EVROPSKÁ UNIE
Evropské strukturální a investiční fondy
Operační program Výzkum, vývoj a vzdělávání

MINISTERSTVO ŠKOLSTVÍ, MLÁDEŽE A TĚLOVÝCHOVY

10. DC machines, synchronous machines

10.1. Principle and design of DC machine

10.2. Types of DC machines, areas of usage

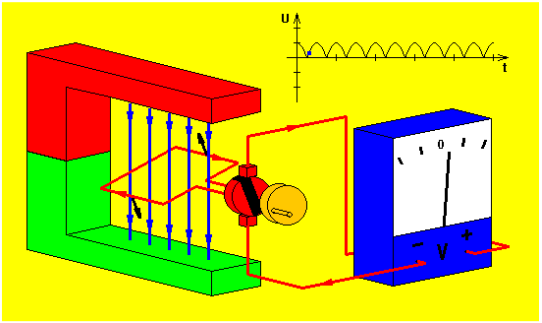
10.3. Principle and design of synchronous machine

10.4. Usage of synchronous generators

Doc. Ing. Stanislav Kocman, Ph.D.
May 2018

10.1. Principle and design of DC machine

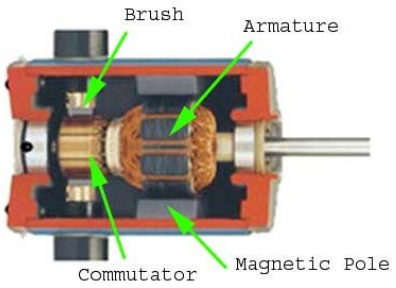
10.1.1. Principle of operation



Direct-current machines are DC generators or DC motors. DC generator is a machine that converts mechanical energy into electrical energy using the principles of magnetic induction, whereas DC motor converts electrical energy into mechanical. The elementary DC generator consists of a wire loop (called armature loop) rotating in a stationary magnetic field. This will produce an induced alternating voltage in the loop. The ends of the wire loop are connected to a segment of a two-segment split metal ring using brushes. The two segments of the split metal ring are insulated from each other. This forms a simple commutator. The commutator mechanically reverses the wire loop connections to an external circuit. This occurs at the same instant that the polarity of the induced voltage in the wire loop reverses. Through this process the commutator changes the generated AC voltage to a pulsating DC voltage. This action is known as commutation. (G. Rizzoni: Fundamentals of electrical engineering).

The pulsating DC voltage is however unsuitable for most applications. Therefore in practical generators more armature loops (coils) and more commutator segments are used to produce an output voltage waveform with less ripple.

10.1.2. Design of DC machine



The rotor called armature is made up of laminated cylinder with slots on its surface which is fixed on a machine shaft. There is windings wounded in the slots which coils ends are connected to the commutator segments which surface brushes are slipping on (armature winding). Nearly all practical generators use electromagnetic poles that means main poles with field windings (instead of the permanent magnets used in the elementary generator) secured to the stator frame. The main advantages of using electromagnetic poles are increased field strength and a means of controlling the strength of the fields. By varying the field strength, the voltage output of the generator can be controlled. The DC motor consists of the same components as the DC generator. In fact, most DC generators can be made to act as motors, and vice versa. Stated very simply, a DC motor rotates as a result of two magnetic fields interacting with each other. The rotor (armature) of the DC motor produces the magnetic field when current flows through its winding. Since the rotor is located within the magnetic field of the field poles (on the stator) or of the permanent magnet, these two magnetic fields interact (G. Rizzoni: Fundamentals of electrical engineering).

Induced voltage in DC machine (generator) in one wire on the rotor (armature):

$$V_{\text{ind}} = B_{\text{av}} l v$$

Induced voltage in windings:

$$V_{\text{ind}} = c\varphi\omega$$

where c is armature constant depending on coil geometry.

