GEARLESS-TECHNOLOGY
STATUS AND INNOVATIVE OUTLOOK

Gerhard Thumm
Thyssen Aufzugswerke, Germany

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Abstract

The motor and drive technology in the lift industry have changed quite rapidly within the last three years. The great success of lifts without machine room has also brought a great number of gearless machines into the field. As a consequence, gearless machines are replacing more and more hydraulic and geared applications. This paper is to highlight today's state of the art gearless technology and it is to introduces a brand-new concept of a small gearless machine with integrated drive.

1. General

With the introduction of lifts without machine room, our industrie did not only open up a new chapter in lift technology itself; in particular the drive technology of rope-driven lifts went through a whole series of innovations. This is illustrated very clearly by the developments not only in the German market. The figures given below can now easily be transferred onto many other European countries as well.

Illustration number 1 compares how the German market is divided between hydraulic lifts, rope-driven lifts with gear, and gearless lifts in the years 1997 and 2000. The figures of 2000 show very clearly how dramatically the number of lifts without machine room has increased. This new system now has a market share of roughly 40%, and it is still increasing. Hydraulic lifts as well as rope driven elevators with traditional machine room have been increasingly replaced by lifts without machine room. An important point is, however, the large share of lifts without machine room using gearless machines.

Fig. 1 (1) German Market, ratio hydraulic, traction

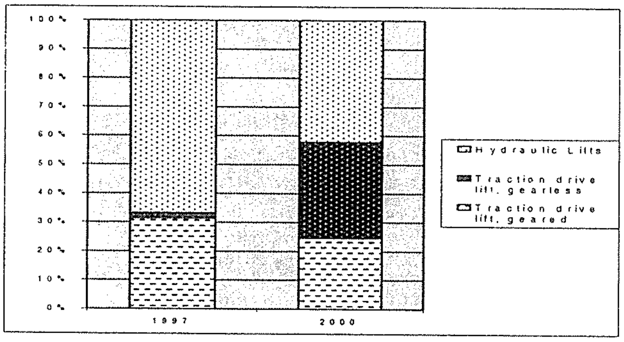
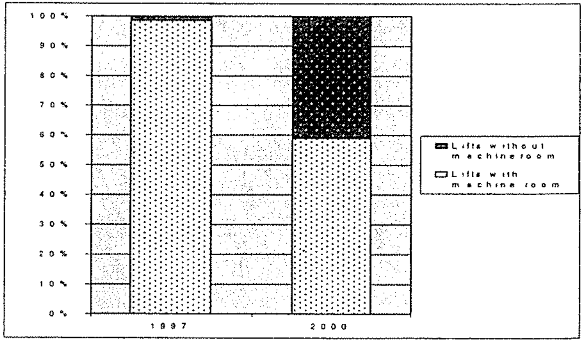
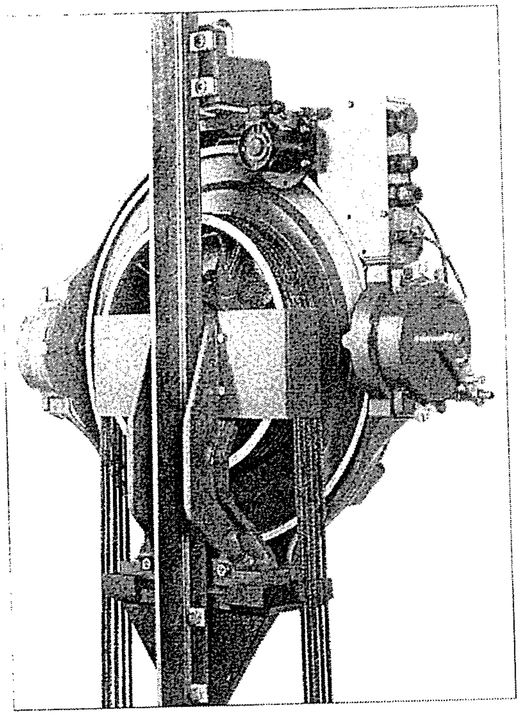


Fig. 1 (2) German Market, ratio machineroom



Kone were the ones to introduce lifts without machine room, and by developing an extremely flat gearless drive, they were able to realize their Monospace System. This triggered a process which the whole lift industry had to follow.

