2.4. DC Machine Windings

Lap and Wave Winding

Drum-type armatures are wound with either of two types of windings the LAP WINDING or the WAVE WINDING.

The lap winding is illustrated in figure view A. This type of winding is used in dc generators designed for high-current applications. The windings are connected to provide several parallel paths for current in the armature. For this reason, lap-wound armatures used in dc generators require several pairs of poles and brushes.

The wave winding is illustrated in figure view B, shows a wave winding on a drum-type armature. This type of winding is used in dc generators employed in high-voltage applications. Notice that the two ends of each coil are connected to commutator segments separated by the distance between poles. This configuration allows the series addition of the voltages in all the windings between brushes. This type of winding only requires one pair of brushes. In practice, a practical generator may have several pairs to improve commutation.

FIELD EXCITATION

When a dc voltage is applied to the field windings of a dc generator, current flows through the windings and sets up a steady magnetic field. This is called FIELD EXCITATION. This excitation voltage can be produced by the generator itself or it can be supplied by an outside source, such as a battery. A generator that supplies its own field excitation is called a SELF-EXCITED GENERATOR. Self-excitation is possible only if the field pole pieces have retained a slight amount of permanent magnetism, called RESIDUAL MAGNETISM. When the generator starts rotating, the weak residual magnetism causes a small voltage to be generated in the armature. This small voltage applied to the field coils causes a small field current. Although small, this field current strengthens the magnetic field and allows the armature to generate a higher voltage. The higher voltage increases the field strength, and so on. This process continues until the output voltage reaches the rated output of the generator.
A rotating electrical machine consists of a field and an armature that rotate with respect to each other.

The armature is the part of the machine in which the energy conversion takes place.

The field provides the magnetic field to aid this process.

In DC machines, the field is stationary (the stator) and the armature rotates within it (the rotor), because the rotation is necessary to switch the armature connections by means of the commutator, but it is only the relative motion that counts.

In ac Machines, the armature is stationary and the field rotates.

The field consists of an iron core to carry the magnetic field, and a winding to excite the magnetic field by the current passing through it (first principle). The magnetic field is a passive but essential component in the operation of the machine.

Like the field, the armature also consists of iron to complete the magnetic circuit, and is separated by a short air gap from the iron of the field. The armature also has windings.

It is important that the air gap be as small as possible and remains uniform as the armature rotates.

In a Generator, these conductors are moved in the magnetic field producing a voltage (generator action). If a circuit is completed and current flows in these windings, a force is produced resisting the rotation of the armature (motor action) so that the driving machinery experiences a mechanical resistance and does work, which is being transformed into electrical energy.

In a Motor, these conductors are supplied with an electrical current, so that a force acts on them in the magnetic field (second principle), and this force can do external work. When the armature rotates while exerting the force, work is done, but a voltage is also produced opposing the applied voltage, resisting the flow of current in the armature (third principle), implying a change of electrical work into mechanical work.

This opposing voltage generated when the armature of a motor turns is called counter-electromotive force. It might seem that it resists current flow through the motor, and of course it does, but it is really the essential factor in turning electrical into mechanical energy. Only the current that is driven into a counter-emf appears as mechanical work at the motor shaft; all else is wasted, the energy going into heat instead of mechanical work. Early inventors of electric motors did not realize this, and tried simply to get as much current into the motor as possible, which only burned the motor up without producing any mechanical effect.

Current is supplied to the armature through sliding contacts formed by graphite blocks (called brushes because originally brushes of phosphor bronze wire were used instead) pressing against copper rings. It is usually necessary to change the connections of the armature windings as they rotate with respect to the magnetic field, and this can conveniently be done by making the copper rings in segments. The result is the rotary switch called the commutator.
These days, semiconductor switches can be used for this purpose in small motors, eliminating the commutator, but the principle is the same. The commutator and brushes are the only parts of a machine that normally require maintenance, except for the bearings and other mechanical elements. If it is not necessary to switch the current, as in AC machines, the moving contacts are called *slip rings*.

The ways that windings of wire are arranged in modern machines are shown below. The windings are either around the pole pieces, or placed in slots on the surface.

The part that rotates is called *the rotor*, and

The part that remains at rest is called *the stator*.

Both are of a magnetic core iron alloy, and are laminated if they are subject to alternating magnetic fields, to reduce eddy-current losses.

