ELECTRICAL MACHINES vol. 2

A. IVANOV-SMOLENSKY

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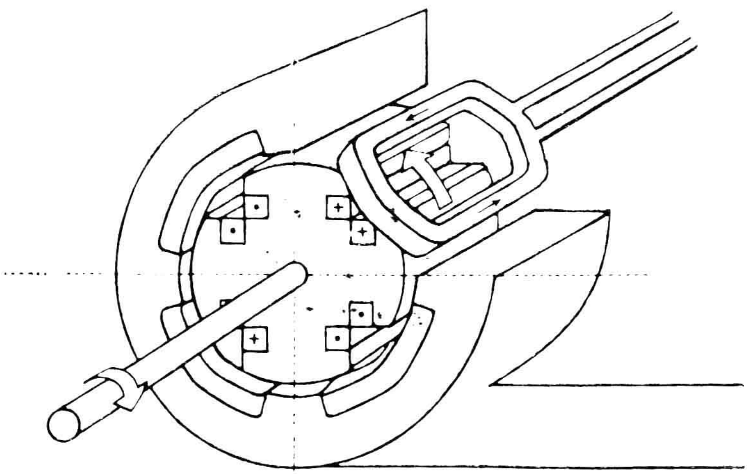
ЭЛЕКТРИЧЕСКИЕ МАШИНЫ



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32-1 Parts of an Electrical Machine and Their Functions

In an electrical machine, energy is converted within a space taken up by an electromagnetic field. The parts that serve to establish and confine the field may be called *active* (or *electrical*) as they directly contribute to energy conversion. These are the cores, conductors (coils), and air gaps.

In addition, there are parts which do not contribute to energy conversion directly, but are essential to the operation of a machine. They may be called *structural* (or *mechanical*) parts. Among other things, they

(a) hold the stator and rotor in their designated relative position and ensure (or limit) the desired degrees of freedom;

(b) transfer electric energy between the cores and coils, on the one hand, and external lines, on the other;

(c) transfer mechanical energy between the prime mover and the driven machine;

(d) provide cooling;

(e) insulate the coil turns from one another, from mechanical parts, and from the cores electrically;

(f) protect the cores and coils against exposure to external factors (moisture, harmful gases or fumes, and the like) and prevent ingress of foreign objects inside the machine;

(g) ensure safety to attending personnel by limiting (or preventing) access to and contact with rotating or live parts;

(h) facilitate the installation of a machine at its permanent location.

The typical parts of an electrical machine are illustrated in Fig. 32-1 which shows a salient-pole synchronous machine. The arrangement shown will be found in most electrical machines in general.

The active parts are stator winding *1*, rotor winding *7*, stator core *2*, and rotor core which consists of poles *3* and

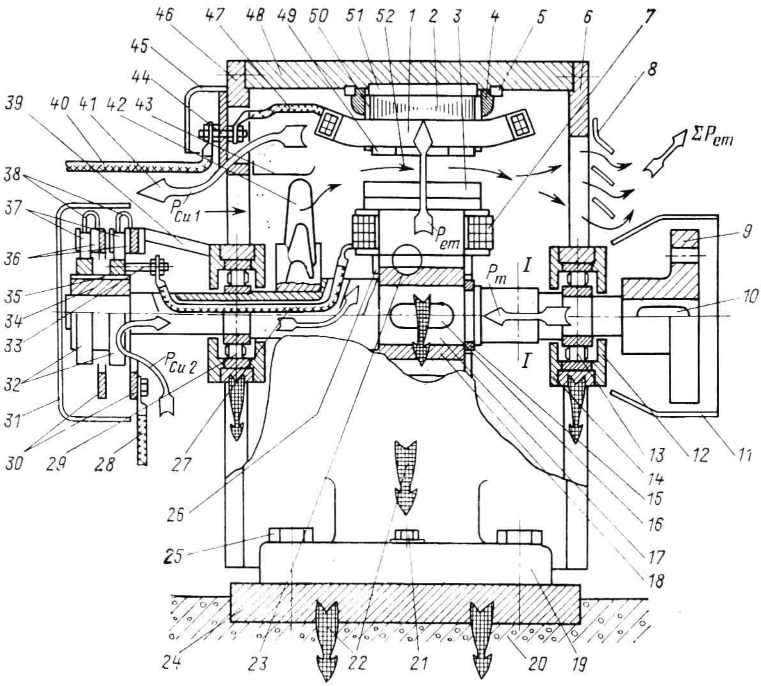
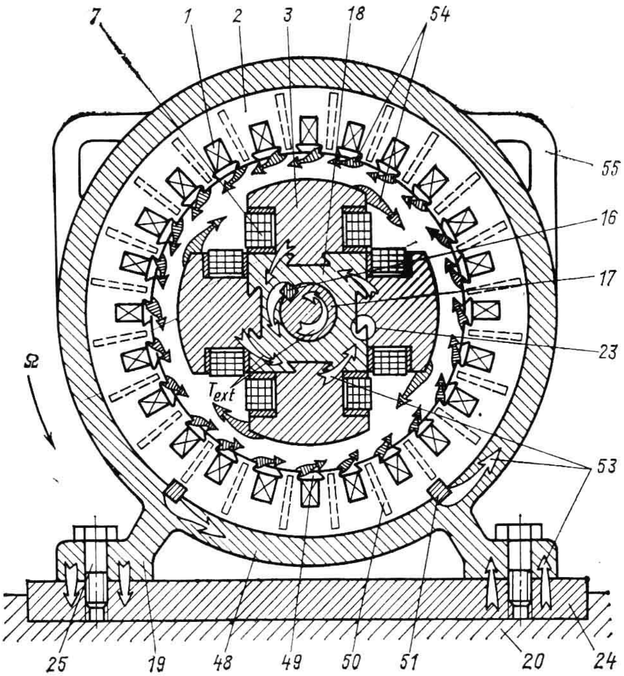


