransformer

An autotransformer's principal drawback is that it lacks the primary to secondary coil isolation seen in a typical double wound transformer. In such case, stepping down larger energies to much lower voltage levels appropriate for lesser loads cannot be done safely using an autotransformer.

The primary winding's load current ceases flowing through it, terminating the transformer's activity, and the whole primary voltage is supplied to the output terminal if the equivalent circuit winding becomes open-circuited.

Because of the increased current flowing harming the autotransformer, if the secondary circuit experiences a short-circuit situation, the ensuing main current would be much higher than a comparable double wound transformer.Since there is no isolation between both the primary and secondary windings as well as the neutral connector is shared by both, earthling the secondary winding also continents the primary. Equipment isolation from the ground occasionally involves the use of double wound transformers.The autotransformer can be employed to transform energies whenever the primary to secondary proportion is near to unity, as well as for starting electromagnetic induction, controlling transmission line voltage, and beginning electromagnetic induction.The main and secondary windings of a typical two-winding transformer may also be connected in series to create an autotransformer; however, depending on the way the interconnection is made, the secondary current may either add to or remove from the primary voltage.

CHAPTER 12

Variable and Current Transformer

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Another important application of the auto transformer type of configuration is to create a variable AC voltage from either a fixed voltage AC source in addition to having a permanent or tapped secondary that delivers a voltage output at a set level. The Variac is the more popular name for this sort of variable autotransformer, which is often used in laboratory and science laboratories in schools and universities. A variable autotransformer, often known as a variac, is built similarly to a fixed type. The auto transformer has a solitary primary winding wound around a lamination magnetic core, but the secondary voltage dynamically tapped using a carbon brush as opposed to being set at a predefined tapping point.

The main winding is exposed, and this carbon brush is spun or allowed to glide along it, coming into contact with it as it travels and producing the necessary voltage level.The secondary voltage output of a variable autotransformer is entirely changeable from the main supply reference voltage to zero volts because it has a variable tap inside the form of a charcoal brush that glides upward and downward the primary winding to regulate the secondary winding length.

A substantial number of primary windings are often used in the construction of the variable autotransformer to provide a secondary voltage that may be varied from a few volts to a few hundredths of a volt per turn. This is made possible by the carbon brushes or slider's constant contact including one or more principal winding turns. Itself along the length, the main coil's turns are uniformly spaced. The output voltage then starts to follow the angular rotation.

Variable Autotransformer

As people can see, the variac can smoothly change the voltage applied to the load from zero towards the recommended supply voltage. The output voltage gain may be more than the actual voltage supply if the power source was tapped anywhere along the main winding. Additionally, variable autotransformers may be used to lower lights, and when they are, devices are commonly referred to as "dimmer stats." Because they may be utilized to give a changeable AC supply, vacs are also particularly helpful in electronics and electrical workplaces and laboratories. However, care must be taken with appropriate fuse protection to make sure that, in the event of a breakdown, the greater supply voltages is not represented somewhere at secondary terminals in Figure 12.1.

