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Susanne Jakob
Dipl.-Ing. Helge Drumm

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51. Internationales Wissenschaftliches Kolloquium
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Peter-Klaus Budig

Simplification of the Mechanical Design of Drives with the Application of Direct Drives

Prof. Dr. sc. techn. Dr.h. c. Peter- Klaus Budig
EAAT GmbH Chemnitz
Annaberger Str. 231
G – 09120 Chemnitz
Tel. ..49 371 5301911, Fax. .. 493715301913
e-mail : eaatgmbh@t-online.de

Abstracts: **A direct drive means a gearless mechanical connection between motor and machine. This principle can be realized with revolving and linear motors as well.**
The gearless design has advantages for the simplification of the system as well as for the dynamic performance of the drive. Last but not least the energy consumption is reduced. The simplification leads to the integration of actuator and machine components. This brings a cost reduction as well as a reduction of the maintenance costs. Some practical applications are discussed.

I. Introduction

In many countries 60 % of the electro- energy is changed by electrical drives in mechanical energy. The electrical drive are able adapt speed and torque very tight to the machines or process need. Thus energy can be saved in an amount of several percents to 30%. This is important for the global economy and means a high responsibility of the drive engineers to save energy.

II. Structure of a drive- system

As Fig. 1 shows the classic drive has a gear- box between the motor and machine. Even more it can be any mechanism to perform revolving motion to liner motion. In the structure there are power- loss sources in the motor, the gear box or mechanism and finely in the machine. Similar it is with the moments of inertia. The energy is at least twice converted.

Much more simple is the system using a direct drive. That one is characterized by the direct connection of motor and machine. According to this there is at least one source less of losses and of inertia.

The mechanical gear is not necessary as well as a mechanisms for changing revolving motion to linear motion are not needed.

Less losses leads to less energy- costs and less inertia gives a higher dynamic performance. But there are some more financial advantages:

- less space - less investigation amount
- less noise
- less amount of maintenance
- no costs for the gear- box or the mechanism.

III. Drive structure

As shown in Fig. 2 there is the direct drive structure of a revolving and a linear drive. Revolving drives mostly using low speed and high torque. Now there are many producer are offering so called “torque motors” which are designed for the mentioned condition. Similar it is in a linear drive- system. There is an interesting exception in the field of revolving drives the magnetically suspended spindle. Here are used extremely high speeds like several 10^3 rpm (Fig. 3).

A more detailed introduction to a linear direct drive shows Fig. 4. Here are compared a linear drive of a machine- tool with a drive with a ball- screw drive. It is to be seen the last one has much more elements of elasticity and much more mechanical components. In these components are hidden damping performance as well as torsion-effects. They are a additional source of oscillations. Therefore the diff. equation becomes of a higher order has additional resonance effects as well as a reduction of the response time of the drive. Of high importance is that in a direct drive there is no back- lash which influences the dynamic performance negative.

One more system design is of interest the combination of a revolving and a linear motor as it shows Fig. 5. Here it is necessary to design the revolving motor in that way that its rotor can be moved with the linear motor without to leave the stator boring.

IV. Synchronous or asynchronous motor

The power distribution gives Fig. 6 for both motor-types. The asynchronous motor has the disadvantage of the rotor losses s x P_δ. On the other hand the synchronous motor may have additions eddy- current- losses in the surface of the permanent- magnets. Since the speed of a torque- motor is rather low these losses are to be neglected. The synchronous motors are mostly not fitted with a exciter- system for the magnetic field. They have permanent- magnets according to Fig. 7. Torque motors have surface- magnets. They can have a shaped configuration or there are composed of small strips.

Since the synchronous machine does not need an excitation the power per volume is higher than in an asynchronous machine (see Fig. 8).

In the air- gap of the synchronous machine there is are the permanent magnets as well as the stator- winding. Its current coverage drives a magnetic field strength perpendicular to the machines d- axis. Thus the magnetic induction of the permanent magnets is decreased at the one side and increased at the other side of the pole. If the magnetic field- strength is big enough a demagnetisation can occur (Fig. 9).

As the vector diagram of currents and voltages show the speed of a synchronous machine is limited by the terminal voltage. According to equ. 2 and Fig. 10 is:

$$U_s = U_p + I (R_s + j \omega l_s) \qquad (2)$$

For increasing the speed it is demanded for a weakening of the magnetic fields and according to this of the voltage U_p. For this the component I_{sd} is needed. Now there is a decreasing of the magnetic field and the above mentioned voltage. Now speed above the normal rated value becomes possible. But there is a danger. If the terminal- voltage fails suddenly there now is induced a voltage U_P is:

$U_{pd} = U_p$ x n_{max} / n_{rated}.

Its value can is much higher than the terminal voltage. Thus the maximum permissible voltage of the inverters power- components is exceeded and they have a break through – they are damaged.

V. Operation diagram of the synchronous motor

Fig.11 shows the operation- diagram. There is plotted torque above speed.

T_c = continuous torque, according to the iron- losses it decreases with increasing speed.

T_{max} = the maximum torque, can be used only for a short time. It is limited by the maximum permissible current of the inverter.

Demagnetising limit. As already discussed demagnetisation can happen if the current becomes too high.

Limitation by the inverter- voltage. In between continuous torque and maximum torque there is the range of short- time operation.

VI. Revolving direct drives

Two realised examples are shown in Fig. 11. In both cases is well to be seen the integration of mechanical and electromagnetic components. This is the remarkable effect of the direct drive concept. Now there is a change of the limits of responsibility between machine- engineers and drive engineers.

Next it is remarkable that the mechanical bearing for both of the partners is the same. This shows the effect of simplification.

The second picture shows the integration of the mechanical bearing in the magnetic circuit of the motor. The outside bearing ring is extended in that way that now it has the double- function – part of the bearing and magnetic rotor iron. It was proved that there is no influence of the magnetic field lines to the iron- bearing balls.