Fig. 2



[Kone]

All big lift producers, some of which had started in the machine roomless market with geared machines, are now offering gearless systems as well.

Thyssen Aufzüge was second in line right after Kone to introduce EVOLUTION, with a highly innovative gearless technology. 60 % of all new systems that are being installed today from Thyssen within Germany, are driven by the new micro gearless machine.

For this reason, this paper wants to highlight, the advantages of gearless technology, as well as showing the different working principles of electric drives.

The advantages of gearless technology as compared to hydraulic or geared lifts have been shown in many different publications. Therefore, in this context, a summarised comparison as given in the table below should be sufficiant. The following statements refer to a lift with a capacity of 630 kg and a speed of 1 m/s (0,63 m/s for hydraulic):

Tab. 1

Criteria	Hydraulic	Worm Gear	Gearless (Synchronous)
Motor Output (kW)	11	5,5	4,0
Electricity consumption (kWh/year)	7.000	5.000	3.000
Maintenance	-	Ø	+ +
Production costs of drive	+	Ø	-
		Suspension comparable 2:1	
Life Cycle Costs of Drive (Wear and Tear)	-	-	+ +
Ride comfort	-	Ø	+
Space needed	- -	-	+
Noise	-	-	+

- - big disadvantage Ø neutral + + big advantage

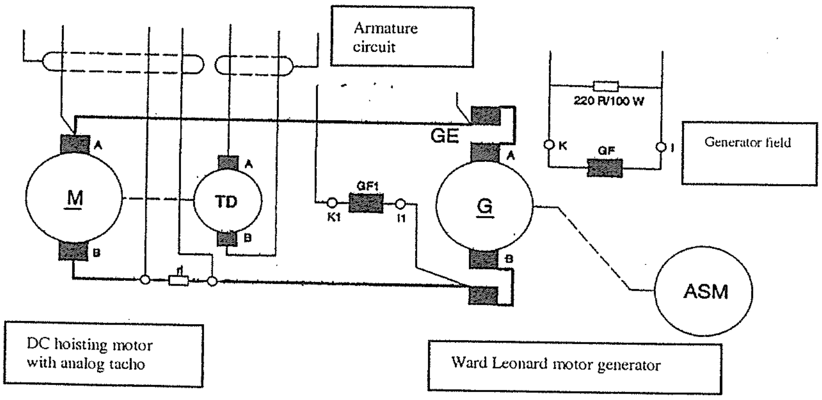
2. Electric Drive Systems are Changing

The history of gearless drives in the lift industry dates back to almost one whole century.

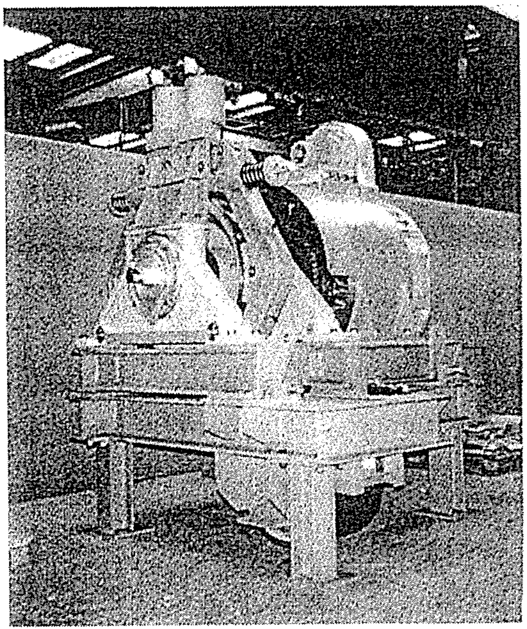
It was already in 1911 that the Woolworth building in New York City was equipped with 29 lift systems with a speed of 3,5 m/s. Until 1930, this was the highest building in the whole world.

