CONTROL OF ELECTRICAL MACHINES FOR DRIVES

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Summary

Electric drive systems are one of the most important components of our life; billions of them are used in industry, traffic applications and private environment. In the recent past an accelerated development of controlled drive systems could be experienced. The scientific and technical background of today’s most important drive systems, the converter controlled DC-drives and the vector controlled induction motor, are described in detail.

1. Introduction

Industrialization is closely linked to the development of drive technology. With the steam engines of WATT and others the first era with mechanical drive systems began at the end of the 18th century. In the last third of the 19th century electrical drive systems were developed. In industry within a short period the line shaft drives disappeared and the motor was integrated into the machine. With the advent of power electronics some decades ago again new possibilities came up for speed variable drives. Their technical performance and economical design opened a new philosophy of drive applications. Now an individual motor and control system is foreseen for each function, these multidrive systems are governed and controlled from a central control unit.

The majority of all drive systems are electrical drives with growing tendency. This is not self evident. Electrical drive systems do not have a power density as high as pneumatic or hydraulic systems. Electrical motors are bulky and heavy in comparison to these competitors. But electrical drives are for three reasons superior to such an amount that pneumatic and hydraulic systems will be superseded the longer the more:

- Cleanliness of the energy supply
- Dynamics of control
- High efficiency of electro-mechanical power conversion

Even pneumatic systems, which have principally a low efficiency in consequence of the thermodynamics of compressed air, are by no means clean systems because the air must contain some oil for lubrication. Compressors, dual piping and oil separators are expensive equipment. They are mainly operated in the bang-bang mode from stop to stop. On the other hand an exact control of electrical power today is possible within microseconds for Megawatts. No other form of energy can be controlled so fast.

The general arrangement of a drive system is shown in Figure 1. The energy conversion between electrical and mechanical power is performed by the electrical machine (3) in both directions. Braking is as essential as driving and only small drive systems with relatively high friction losses can be built without an active brake. The energy supplied by the mains has to be controlled and for variable-speed drives converted to other voltages and frequencies. Normally motors, directly supplied from the mains, have nearly constant speed. But also these must possess a suitable power switch which is nothing else than a simple power amplifier (2). The power supply (1) may be the mains, batteries or any other source. Between the motor and the driven load (5) a gear (4) is applied. Direct coupling is not always possible or makes not much sense. The gear may be an ordinary spur wheel set, a belt drive or an arrangement with worm and worm-wheel. But also more complicated devices for generating linear or non uniform movements may be represented by block (4).

The control center (6) is the brain of the complete drive system. Not only the commands are given to the power amplifier, also the complete monitoring of all parts of the system is performed by this unit.

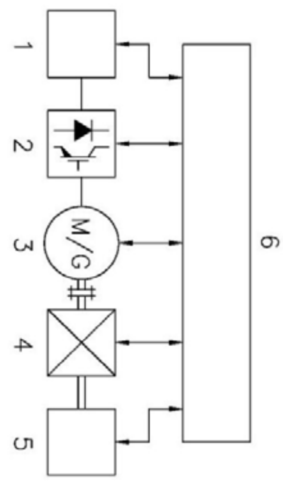

Figure 1: General arrangement of a drive system (1. Power supply, 2. Electrical power converter, 3. Electromechanical power converter, 4. Gear, 5. Load, 6. Central control unit)

The steady-state behavior of a drive system is best understood with a look at its torque-speed graphs. The motor as well as the machine driven have a special torque-speed characteristic, as shown for an example in Figure 2. The intersection of the two curves determines the point of operation (PO). If curve (1) is assumed to be the motor characteristic and curve (2) the torque-speed function of the mechanical load the PO is statically stable. This follows directly from the type of intersection. For lower values of speed than the speed at the PO the torque difference will accelerate the system to the equilibrium, for higher speeds a deceleration would be the consequence. An opposite behavior could be expected, if motor and load would exchange their characteristics. Then the PO would be instable and the system either speed up or brake down.

The PO in Figure 2 is in the motor mode. Either the torque or the speed has to be reversed, to have a brake mode. Then the PO must change to the second or fourth quadrant of the diagram. In the third quadrant with negative torque and speed again the drive is in the motor mode, but in reverse direction. Drives with the full capability of both speed and torque directions are called four quadrant systems.