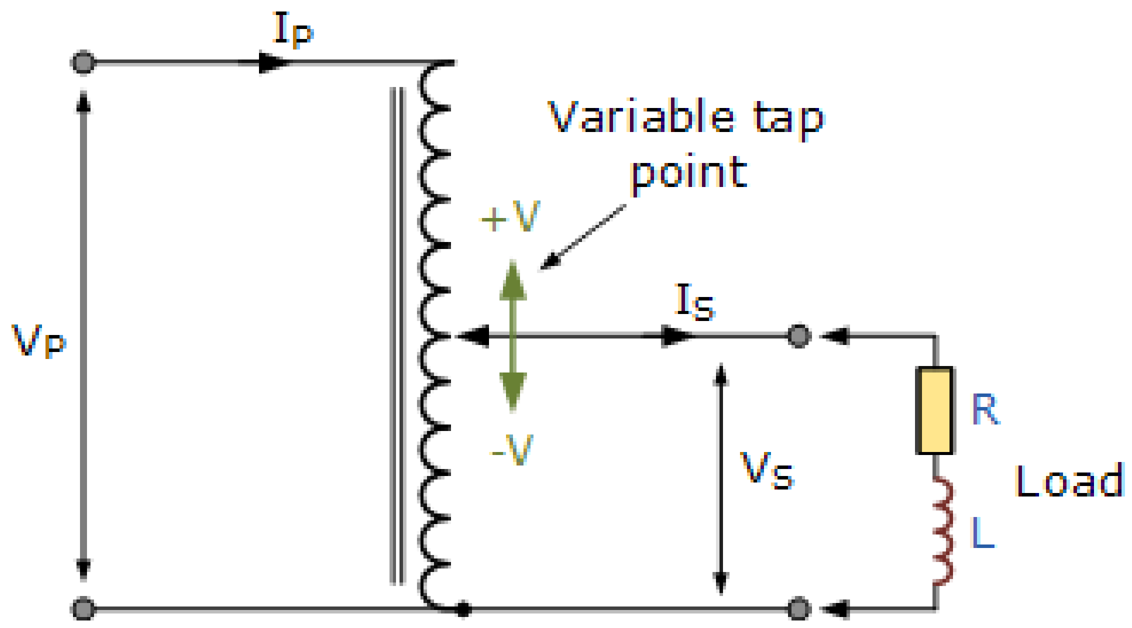


Figure 12.1 Variable Autotransformer

The Autotransformer is superior to traditional double wound transformers in very many ways. They are often smaller, better efficient for the identical VA rating, and less expensive than double wrapped transformers that have the same VA rating since they use less copper in their manufacture. Additionally, they have better voltage control than a comparable two winding transformers owing to their reduced resistance and permeability reactance, lower core plate copper inefficiencies, and lower I2R.

The Current Transformer

Due to a constant voltage on the main winding, current transformers provide an output proportional to the current that flows through it. A particular kind of "instrument transformer," the Current Transformer (C.T.), is made to create an alternating current through its secondary winding that is proportionate to the current being monitored in its primary. Current transformers therefore provide easy solution to securely monitor the real electrical current travelling in an AC transmission line. Using a normal ammeter while reducing high voltage currents to a considerably lower value. Figure 2 shows how the fundamental current transformer's operating principle differs somewhat from a conventional voltage transformers.

The main winding of a current transformer has one or a very small number of turns, unlike with the voltage or energy transformers we previously studied. One flat turn, a coil of sturdy wire wrapped all around core, or merely a conductor or dc power supply inserted through the center hole, as illustrated, may be used as the main winding. The main winding of the current transformer, which never has more beyond a few turns, seems to be in series with both the current carrying wire feeding a load, and as a result, the arrangement is what gives rise to the term "series transformer" for the device (Figure 12.2).