Table 1 gives a survey of realized torque motors. This list will be extended in the next time for motors with a torque in the range of 14 000 Nm till 16 000 Nm. Fig. 13 shows the photo of a rotor and a stator

The combination of linear- and revolving- motor shows Fig. 14.

VII. LINEAR DIRECT DRIVES

The primary and secondary of typical motor- design of linear motors is shown in Fig. 15, 16 and 17. There are flat motors with iron at the stator and secondary as well and even more there is a iron- less stator.

The drive of a tower with a weight of 10 000 kg and a high position accuracy shows Fig. 18. The Components of a spherical motor shows Fig. 19. Its Thrust is 1 Newton and the resolution in the range of 1 000 Hz is 0,0002°. It was designed for space application.

VIII. SUMMERY

Direct drives are important for the future of the electrical drives they offer new performance under the point of view like commercial consideration, simplification of the structure of the drive system, dynamic performance of the drive. Last but not least there are advantages for the application by lest space, less noise, less maintenance, less wearing. Thus the applicant can save money.

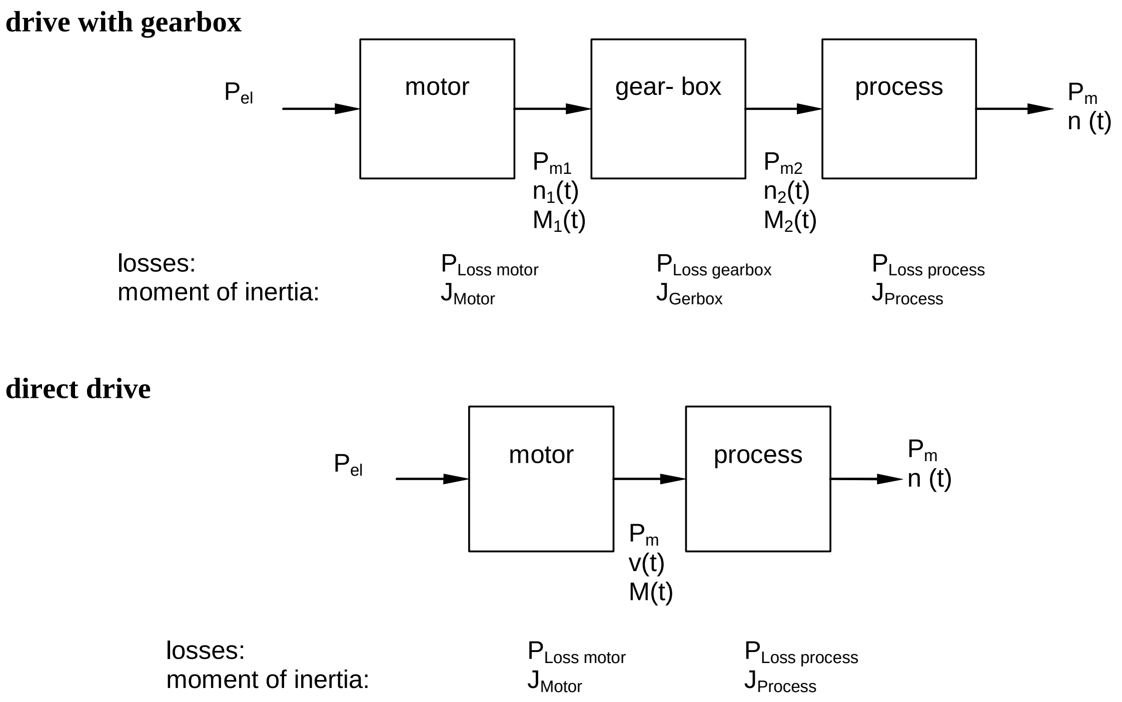


Fig. 1. Comparsion of drive systems

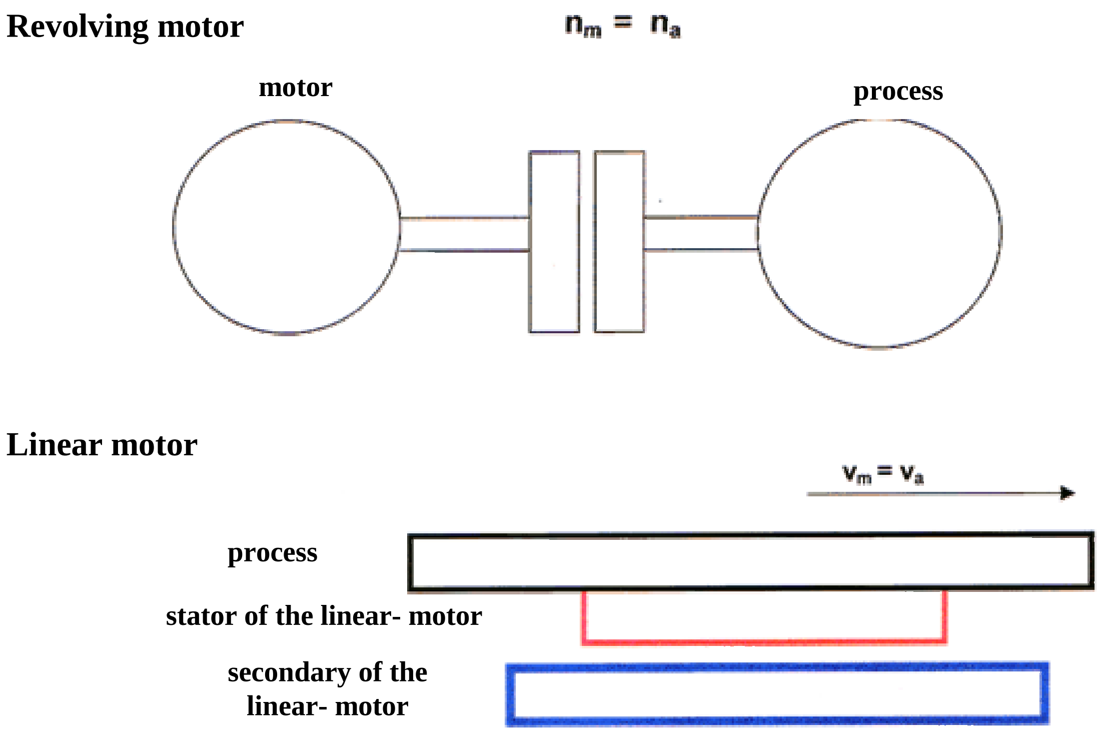


Fig. 2. Direct drive

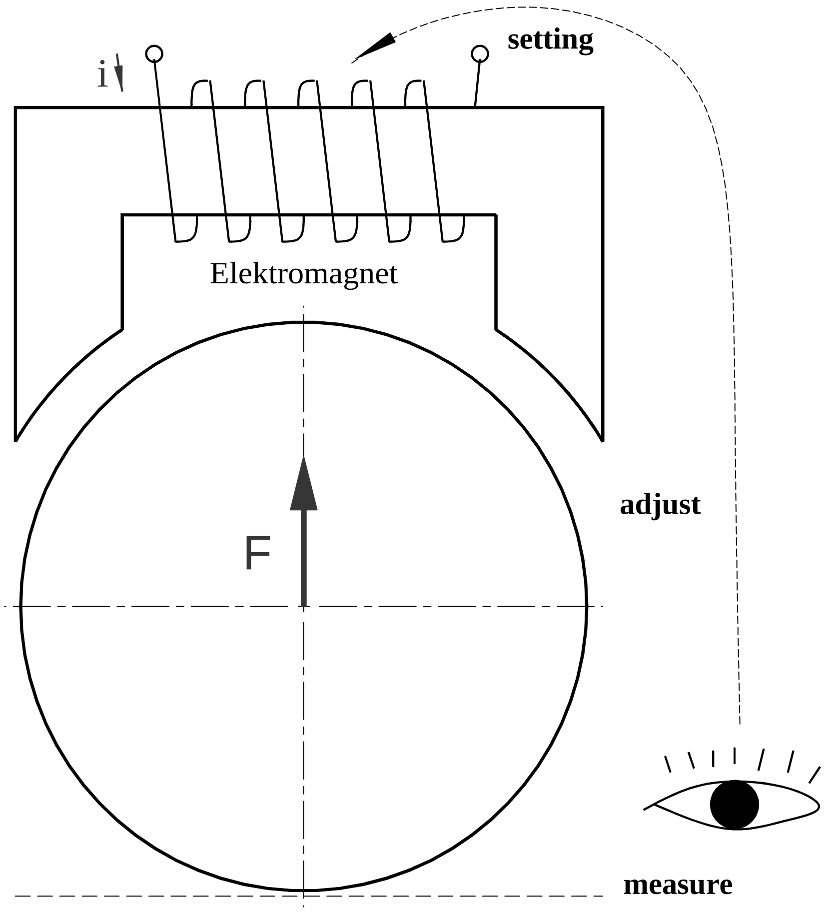
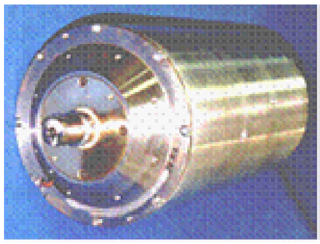
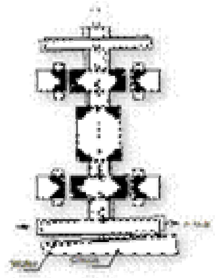


Fig. 3a. Magnetic bearing. Principle

milling spindle
speed: 50.000 min^{-1}
power: 50 kW
radial force : 2.000 N
axial force: 1.000 N



grinding spindle
speed: 8.000 min^{-1} (max.)
power: 4,8 kW
TTV (total thickness variation) > 2 micrometer



polishing spindle
speed: 1000 min^{-1}
power: 100 W
motion in x, y and z- direction