Torque in DC machine (motor) acting on the rotor (armature):

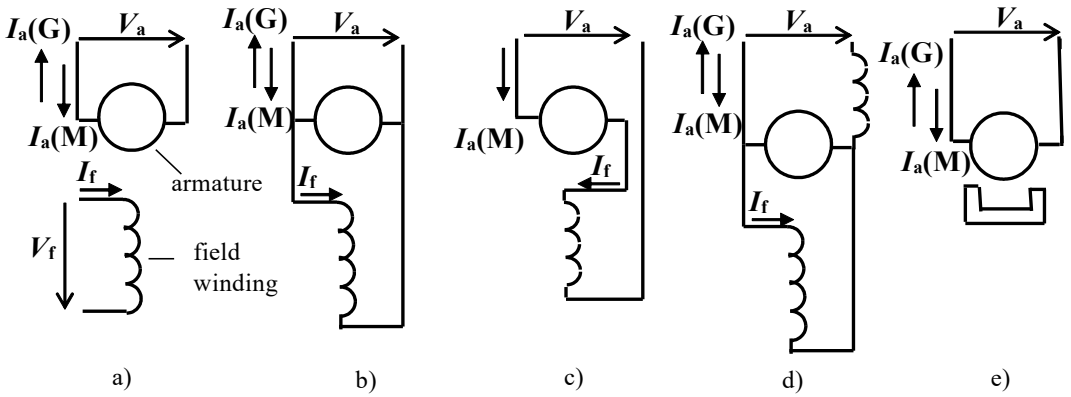
$$T = c\varphi I_a$$

10.2. Types of DC machines, areas of usage

10.2.1. Types of DC machines

The DC machines have two electrical circuits: field circuit (winding) on the stator and armature circuit (winding) on the rotor. According to a mode of these two circuits connecting, it is possible to divide DC machines as follows (G. Rizzoni: Fundamentals of electrical engineering):

a) separately excited: the field winding is not connected with the armature winding and instead of it, it is supplied from another DC source
b) shunt-connected: the field winding is connected in parallel with the armature windings
c) series-connected: the field winding is connected in series with the armature winding
d) compound-connected: it has two field windings, one is the parallel field, the other is the series field
e) with permanent magnets: magnets on the stator



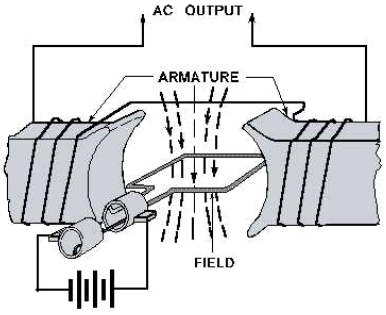
10.2.2. Areas of usage

- separately excited: motors in variable speed drives, mining machines, electric cars, ships, aircrafts…
- shunt-connected: field excitation for synchronous generators
- series-connected: motors in electrical traction, lift trucks, universal AC/DC motors (drills, grinders, cleaners…), engine starters…
- compound-connected: motors in special applications
- with permanent magnets: motors for car drives, cameras, air-conditions, domestic appliances…

10.3. Principle and design of synchronous machine

10.3.1. Principle of operation

Synchronous generators are the most important means of producing electrical power. Synchronous generators are generally called alternators. All electrical generators depend upon the principle of magnetic induction. The stator of synchronous generators is called armature. It holds the windings that are cut by the rotating magnetic field excited with DC current flowing through a DC winding placed on the alternator rotor. The voltage generated in the stator (armature) as a result of this cutting action is the AC power that will be applied to the load (G. Rizzoni: Fundamentals of electrical engineering).



All generators require a source of mechanical power to turn their rotors. This source of the mechanical energy is called a prime mover: steam and gas high-speed turbines, water low-speed turbine, electric motors, etc.

Frequency of induced voltage into stator (armature) for two-pole generator:

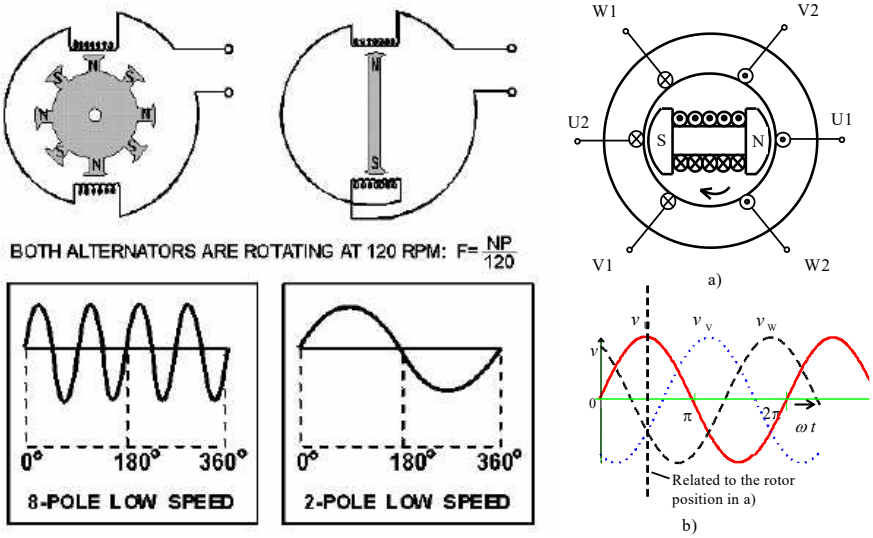
$$f = \frac{n}{60} \text{ (Hz, min}^{-1}\text{)}$$