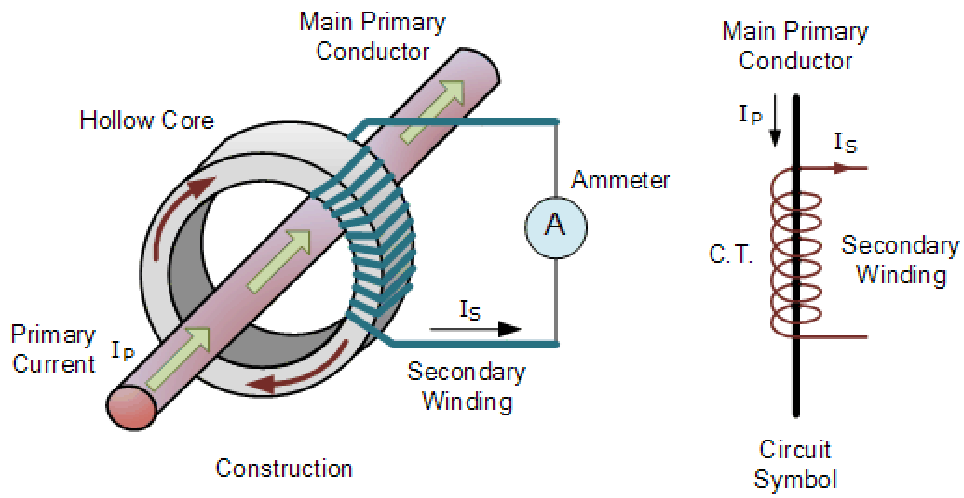


Figure 12.2 Construction of Current Transformer

However, a laminated cores of low-loss magnetic material may have a significant number of coil turns wrapped on it for the secondary winding. Depending on the amount that the current must always be stepped down as it attempts to generate a constant current, irrespective of the connected load, this core has a big cross-sectional area, which makes it such that the concentration of magnetic flux formed is low utilizing wire with much lower cross-sectional areas. Until the voltage produced in the supplementary is sufficient to saturate the core or result in failure from high voltage breakdown, this same secondary winding will feed current either through a short circuit, represented by an ammeter, or through a resistive load. In contrast to a voltage transformer, a current transformer's main current is not controlled by the secondary load present but rather by an external load. Typically, the secondary current has a rating of 1 Ampere or 5 Amperage for main currents with higher values. Current transformers come in three fundamental varieties: wound, toroidal, and bar.

Wound Current Transformer - The wire carrying the measured current flowing throughout the circuit is physically linked in series with the primary winding of the transformer. The transformer's turn ratio affects how large the secondary current will be.

These Toroidal Current Transformers lack a main winding. Instead, the toroidal transformer's windows or hole is used to thread the line carrying the network's electricity through. Due to their "split core," certain current transformers may be opened, installed, and shut without interrupting the circuit to that they are connected.

Current transformers with a bar-style primary winding equivalent to one turn use the cable or bus-bar of both the main circuit as that of the primary winding. They are typically fastened to the current carrying equipment and are completely insulated from either the system's high working voltage.

Current Transformer

For regular operation, current transformers may "step-down" or lower current levels between thousands of micro amp to an output device of a defined ratio either with 5 Amps or 1 Amp.

Because CTs are shielded from just about any high-voltage power lines, they may thus be employed with tiny and precise instruments and control equipment. Current transformers may be used in a wide range of metering applications, including wattmeter's, power factor counters, watt-hour meters, protection devices, and trip circuits in ferromagnetic circuit breakers, or MCBs. Typically, current transformers and amperage are employed as a matched pair, with the current transformer's design providing a maximum secondary voltage that corresponds to an ammeter's full-scale displacement.

The two currents throughout the main and secondary windings of the majority of current transformers have a roughly inverse turn ratio. For this reason, the CT is often calibrated for a certain kind of ammeter. The secondary capacity for most current transformers is typically 5 amps, and the main and secondary currents are stated as a ratio like 100/5.

Accordingly, when 100 amps are flowing in the main conductor, there will be 5 amps flowing throughout the secondary winding since the current flowing is 20 orders of magnitude larger than the secondary current.

A current transformer with a ratio of, example, 500/5 will generate 5 amps throughout the secondary for a primary wire current of 500 amps, a 100-fold increase. The secondary current may be made considerably less than the main current being measured by increasing the number the secondary coil, Ns, since as Ns grows, is decreases proportionally.

In other circumstances, the current in the main and secondary windings as well as the number of turns made are inversely proportional. The amp-turn equation applies to all transformers, including current transformers, as we learned in our course on double wrapped voltage transformers.

.

$$T.R. = n = \frac{N_P}{N_S} = \frac{I_S}{I_P}$$

from which it get:

secondary current, $I_S = I_P(\frac{N_P}{N_S})$

The turns ratio is determined by the current ratio, and since the primary typically has one or two bends while the secondary might have hundreds, the proportion between the two can be fairly high. Consider the main winding's 100A current rating as an example. The secondary winding is rated at the industry-standard 5A. Then, the main and secondary liquidity amount is 100A to 5A, or 20:1. In other words, the main current dominates the secondary current by a factor of 20. To be clear, a current transformer with a rating of 100/5 does not correspond to one with a rating of 20/1 or other subdivisions of 100/5. This is due to the fact that the ratio of 100/5 does not really represent the ratio of main to secondary currents, but rather the "input/output current rating." Also take notice of the inverse relationship between the number of revolutions as well as the current in the main and secondary windings. However, very considerable changes in the ratio of turns in a current transformer may be made by altering the primary turns via the CT's window, where first primary turn is equivalent with one pass and more around one pass through into the window alters the electrical ratio.