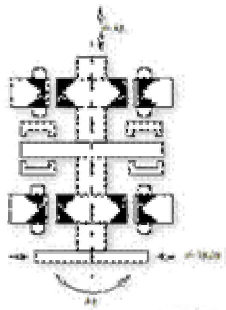


Fig. 3b. Magnetic bearing. Applications

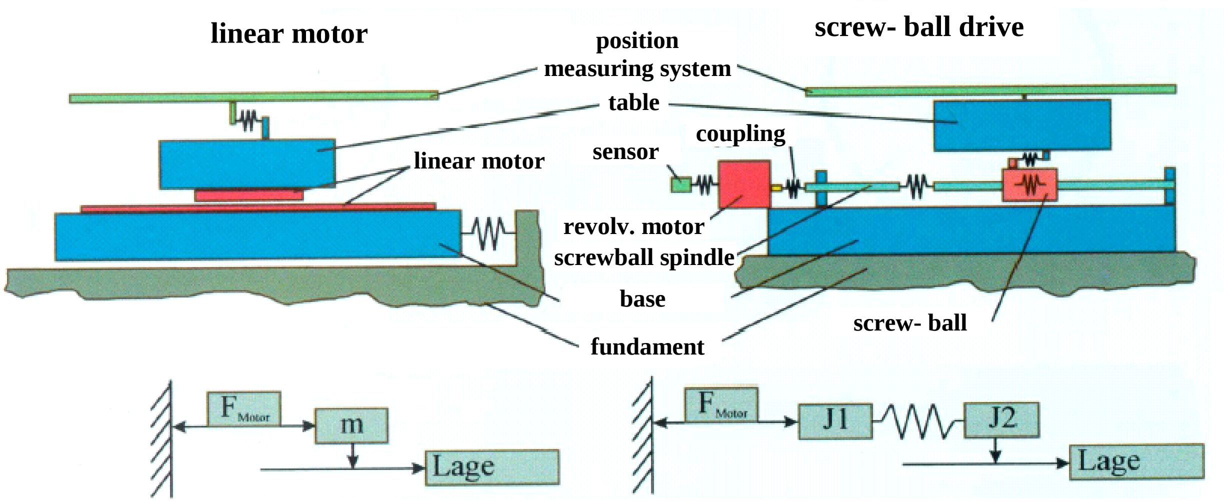


Fig. 4. Comparison of direct- drive and screw- ball drive

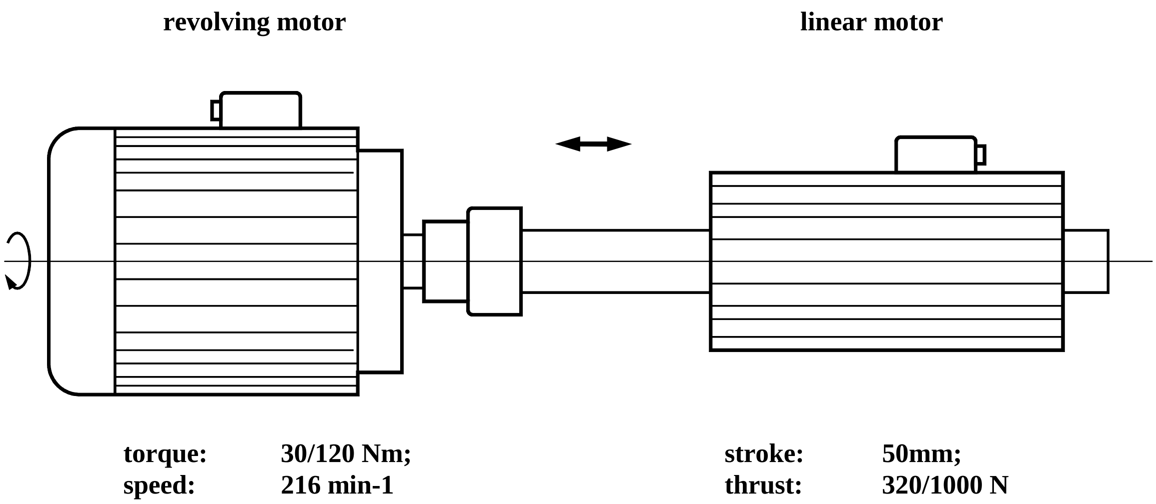


Fig. 5. Combination of linear- and revolving drive

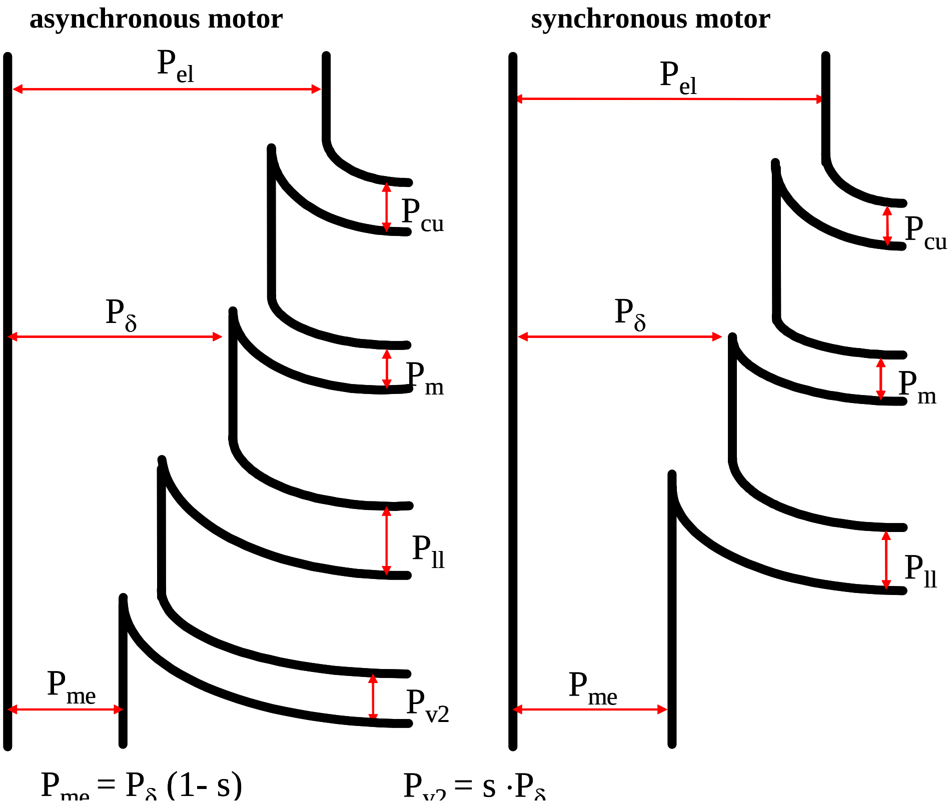
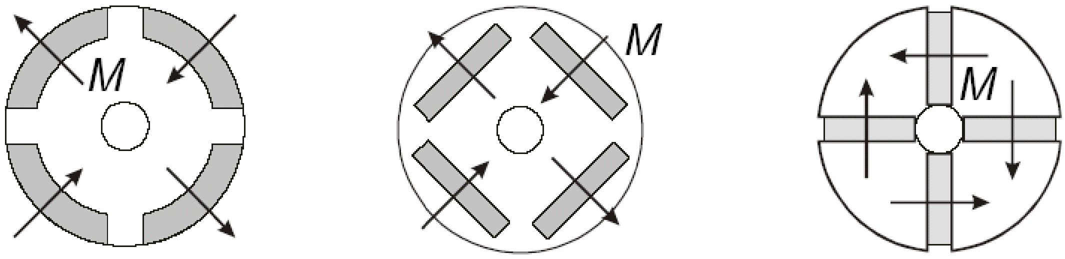


Fig. 6. Power and losses



- **surface magnets**
- **embedded magnets with radial magnetization**
- **embedded magnets with tangetial magnetization**