Fig. 32-1 General arrangement of an electrical machine

yoke *18*. In the arrangement shown, the magnetic field in the poles and yoke of the rotor is constant in magnitude and direction. This implies that these parts are not subject to cyclic magnetization, so they may be fabricated of solid (one piece) steel forgings.

In the stator core, the magnetic field varies periodically at the supply frequency. To minimize hysteresis and eddy-current losses (see Sec. 31-3), it is built up of insulated electrical-sheet steel laminations *2* clamped together by clamps *50*, pressure blocks *4*, and keys *5* inserted in annular recesses in frame *48*.

The tangential electromagnetic forces acting on the stator are mainly applied to the stator teeth (see Sec. 29-3). These forces are, in the final analysis, transmitted to and absorbed by the foundation. Their path is from the stator teeth and



yoke, through keys *51*, frame *48*, frame feet *19*, anchor bolts *25*, baseplate *24*, to foundation *20*. (The electromagnetic forces and the forces transmitting external torque via fixed parts are shown by arrows *53* and *54*, respectively, in Fig. 32-1).

Appreciable electromagnetic forces (especially during transients) are acting on the coil conductors as well. To counteract them, the active conductors are anchored to slots by wedges *49*, whereas the coil ends (overhangs) are held in place by tape or clamps.

The tangential electromagnetic forces acting on the rotor are mainly applied to the pole-shoes. On the shaft acted upon by the external torque that balances the torque due to the tangential electromagnetic forces, the poles are held by a combination of dovetail joint *23*, rotor yoke *18*, and key *16*.

Axially, the rotor parts are additionally locked by straps *26* that prevent the poles from moving in the dovetail joints, and also annular key *15*. The rotor is held in its designated position and permitted to rotate relative to the stator by axial and radial bearings. The radial bearings in the design shown in Fig. 32-1 are of the roller type, *13* and *29*, held in end shields *6* and *46* by caps *14* and *12*.

The weight of the rotor is transmitted to the foundation via end shields *6* and *46*, and frame *48* to which the end shields are fastened by means of flanges. To the rotor weight is added the weight of the stator (the respective forces are shown in Fig. 32-1 by arrows *22*).

The flow of electromagnetic power, P_{em}, across the air gap separating the cores is shown by arrow *41*. For the adopted sense of rotor rotation, Ω, the directions of torques, forces, and energy fluxes are those existing in the generator mode of operation.

Mechanical power, P_m (the direction of its flow is shown by arrow *41*), is transmitted from the associated prime mover to the rotor via a chain of mechanically strained rotating parts. Starting at half-coupling *9*, the mechanical power is transmitted via key *10*, through shaft *17* and key *16* to the rotor, whence it is directed to rotor yoke *18*, dovetail joint *23*, and poles *3* which are acted upon by the bulk of the electromagnetic forces (see Sec. 29-3) shown in the cross-sectional view by arrows *53*.