Handheld Current Transformers

Currently, a wide variety of specialized current transformer types are available. Clamp meters, as seen, are a common and portable variety that can be employed to measure circuit loading. Without interrupting or opening the circuit, clamp meters encircle a current-carrying wire and measure its current by calculating the magnetic field around it. The reading is often shown on a digital display. Split core current transformers are an alternative to portable clamp-style CTs; they include a detachable end that eliminates the need to disconnect the load conductor or bus bar in order to install them.

These have square window diameters ranging from 1 inch to over 12 inch, and they can measure currents from 100 amps to 5000 amps (25-to-300mm. In conclusion, a current transformer, also known as a CT, is an instrument transformer that transforms a primary current into a secondary winding using a magnetic medium. A significantly lower current is then produced by its secondary winding, which may be utilized to identify overcurrent, underneath, pulse duration, or average current circumstances.

A current transformer is sometimes referred to as a series transformer because its primary coil is always wired in series with the main conductor. For convenience of measurement, the nominal secondary current is regulated at 1A or 5A. Construction may be one single election turn just like in Toroidal, Doughnut, or Bar types, or a several wrapped primary turns, generally for low current ratios. Transformers for current are designed to be utilized as proportional current equipment. Consequently, just as a voltage transformer should not be run into a short circuit, a current transformer's secondary coil should never be controlled into an open switch. If the digital multimeter is to be disconnected or when the CT is not in use, their connections must be short-circuited prior to actually charging up the system since opening the secondary circuit of an active current transformer would result in very operating voltage.

Three Phase Transformers

Three-phase Transformers, whether it's with Delta or Star linked windings, are the foundation of electrical power distribution. To create and transfer electric power over great distances for usage by businesses and industry, a three-phase electrical system is employed. Three phase transformers are used to increase or reduce three-phase voltages (including current flow) because the three phase transformer's windings may be linked in a variety of ways. We have examined the design and functioning of the single-phase, two-winding voltage transformer up to this point, which may be used to alter the secondary voltage's relationship to the primary voltage supply. However, voltage transformers may also be built to link to two, three, six, or even intricate combinations of up to 24 phases for certain DC rectification transformers, in addition to only one single phase.

We can utilize three single-phase transformer on something like a three-phase supply if we fixably link their main windings to one another and respective secondary windings to one another. For the production, transmission, and distribution of electricity as well as for all industrial uses, three-phase supplies—also known as 3-phase or 3 supplies—are employed. While compared to single-phase power, three-phase supplies offer several electrical benefits. However, when thinking about three-phase transformers, we must deal with three opposing voltages and currents that vary by 120 degrees of phase-time.

It seems obvious that we would require three-phase transformers to be able to scale voltages up or down because three-phase is utilized so often for power distribution networks. This is only partly accurate since it is possible use gang conventional single-phase transformers to change electricity between two three-phase systems in an assortment of ways, doing away with the need for a special three-phase transformer. But in contrast to their modular equivalents, unique three-phase transformers designed for specific jobs may operate with less materials use, smaller size, and lighter weight. Each pair of both primary and secondary windings of a three-phase transformer is coiled around one leg of the an iron core assembly. As seen in Figure 12.3, it resembles three single-phase transformers having a connected core in essence.

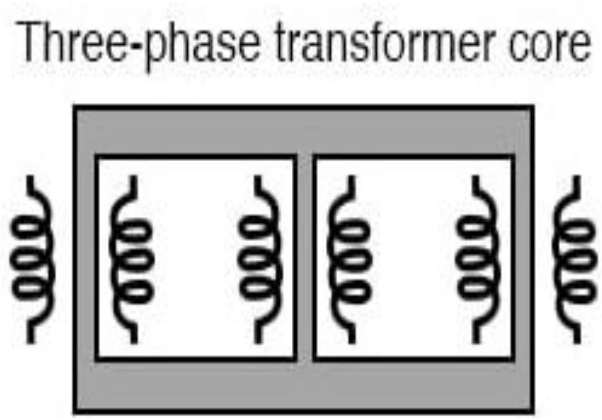


Figure 12.3 Core of Three Phase Transformers

These pairs of main and secondary windings will be combined into a single unit using either Y or connections. The emphasis of this section will be on the different permutations of ways that even these windings may be joined to one another. The winding connection choices are the same whether the winding sets have a common core assembly or if individual winding pair is a separate transformers:

Primary - Secondary

Y - Y

Y - Δ

Δ - Y

Δ – Δ

For transformer winding connections, the same factors apply as they would with any other three-phase application: While connectors are more reliable than Y connections, they can accommodate numerous voltages (if one winding fails open, the other two can still maintain full line voltages to the load). Paying close attention to accurate winding phasing (the dots used to represent "polarity" of windings) is perhaps the most crucial step in connecting three different sets of primary and secondary windings to one another in order create a three-phase transformer bank.

Remember the proper phase relationships between the phase windings of Δ and Y: (Figure 12.4)

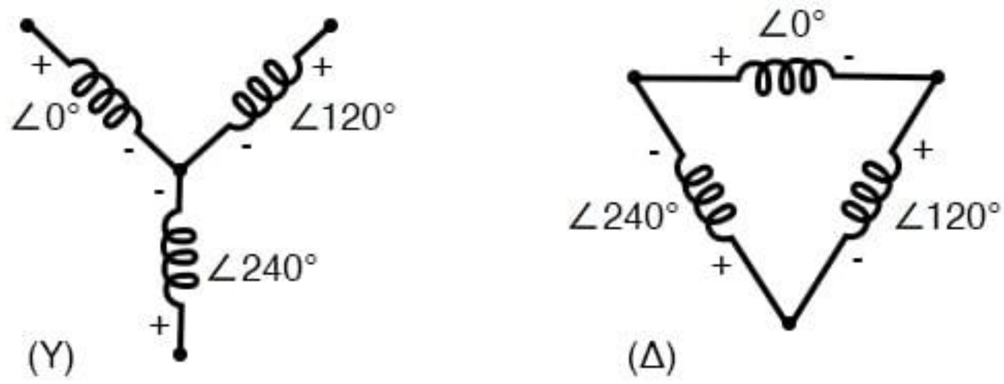


Figure 12.4 Phase relationships between the phase windings of Δ and Y

(Y) Either all of the "-" or all of the "+" winding points must be connected at the "Ycenter. "'s The polarity of the windings must be complimentary to one another (from + to -).

(Y) Either all of the "-" or all of the "+" winding points must be connected at the "Ycenter. "'s The polarity of the windings must be complimentary to one another (from + to -).

When the windings aren't shown in their typical Y or layout, it might be challenging to get this phasing right. Let me provide an example, beginning with the image below 12.5.

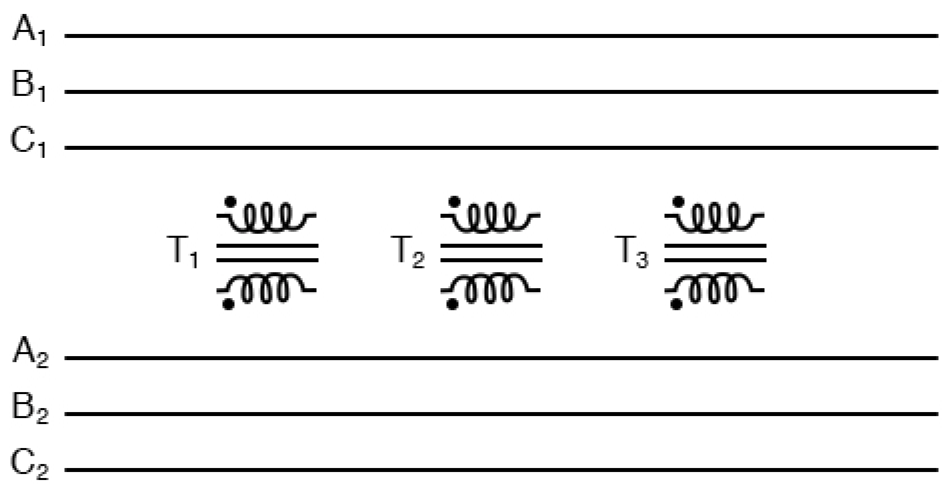


Figure 12.5 Phase relationships between the phase windings

Inputs A1, A2, A3 may be wired either “Δ” or “Y”, as may outputs B1, B2, B3.