Fig. 7. Permanentmagnets of a 4- pole machine

Specific thrust

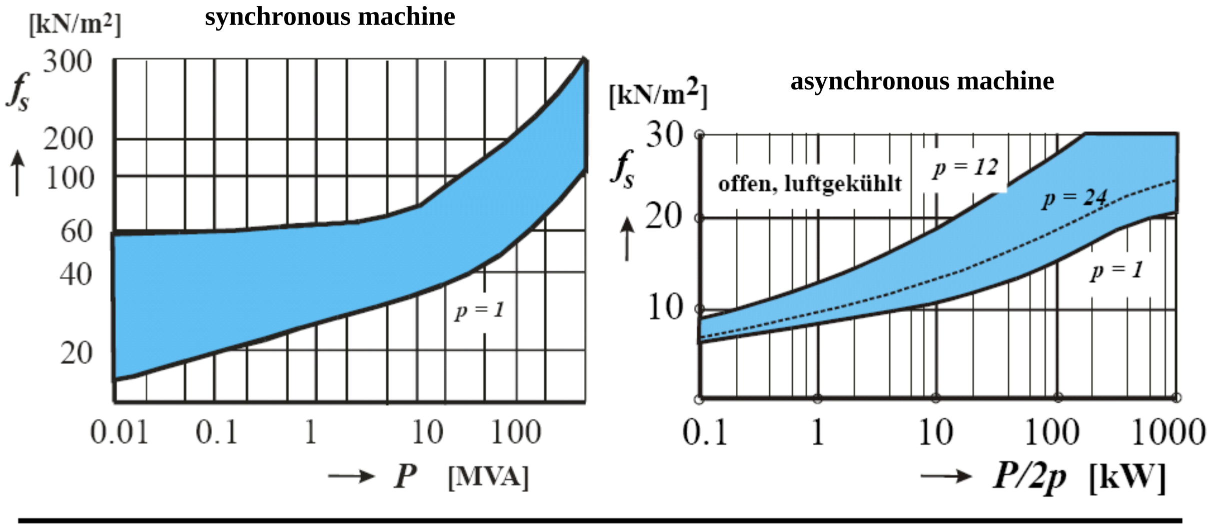


Fig. 8. Specific thrust

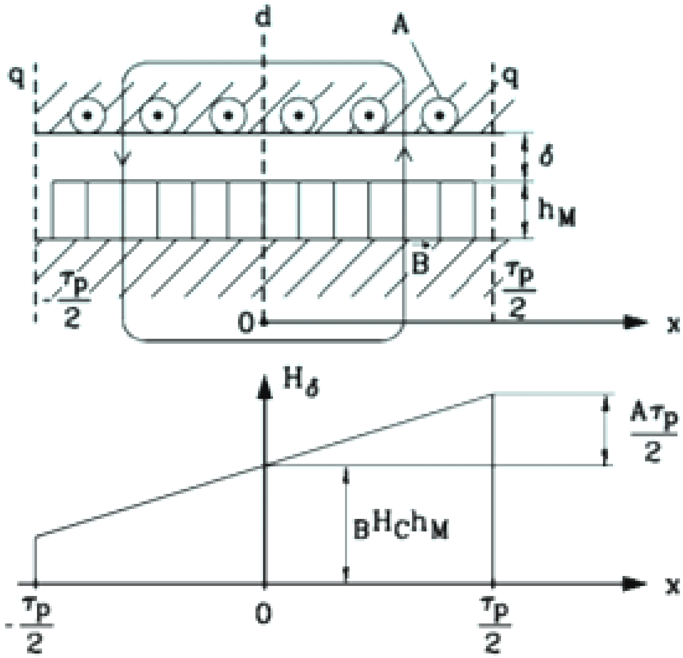


Fig. 9. Demagnetization of permanent magnets

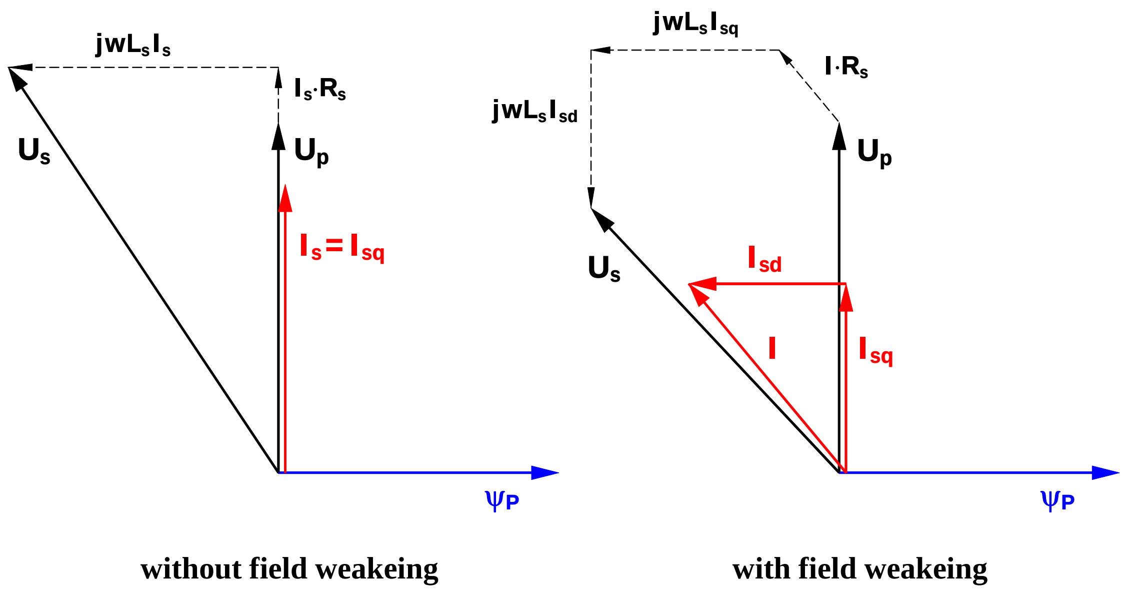