These lifts were driven by so-called Ward Leonard direct current gearless machines, a drive system which was used in the lift industry for many decades. The principal behind this system is that a motor is run by the three-phase mains electricity supply, and that this motor in turn drives a direct current generator, which in turn supplies the drive motor of the lift with a direct current.

Fig. 3 DC Ward Leonard Drive



DC Gearless Machine built in 1975



[Thyssen]

Even today, thousands of Ward Leonard drives are still in use all over the world. Their main advantage is that their speed can easily be adjusted by reducing or increasing the voltage. The disadvantages of this technology however are:

- The system requires a total of 3 electric machines, raising costs and the amount of space required.
- Due to the fact that a generator and a motor are being used, the efficiency of the system amounts to only about 60%.
- The drive system is not maintenance-free. Both the commutator brushes and the commutator itself must be exchanged regularly.
- The generator set is noisy.

On the other hand, this drive system is quite outstanding when it comes to electro-magnetic compatibility. Electro-magnetic emission and effects on the mains supply (harmonics) are very low when compared to modern frequency-converter drives.

Yet, it is due to the disadvantages listed above that the Ward Leonard technology is not used any more in new installations.

The use of maintenance-free alternate-current (AC) motors as gearless drives in lift operation was long hampered by the necessity of being able to adjust the speed of rotation in the four-quadrant operation. It is the special nature of traction sheave, rope-driven lifts with counter-weights that they have to operate in accelerating or braking mode, depending on the load situation, and the speed of rotation has to be adjusted to each of these different situations.

For this purpose, Thyssen Aufzüge introduced the Thyssotron system **(Fig. 4)** at a very early stage. This is a fully thyristor-controlled system which enabled a state of the art four-quadrant operation.

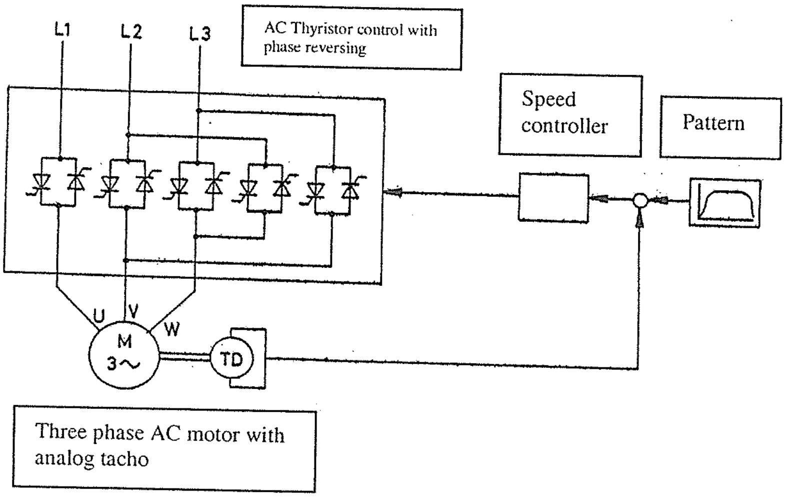


Fig. 4 Thyssotron

This system, as other comparable speed control systems, which work with an adjustment of the voltage of the power supply with 50 Hz (phase control), had the disadvantage that losses of energy caused by slip in the motor are converted into heat within the motor itself.

It was only the considerable fall in the prices of electronic parts and the integration of power electronics which enabled engineers to develop an efficient technology for the adjustment of speed of rotation in AC motors.

For better understanding, only two formulas are to show the connection between speed of rotation, torque, voltage supply, and frequency:

1. $$n = \frac{60 \bullet f}{p} \quad [\text{rpm}]$$

n = speed of rotation of motor [rpm]
f = frequency of stator field [Hz]
p = number of pairs of poles

2. $$M \sim \frac{U^2}{f^2}$$

M = torque at motor shaft
U = voltage supply to stator [v]
f = frequency supply to stator [Hz]

The above formulas show that by adjusting the frequency, you can also adjust the speed of rotation of an AC motor. However, if the torque generated by the motor shall remain constant, the terminal voltage of the motor must be adjusted simultaneously.

It was only the introduction of frequency converters with field orientation which made such adjustments possible and therefore helped to establish gearless drives in elevator technology.