Inputs A1, B1, C1 may be wired either “Δ” or “Y”, as may outputs A2, B2, C2.

Phase Wiring for “Y-Y” Transformer

To convert electricity from one three-phase system to the another, three separate transformers must be linked together. The wiring connections for a Y-Y arrangement will be shown Figure 12.6 first:

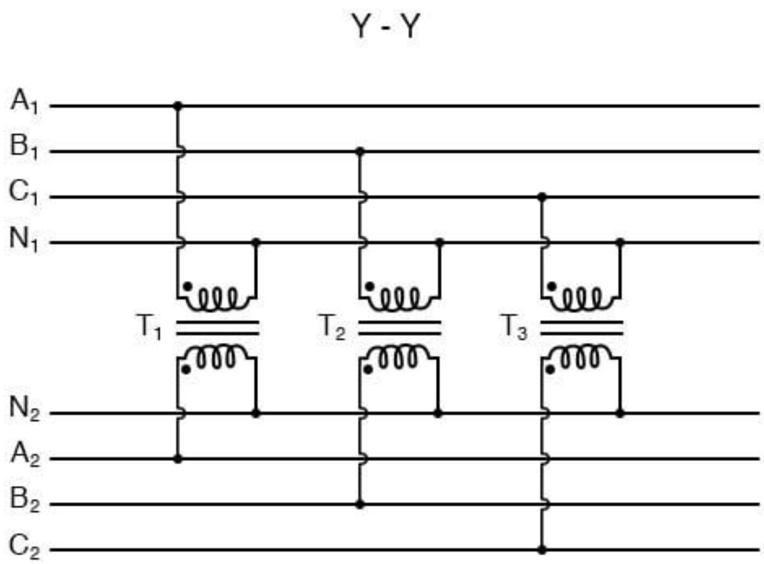


Figure 12.6 Wiring connections for a Y-Y arrangement

Phase wiring for “Y-Y” transformer.

Note in the above figure how the non-dot ends are joined to create the centers of each "Y" while the winding endpoints indicated with dots are connected with their corresponding phases A, B, and C. Each power system may employ neutral conductors (N1 and N2) by connecting the main and secondary winding sets in a "Y" shape (Figure 12.7).

Phase Wiring for “Y-Δ” Transformer, Now,

we’ll take a look at a Y-Δ configuration

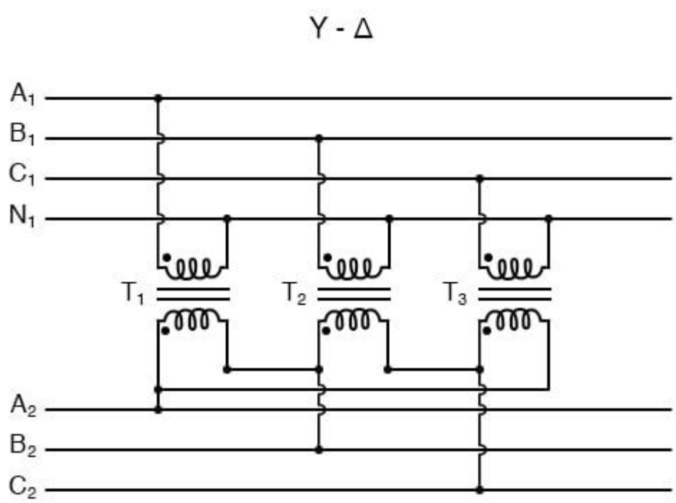
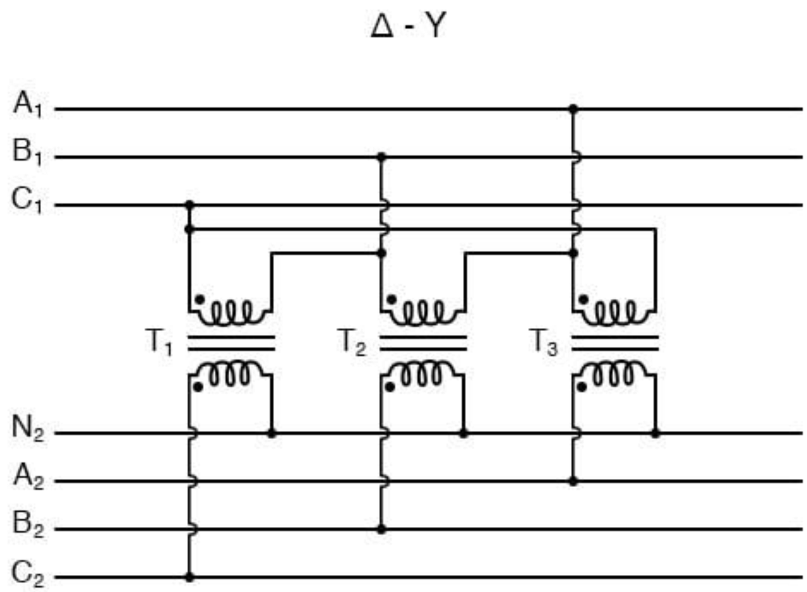