Fig. 10. Phase- diagram of a synchronous machine

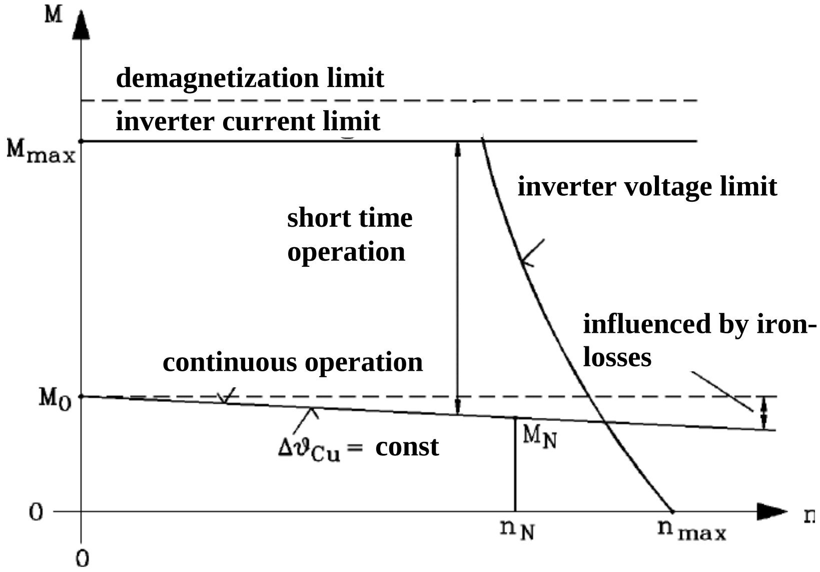


Fig. 11. Operation diagram

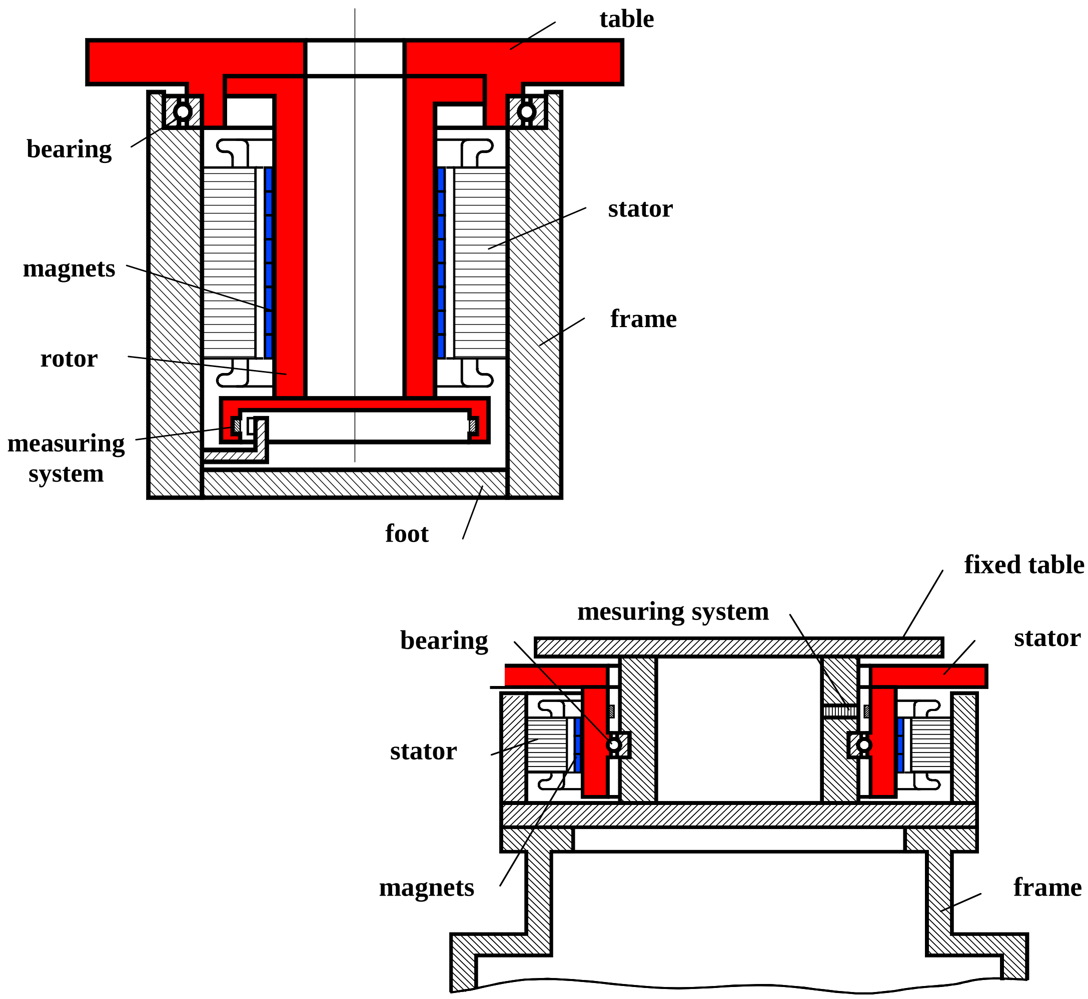
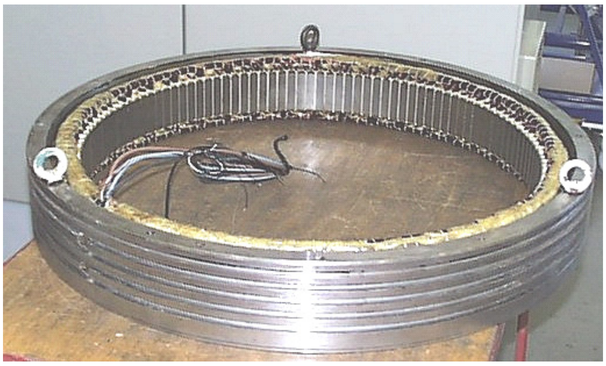
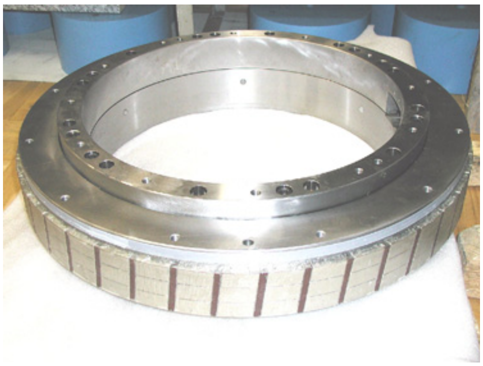