3. Types and Styles of Gearless Machines

Basically, we can differentiate between two types of AC gearless machines:

- Asynchronous machines
- Synchronous machines

Both principles are known since over 100 years.

Fig. 5 shows the structure of an AC asynchronous motor. Its major constituents are the stator and rotor windings which are quite similar in structure. The windings are embedded in insulated grooves of the bundle of laminations of the stator and rotor.

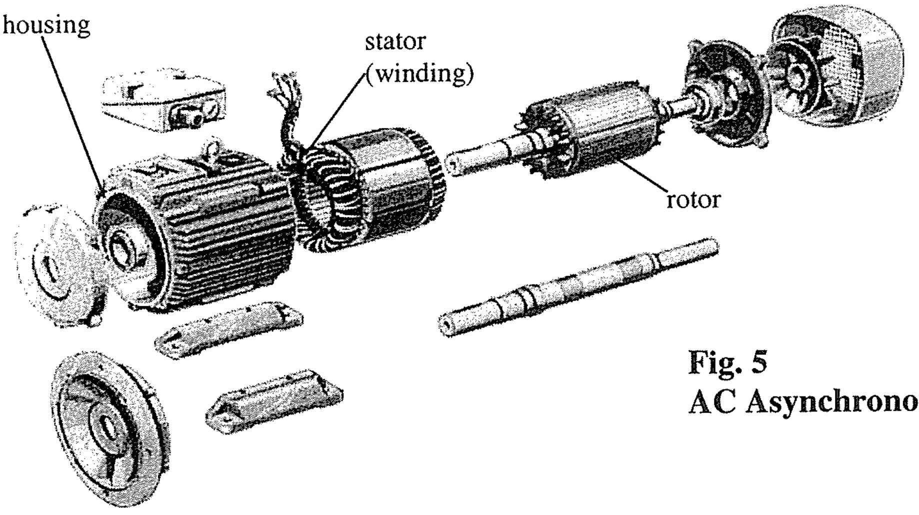


Fig. 5
AC Asynchronous motor

The sinus-shaped 3-phase alternate voltage connected to the motor terminals generates a rotating field in the stator. Due to the law of induction, a transformatory current is generated within the rotor winding via the air gap.

The resulting number of revolutions of the rotor is lower than the rotation speed of the rotating field in the stator by the amount of so-called slip. It is from this effect that the common name asynchronous motor is derived.

In the synchronous motor, the rotor winding is replaced by permanent magnets. The structure of the stator is comparable to that in the asynchronous motor. The rotor follows the adjacent rotor field very closely, so that a synchronous speed of rotation is achieved. Slip (s), which is a necessary characteristic of asynchronous motors, does not occur in synchronous motors.

This leads to reduced losses in the motor, allowing a design with high power density. Although the motors are usually self-ventilated, in case of high speeds of rotation and higher outputs, there would be such high eddy current losses that external ventilation becomes necessary, in order to dissipate the heat.

Table 2 compares the major criteria of asynchronous (ASM) and synchronous motors (SM).

Tab. 2

Criteria	ASM	SM	Notes
Power density	Ø	+	
Weight	Ø	+	
Control behaviour	+	Ø	More elaborate encoder with absolute-position control necessary
Efficiency	80 ... 88 %	88 ... 93 %	
Production costs	Ø	+	
Demagnetisation possible	+ +	-	
Moment of rest	+ +	Ø	
Idle power φ	-	+	

Now, if we look at the shapes of gearless machines, we will find two basic forms:

- Internal rotating motors
- External rotating motors

Fig. 6 shows the basic shape of an internal rotating gearless, while Fig. 7 depicts an external rotating gearless. Thyssen Aufzüge has been using the external asynchronous version increasingly, especially for installations with larger machines with an output of > 40 kW. The advantages and disadvantages of these two forms of motors are depicted in table 3:

Fig. 6 Internal rotating principle

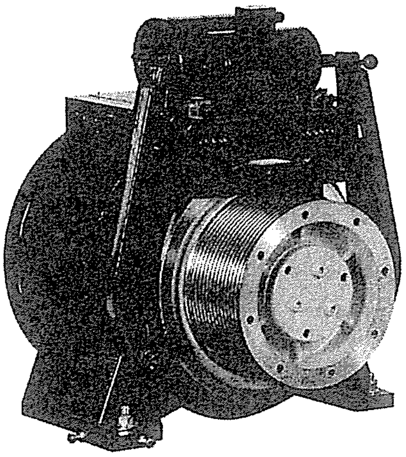
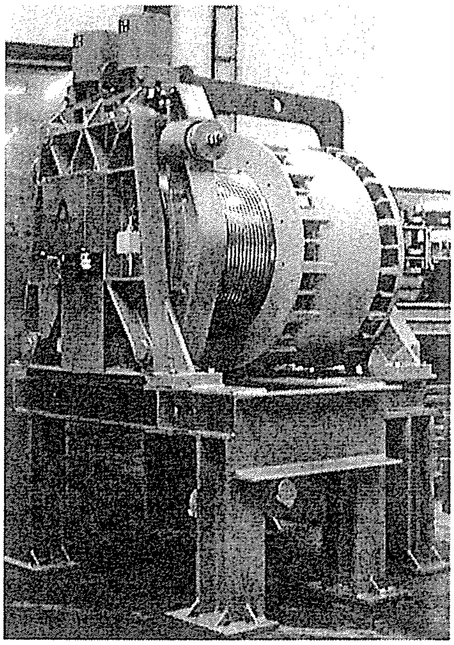


Fig. 7 External rotating principle



[Thyssen]

Tab. 3

Criteria	**Internal**	**External**	**Notes**
Closed construction (high protection degree)	+ +	-	
Stress of mechanical parts	Ø	++	(no revolving shaft under load)
Power density, compactness of shape	Ø	+	
Adjustment of encoder	+	Ø	
Adjustment of brakes and traction sheave	Ø	+ +	Brake and traction sheave in one piece
Heat dissipation	φ	+	No external ventilation necessary

4. Various Construction Forms of Synchronous Gearless Machines

Engineers of electric machines are required to design and construct increasingly compact machines with the highest possible output; this has led to the design of many different construction forms for synchronous machines.

In the following, three major examples of these many different construction forms shall be highlighted.

4.1 Transversal-Flux Motor

This construction type was first developed 20 years ago and is still undergoing extensive research.

The transversal-flux motor is a permanent-magnet synchronous machine with an extremely high number of poles. Constructions with as many as 96 poles are not unusual at all. The iron covers the stator winding almost completely.

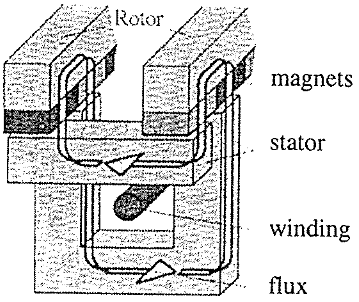
The stator coils run transversally along the motor. Due to the large number of poles and therefore large number of effective power elements, and due to the favourable direction of magnetic currents, this construction type achieves a very high output per volume compared to other types. However, the transversal-flux motor requires very elaborate manufacturing engineering. In addition, this type of machine usually emanates a lot of magnetising noise, a fact which does not render it very useful for elevator installations. Presently, this machine is used as single wheel drive for rail vehicles.

4.2 Reluctance Machine

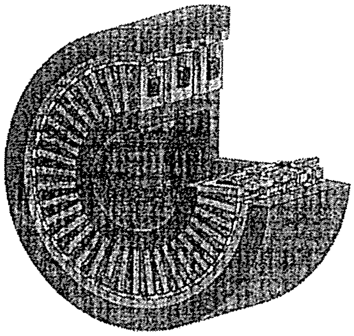
The reluctance machine is a special construction type of the synchronous machine. The basic structure consists of single poles with windings in the stator and a winding-free rotor without permanent magnets. The number of rotor poles is lower than that of the stator poles. The function is secured by a stepwise switching of the stator windings, depending on the location of the revolving field.

Although a simple rotor without windings or magnets is cheaper to produce, this type of machine does not run concentrically and, in addition, emanates also a lot of noise. For that reason, so far, this motor principle is not being used in elevator installations. However, further research is also being conducted on this subject.