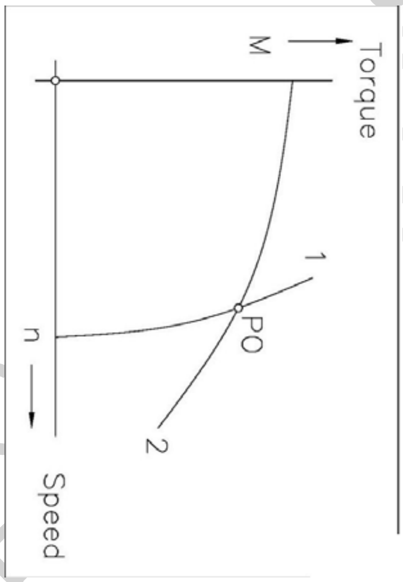

Figure 2: Torque-speed characteristics of motor and load (1. Motor, 2. Load)

2. General Remarks on Electrical Machines

The drive technology spans from milliwatts to Megawatts. The smallest drives are for instruments, watches etc.; the most powerful for the propulsion systems in vessels, for pumps in power stations and for heavy industrial applications. The size of any electrical machine of similar design is given by its torque. Under similar conditions the volume or weight ratios of machines grow with an exponent $\kappa = 3/4$ to the torque, this means that two machines with a torque ratio $M_2 / M_1 = 10$ will only have a mass ratio $m_2 / m_1 = 5.6$. On the other hand, the inertia of rotation has the growth exponent $\kappa = 4/3$, for the aforementioned example this will give an inertia the ratio $J_2 / J_1 = 21.5$. These facts have to be taken into consideration for drive control if a high dynamical performance is expected.

Electrical machines are built with many designs; each of them has advantages and disadvantages. For all types best suited applications are found. But the so-called heteropolar types show the best overall performance. The basic principle of these is shown in Figure 3. An ensemble of electric conductors is arranged on a rotating cylinder or rotor within a magnetic field. Currents in the conductors will generate the forces **F** and -**F** perpendicular to the magnetic field **B** and to the direction of currents **I** and -**I**, the sum of all forces theoretically is zero, but a torque **M** is generated. With the current distribution shown in Figure 3 the torque will have its maximum value. If the current distribution is unaltered in relation to the rotor, the torque **M** will cause a turn of 90° in the counterclockwise direction into a balanced position. It is therefore necessary to keep the distribution of currents constant rather in relation to the magnetic field than to the rotor; the current distribution on the rotor must be shifted according to its angular displacement. The different types of heteropolar electrical machines are distinguished by the method, how the current layer is moved on the rotor. For all electrical machines in principle stator and rotor can be built with their functions exchanged, this fact has no influence on their fundamental performance.

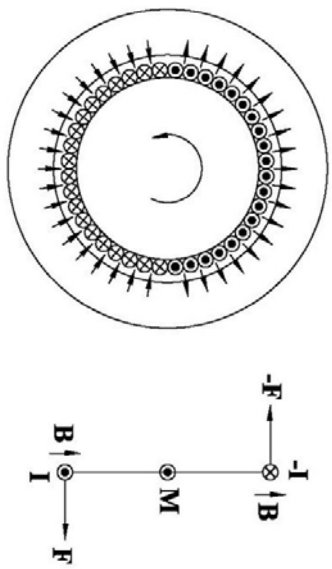

Figure 3: Principal scheme of the heteropolar electrical machine

In the DC machines there is a mechanical switching apparatus, the commutator, responsible for the correct current distribution. In the AC machines the current shift is performed by a two-, three- or poly-phase AC system.

The magnetic field may be excited by field windings or permanent magnets which offer an advantageous way for the loss-less magnetization. In the induction motor the magnetic field is generated from a three-phase AC voltage with a three-phase winding system and the conductor current transformed to the rotor windings by induction. Normally these are designed as a cage of aluminum, embedded in the rotor iron. Not to go too much into details, some few remarks to this simplified explanation of the electrical motor shall be added. The currents, generating the torque, always give a contribution to the excitation of the magnetic field to a more or less extent. This so called armature reaction is the main reason why the most important AC machine, the induction motor, is so complicated at first look and sometimes is not well understood.

Secondly the theory necessary for investigating and designing control systems is by no means sufficient for the motor design. For control purposes the overall behavior of the motor is essential, local specialties of operation within the motor are of no detailed interest.

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Biographical Sketch

Jörg Hugel, born in Stuttgart in 1938, studied Electrical Engineering at the Stuttgart Technical University and wrote his doctoral thesis on the subject of control engineering under the guidance of A. Leonhard. His subsequent activities in industry in the fields of plant engineering and power electronics were broad in scope and internationally oriented. Since 1982 he holds the Chair of Electrical Engineering Design at the ETH Zurich, Switzerland.