Figure 12.7 Phase wiring for “Y-Y” transformer.

The "dot" side of one winding is linked to the "non-dot" side of the next, making the "" loop. This is how the secondary windings (bottom set, above Figure) are connected in a chain. A link to a line belonging to the second power system is formed at each junction between pairs of windings (A, B, and C).

Phase Wiring for "Δ-Y" Transformer

Now, let's examine a Δ-Y system in the Figure 12.8 below.



Figuer 12.8 Phase Wiring for "Δ-Y" Transformer

Phase wiring for the transformer in the "-Y" direction In the example arrangement (Figure above), different voltages (line-to-line or line-to-neutral) from a source electricity system without a neutral might be provided in the second power system,

Phase Wiring for "Δ-Δ" Transforme,

And finally, we turn to the Δ-Δ configuration (Figure 12.9):

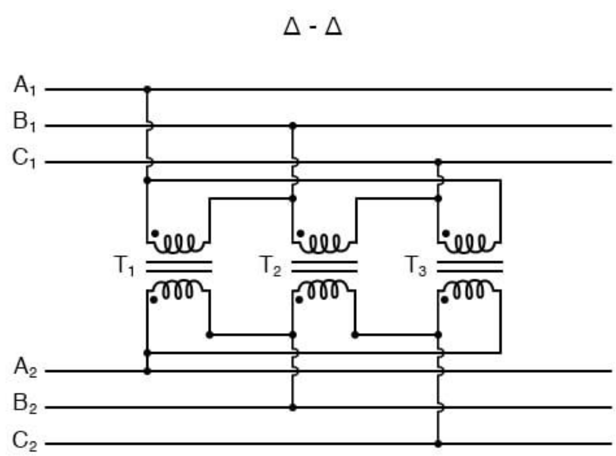
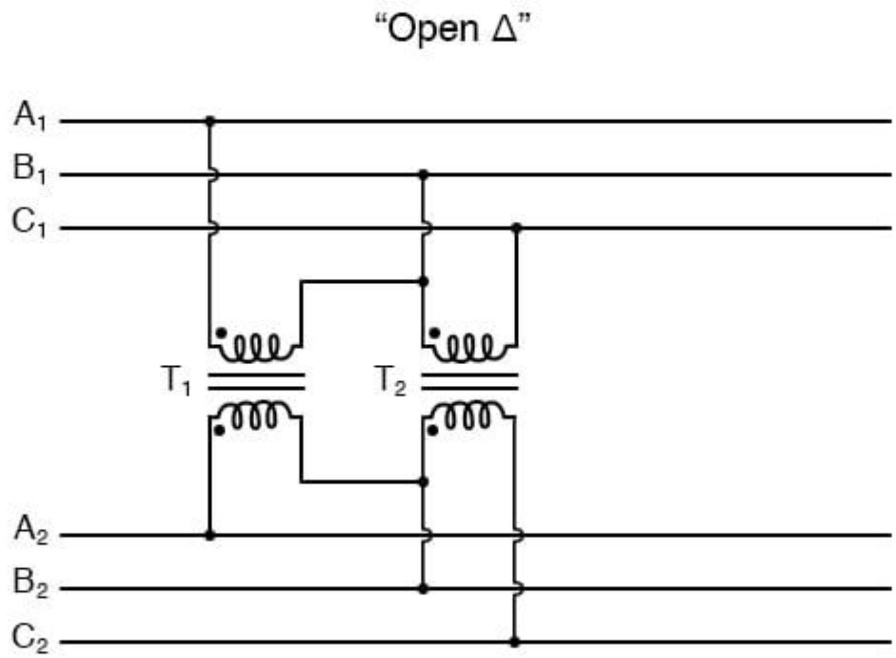