Fig. 12. Realized drive with torque motor



stator with cooling jack



bearing- ring with permanent-magnets

Fig. 13. Photo of components of a torque motor

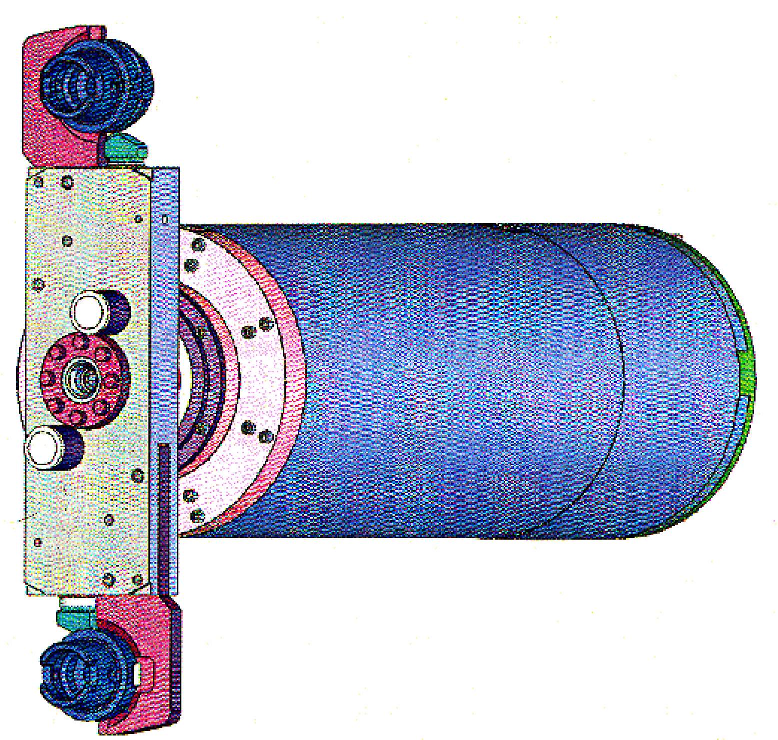
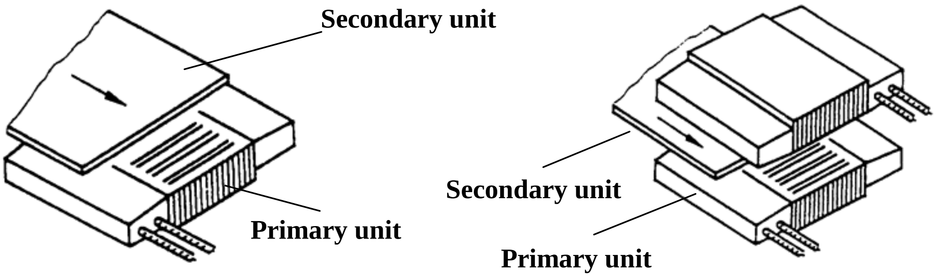


Fig. 14. Combination of revolving and linear direct drive

Flat three-phase linear motor



Cylindrical linear motor

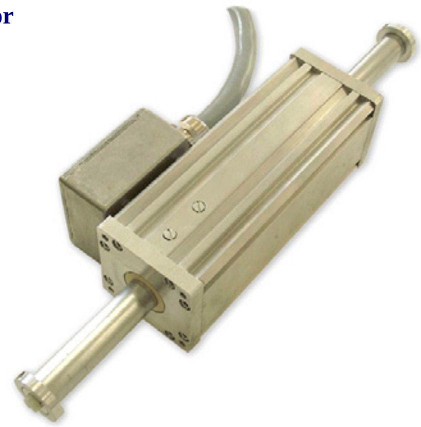
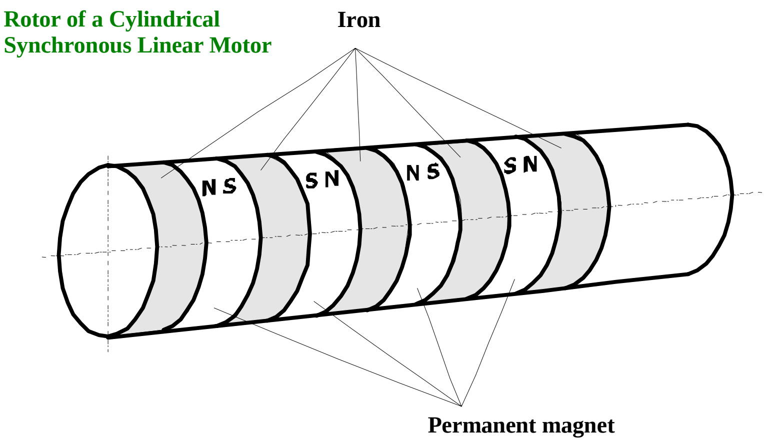