Frequency of induced voltage into stator (armature) for 2p-pole generator (p =pole pairs):

$$f = p \cdot \frac{n}{60}$$

where n is number of rotations per minute.

10.3.2. Design of synchronous machine

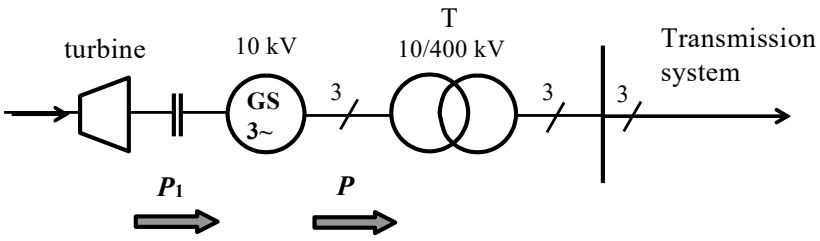


The stator consists of a laminated iron core with the armature windings (usually three-phase windings) embedded in this core. The core is secured to the stator frame. There are two types of rotors used in the alternators. They are called a turbine-driven and salient-pole rotors.

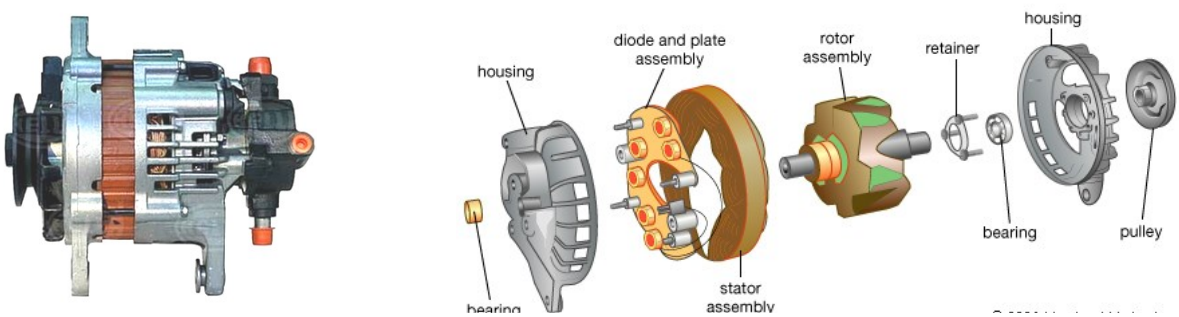
The turbine driven rotor is used when the prime mover is a high-speed turbine. The windings in this rotor are arranged to form two or four distinct poles. The windings are firmly embedded in slots to withstand the tremendous centrifugal forces encountered at high speeds. The both ends of the rotor winding are connected to two metal slip rings fixed on the machine shaft. Two brushes are slipping on the rings and they are connected to a source of DC voltage (e.g. DC generator) to supply the rotor winding with direct current. The salient-pole rotor is used in low-speed alternators. It consists of several separately wound pole pieces, bolted to the frame of the rotor. The slip rings and brushes are also used at this rotor type. The stator three-phase winding with three-phase alternating voltage generated into it by the rotor magnetic flux is connected to the mains to supply loads connected into it. The frequency of the voltage (50 Hz) depends upon the speed of rotation of the rotor and the number of poles (G. Rizzoni: Fundamentals of electrical engineering).

10.4. Usage of synchronous generators

- Turbo-alternators (turbine driven rotor)
- Hydro-alternators (salient-pole rotor)



- three-phase alternator for automobil



- brushless DC motor (special synchronous motor)