Figure 12.9 Phase Wiring for "Δ-Δ" Transforme

Because of the inherent dependability of the design, - connection methods are preferable when a neutral conductor is not required in the secondary power system. 'V' or 'open-' Transformer Phase Wiring(Figure 12.10).

Some power design engineers decide to build a three-phase transformer bank with just two transformers, reflecting a - configuration with such a missing winding on both the main and secondary sides, taking into account that a configuration may function successfully lacking one winding:



Figuer 12.10 Open Transformer Phase Wiring

“With only two transformers, "open-V" or "V" delivers 2-volt electricity.

With only two transformers, "V" or "open-" power may be doubled.

This arrangement is known as "V" or "Open-." However, the total size, weight, and cost benefits are often worth it. Each of the two transformers must be larger to handle the same amount of electricity as three in a typical design.

But keep in mind that this method no longer offers the fault tolerance of a typical - shape with one wrapping set missing. The load current and voltage would undoubtedly be impacted if one of the secondary winding failed

Real Life Example

A bank of step-up transformers may be seen at the Grand Coulee hydroelectric plant in Washington state in the image that follows (figure below). From this vantage point, it is possible to observe a number of transformers (green in hue), which have been grouped equal threes: three transformers every hydroelectric generator, linked in some kind of three-phase design. Although the main winding connections are not visible in the shot, it looks like the secondaries are linked in a Y configuration since each transformer has only one sizable high-voltage insulator sticking out of it. This implies that the secondary winding here on opposite side of each transformer is at or close to ground potential, which is only possible in a Y system. The powerhouse, which houses the generators and turbines, is the structure to the left. The downstream face of both the dam is represented by the sloping concrete wall upon that right.

Important Questions for Practices:

1. What is electromechnical energy converison?
2. What is Singly Excited Rotating Actuator?
3. What form of Energy in Coupling Field?
4. How to determine nature of a magnetic field?
5. How to measure the Relationship between B and H?
6. Ditinguish between the Flux Linkage, Inductance, and Energy?
7. What are the Basic Structure of Electrical Machines?
8. What are component of contruction of DC machine?
9. How many types of Motoring operation of a D.C. machine?
10. What are types of DC machine?
11. What are types of generator?

Recommended Books for Further Reading/ Reference Books:

1. Features of Electrical Machine 1st Edition by Dr. P.S Bhimbra, Volume-1 and Volume-2
2. Electric Machines 2nd Edition by Ashfaq Husain and HarroonAshfaq
3. Electric Machinery Fundamentals 1st Edition by Stephen Chapman
4. Engineering Mechanics 1st edition by Ervin H.Sharma
5. Advances in Electrical Engineering and Electrical Machines 2nd Edition by Dehuai Zheng
6. Special Electrical Machine, 1st Edition by Janardanan E G
7. Special Electrical Machines 2nd Edition by R Saravanakumar and K Vinoth Kumar
8. Electrical Machines 1st Edition by IndrayudhBandyopadhyay and PrithwirajPurkait
9. Electrical Power Quality Control Techniques (Electrical Engineering) 2nd Edition by Wilson E Kazibwe and Musoke H Sendaula
10. Design, Modeling and Evaluation of Protective Relays for Power Systems 4th Edition by MladenKezunovic and Saeed Lotfifard