Fig. 8 Transversal-Flux Motor

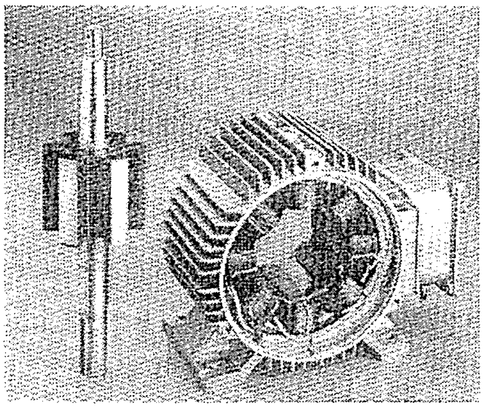


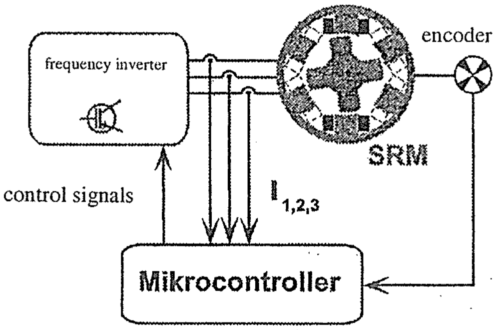
principle



3-phase-design

Fig. 9 Reluctance Machine





4.3 Disk Motor

In a disk motor, the electro-magnetic interaction between stator and rotor takes place via a disk-shaped air gap and not via a cylindrical one, as it is the case for internal or external rotating motors.

Imagine the rotor and stator being cut open and unwound (similar to a linear motor). These unwound elements form an in-plane circuit. Stator and rotor are situated left and right of the air gap.

The advantage of the disk motor, whether as asynchronous or synchronous drive, is its short length, while its disadvantages are the strong axial forces generated between stator and rotor and the broad diameter of the motor as a whole.

5. Looking Ahead

As it can be seen from the above, gearless asynchronous and synchronous machines, together with today's well-matured frequency converters, are an ideal drive system for our elevator industry.

Therefore the question may arise why not all geared installations have been replaced by gearless ones. This cannot be answered easily in one sentence.

On the one hand, the manufacturing of worm or spur gears attached to a standard motor has become a well-established and fully-automated technology, so that these kind of drives can be produced world wide in large numbers at fairly low cost, whereas gearless machines require a lot of costly handwork.

In order to achieve the required power density in synchronous machines, the permanent magnets must be made of so-called rare earth metals which are still very expensive.

On the other hand, all major elevator manufacturers have taken the strategic decision to change their systems towards gearless drives, more or less consequently. The rising demand for such drives increases automation in production and thus decreases manufacturing costs.

There is another new phenomenon which is having a positive impact on these developments, but which cannot be dealt with in more detail within this paper.

New suspension systems, such as Aramid ropes (Schindler Euro Lift) or suspension belts (Otis, Gen. 2), allow smaller traction sheaves and therefore require less torque from the drive. The result of this is that machines are getting smaller and that due to the higher speed of rotation of traction sheaves reduction gears are becoming less and less important.

Thyssen Aufzüge equipped both of its families of lifts without machine room, EVOLUTION and GALAXY, with gearless drives.

In this context our latest state-of the-art concept will be described in the following:

The linear drive's coils of the Transrapid, the fast magnetic train which is now finally being built in Shanghai, are embedded in glas fibre material (epoxy). This technology has been used successfully over years now during test runs of the Transrapid and has now been tranferred to the rotating gearless drive of Thyssen EVOLUTION. This means that the stator housing and the rotor housing do not consist of today's standard casting material but of high-quality epoxy material.

This revolutionary technology enables a much greater degree of automation in the production of drives. In addition, this new material gives no limitations as to the surface geometry of the stator housing.

Surface corrosion protection is unnecessary.

The copper winding and bundle of laminations in synchronous motors are embedded in epoxy and are therefore fully protected.