DC machines typically have a *salient-pole field* on the stator, with the field windings on the pole pieces, and a *non-salient pole* winding on the armature, forming the rotor. The magnetic field of the stator is constant, while the field in the armature alternates. Therefore, the armature is laminated. The actions of salient and non-salient pole windings are equivalent. A *non-salient pole* winding can be arranged to give any desired spatial distribution of magnetic field. The typical *salient-pole winding* of a *DC machine* provides field-free regions between the poles that aids commutation, since switching can be done while the armature conductors are in this region and not generating any emf. In both salient and non-salient pole machines, the windings are firmly held mechanically.

The windings of motors and generators can be connected in one of two basic fashions.

1. If the field windings and the armature windings are in series, they are called *series-connected*. In this case, the field windings are of heavy-gauge wire to carry the main motor current. The field becomes stronger as the armature current increases, leading to a very great force at low speeds.
2. If the field and armature are in parallel, they are called *shunt-connected*. The field winding consists of rather fine wire. If the voltage applied to the motor is constant, then the field strength is also constant. If a generator is rotated at constant speed, then the output voltage is independent of the load.
3. There are intermediate cases where the field has both series and shunt windings, and such machines are called *compound*.
Note:-

? **Power** is rate of doing work.
? One horsepower means lifting 550 pounds by one foot in one second.
? **Mechanical power** is force times speed.
? One watt is a current of one ampere (A) flowing in a potential difference or voltage of one volt (V).
? **Electrical power** is current (in amperes, A) times voltage (in volts, V). 746W is equivalent to 1 hp.
? **Torque** is the rotational equivalent of force, often useful in speaking of motors. It is force times perpendicular distance, and power is torque times rotational speed in radians per second.

**Rotating electrical machines**, there is really only one fundamental principle at work. These machines are transformers between electrical and mechanical energy, just as the usual AC transformer transforms between electrical energy at different voltages.

In fact, the ordinary transformer was also called a *static transformer*.

**Rotating electrical machines** are *dynamic* transformers.

On the mechanical side, the energy is transmitted by rotation. **Torque times angle is work, torque times angular velocity is power.**

**Every machine** has a magnetic circuit, in which certain fluxes are established that are analogous to the flux in a *static transformer*. This magnetic field assists in the energy transfer, but does not receive or give energy itself.

The magnetic flux links conductors, and can exert forces on them if they carry currents, and can induce emf's in them if the flux changes.

**The forces** determine the mechanical power, while **The emf's** determine the electrical power.

There are other energy effects, such as **I^2 R loss** in the conductors and the **eddy currents**, iron losses due to hysteresis, mechanical friction and windage, and the alternating flows of reactive volt-amperes.

However, the induced **emf's** and the **forces** are always such as to represent an ideal conversion between electrical (**emf's** times **current**) and mechanical (**force** times **distance**) energy, accompanied by these losses, which can be minimized, but are unavoidable.

When the conductors are on the surface of the rotor, actually in the magnetic field of the **air gap**, it is easy to see how the emf is induced, and how, if current flows, the force times distance equals the emf times current. It is not so easy to see this if the **windings** are on the **stator**, while the **force** is on the **rotor**, and if the conductors are buried in the iron, or wrapped around the poles. Nevertheless, a careful analysis would show in every case exactly the same relations that are so evident with conductors in the **air-gap**.
To generate electrical energy, we move conductors (armature) in a magnetic field at rest, or else move a magnetic field (rotor) relative to conductors at rest (stator). In either case we get a periodically reversing emf that can be made sinusoidal by careful design.

If generated in the rotor, the motion can be used to switch the connections so that the output current is unidirectional, and more or less constant. Mechanical energy always enters by the rotor, but electrical energy can be taken either from the rotor or the stator. Whenever any current is drawn, the mechanical side feels the effect as an increased drag. The energy received from the mechanical side is always greater than the electrical energy delivered.

To generate mechanical energy, we can place movable conductors (armature) in a steady magnetic field. Torque is produced when we drive a current through the conductors, and when the armature moves, we feel an electrical opposition to supplying the current. Or, we can wind the stator to produce a rotating magnetic field, and have this field drag along conductors on a rotor.

Current is driven through the rotor conductors either by induction, or by an external source. In either case, when mechanical energy is drawn, there is an electrical effect amounting to an increase of the current driven into a back emf. The energy delivered to the mechanical side is always less than the electrical energy supplied.

The only general and satisfactory way to understand the forces on the rotor of an electrical machine is by considering the magnetic field over an imaginary surface surrounding the rotor.

Note:- Electric fields play no role in the forces in electrical machinery.