Fig. 15. Linear motor



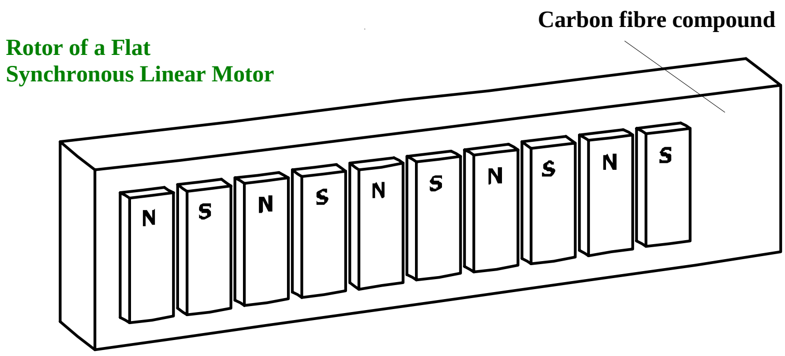


Fig. 16. Secondary of linear motors

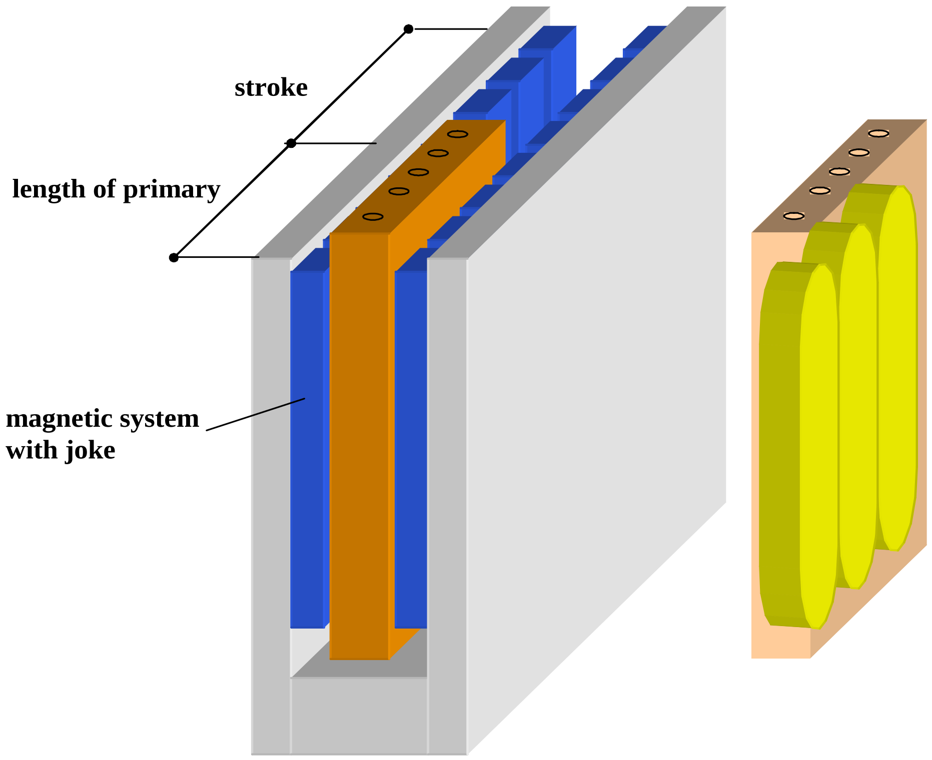


Fig. 17. Ironless flat linear motor

weight	**10000 kg**
moment of inertia	**32400 kgm^2**
max. torque	**3840 Nm**
speed	**0,315 rad/s**
accelleration	**0,063 rad/s^2**
position accuracy	**± 0,04 °**

Fig. 18. Tower drive with flat three- phase linear motor

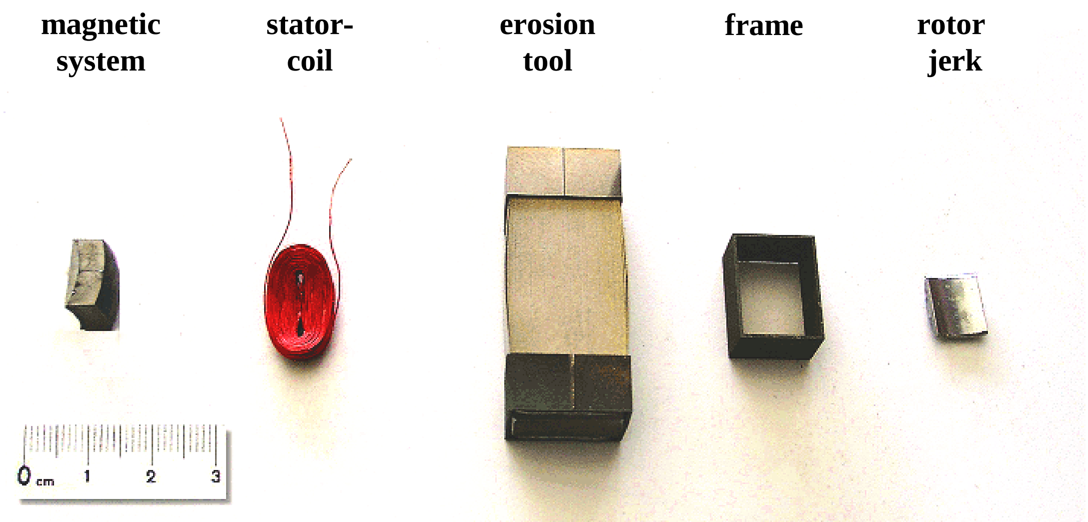


Fig. 19. Components of spherical motor

TABLE I
PROVED REVOLVING DIRECT DRIVES

Application	1	2	3	4
Rated torque (Nm)	1,800	8,300	10,800	1,850
Maximum torque (Nm)	3,000	12,500	16,000	3,700
Rated speed (rpm)	50	63	211	60
Maximum speed	-	-	-	-
Nominal power (kW)	9	55	239	12
Stator outside diameter (mm)	520	1,250	1,590	820
Rotor diameter (mm)	350	930	1,300	650
Length of the iron core (mm)	175	150	250	70
Moved weight	1,100	10,000	300	140
Moment of inertia (kgm^2)	400	8,000	463	20
Positioning accuracy (µm)	0.6 µm over D=1,300 mm	2 ´´		3 ´´

1. Table drive for a machining unit
2. Direct drive for a facing wheel on a machine tool
3. Press drive
4. AKB – rotary table drive