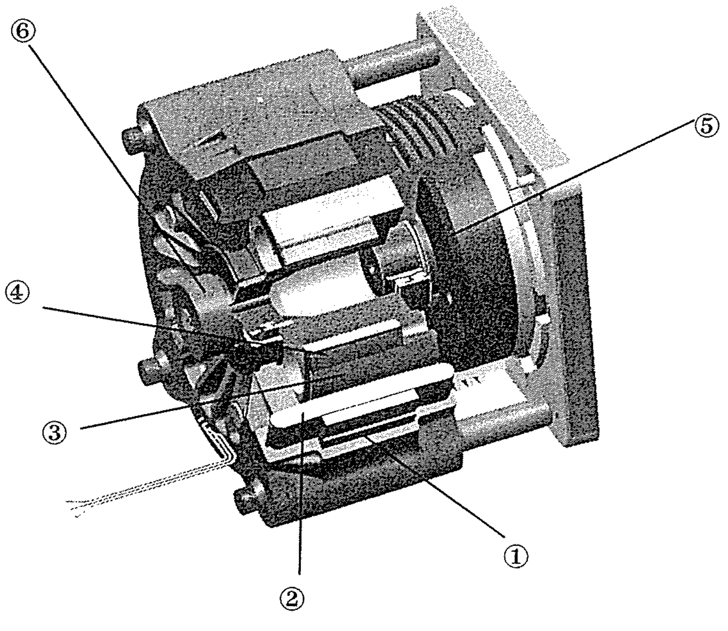
The rotor's bundle of laminations are also completely embedded in epoxy.

The magnets do not have to be glued as before, and they are also being protected against corrosion.

Another highlight of this drive is that the frequency converter as well as the electronic equipment required for the brakes control are integrated in the drive, so that the whole drive is one compact package which requires nothing but input voltage and a CAN bus for communication with a superior control. Motor power-supply cables which today must be shielded to avoid electro-magnetic emission can be dropped completely. The integral drive has its own diagnostic functions, so that any irregularities that might arise during normal operation are immediately communicated to the controller part.

Fig. 11 shows the basic structure of a the machine with a capacity of 630 kg and 1 m/s.

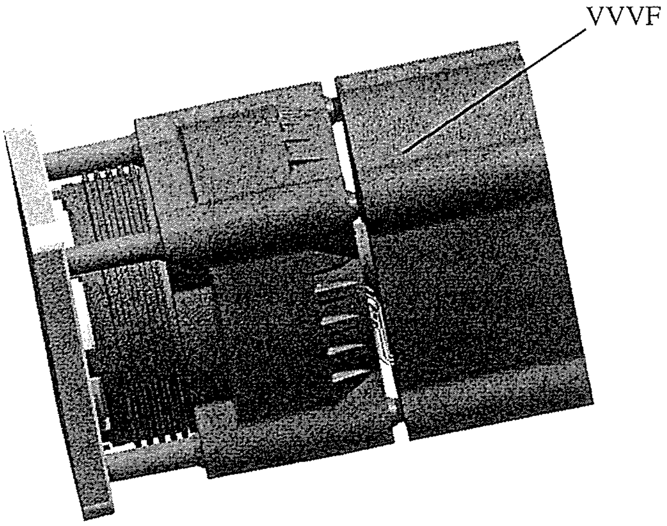
Fig. 11



The hatched area ① is the stator housing made of epoxy with embedded copper windings ②.
Further components are:
③ Rotor
④ embedded permanent magnets
⑤ Dual-circuit safety brake with electric monitoring
⑥ Position control (encoder)

Fig. 12 shows the drive with integrated frequency converter

Fig. 12



6. Summary

This paper highlights different generations in lift drive technologie. Although gearless technology is known since the beginning of the last century, there is still a lot of potential in research and development for this technology.

As research progresses, the drive itself and the corresponding electronics are melting one into each other, forming one functional unit; interfaces are becoming dispensable. Thus the reliability of the technology will be increased.

In the lift market, hydraulic and geared rope lifts will be replaced more and more by gearless technology.

Modern supension devices will enhance this trend even more.

Further innovations in this area of lift drive technology will be exciting.