Electric power is conveyed from the stator coils laid in stator slots by leads *47* to terminals *44* and cables *40*.

To the rotor coils, electric power is conveyed over cables, via conducting segments *30*, pig-tails *38*, brushes *37* which are free to move in brush-holders *36*, slip-rings *32*, slip-ring leads *33*, and leads *27* passing through an opening in the shaft. Segments *30* are attached over insulating parts to rocker-arm *39*; the slip-rings are press-fitted on sleeve *34* insulated by cylinder *35*.

The total power losses, $\sum P$, are dissipated in the machine as heat which is abstracted by cooling air flowing in the direction shown by arrows *52*. The static pressure required to circulate cooling air is produced by axial-flow fan *42*. Air enters the machine by openings in end shield *46*, is directed by baffles *43*, scooped by the fan and, on passing through ventilating ducts in the cores, is expelled from the machine through openings in end shield *6* and louvres *8*. Many of the baffles, ducts and enclosures (*8*, *45*, *31*, and *11*) serve a two-fold function in the machine: they prevent ingress of foreign objects and water drops and also keep attending personnel from direct contact with the rotating and bare live parts.

As a further safety measure, the frame of the machine must reliably be grounded. To this end, it has grounding bolt *21*. This will prevent an electric shock upon contact with the machine, should its insulation be damaged.

To facilitate installation at its permanent location, the machine is fitted with lifting lugs or eyes (at *55* in Fig. 32-1).

As already noted, the arrangement illustrated in Fig. 32-1 is basically common to all rotating electrical machines. Whatever variations there may be, they will mainly concern the core shape and the winding circuits. (Various designs and types will be examined in separate sections and chapters.)

The arrangement and size of the active and mechanical parts vary with the form of cooling used (see Chap. 37), the type of enclosure adopted, the type of shaft, and some other features (see Chap. 33).

32-2 General Requirements for the Construction of Electrical Machines

The active and mechanical parts of a machine must be designed, detailed and manufactured so as to meet the requirements of relevant standards, and so that the machine could perform its designated function adequately.

Among other things, appropriate standards or codes require that a machine should reliably operate under nominal service conditions. In the Soviet Union, the limiting service conditions are taken to be an ambient temperature of +40°C and an altitude of not over 1 000 m above sea level. Also, a machine should remain fully serviceable under conditions of overcurrents, overvoltages, excessive rpms, and starting currents, voltages and electromagnetic torque (in the case of motors) to the extent likewise specified in applicable standards or codes.

The choice of materials and dimensions for the active and mechanical components is decided upon and checked at the time of electromagnetic design and analysis, insulation design, stress-strain analysis (Chap. 34), hydraulic design (Chap. 36), and thermal analysis (Chap. 35). The turn insulation must be designed to withstand the interturn voltage, and the ground insulation must be able to stand up to the voltage between the conductors and the grounded core.

The type and form of insulation (insulating and impregnating materials, clearances, radii of curvature and bends, and the like) must be chosen such that the electric field strength in the insulation at the highest operating voltage will not exceed the safe limit and the insulation will retain its electrical strength for a long time. The insulation must also be checked and tested for its ability to withstand repeated application of atmospheric and switching surges. The electric strength and insulation resistance of a machine should be checked at the time of testing the ground and turn insulation [13]. The insulation is required to pass these tests without any damage or impairment in quality.

The winding insulation must have ample mechanical strength so as to withstand all kinds of mechanical forces during erection and in service (static, impact, vibrational, etc.). The requirements for the mechanical strength of insulation are not very stringent, because the electromagnetic forces transferred from the conductors to the slot sides in a tangential direction are insignificant (see Sec. 29-3). The prevailing factor is the pulsational forces arising from the interaction of currents with the leakage field, which drive the conductors against the slot bottom.

The maximum temperature at which a given type of insulation retains its electrical and mechanical strength and durability (the ability to preserve its properties for a period of 15 to 30 years without noticeable changes) serves as a basis for dividing all insulating materials into several classes, such as listed in Table 32-1. In more detail, this matter is discussed in [13].

The insulation classes listed in Table 32-1 are as follows.

Class A. Cotton, silk, paper, and similar organic materials