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Susanne Jakob
Dipl.-Ing. Helge Drumm

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Peter-Klaus Budig

Direct Linear Drives For The Application in High Vacuum

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

Abstract: **High-vacuum application demands for clean- room conditions. Therefore there is no chance to use roller bearings, air- cushion bearings or even slide bearings. On the other side making motion must be made without mechanical contact f.i. as in a rail- wheel system or similar. Therefore a design was chosen with a permanent magnetic bearing and a linear- drive system.**

I. Introduction

High vacuum means that there is a pressure less 10^{-5} mbar. These applications are typical in fields like microelectronics and vapour deposition. Realized systems are based on magnetic bearings and linear motors. The first one are well known for the application in magnetic suspended spindles for machine tools, pumps or neutron-beam systems. Here are mostly used active magnetic solutions. Since there is no mechanical contact there is no wearing no contamination if the clean- room environment.

II. Magnetic suspension for linear motions

The application of linear drive- systems in a clean-room environment demands for a contact- free and oil-free suspension of the moving part- the carrier. This can be realized with a magnetic field. There are the two possibilities:

active magnetic bearing and
passive magnetic bearing.

In the first case there is a magnetic field (Fig.1.) between two ferromagnetic surfaces. According to the presence of the magnetic field now there is a attractive force between the two parts.

In the second case there are two magnetic poles of the same polarity positioned opposite of each another. Now there is a magnetic field in the air gap between the two poles as it shows Fig. 2. This shows that there are now magnetic field lines between the two pole- faces. The field is a stray field. According to this there is a repulsive force between the two pole- faces. As soon as there is a deviation of position f. i. in the x- direction there are besides the above mentioned stray field a magnetic field occurs connecting the two pole- faces. The number of these field lines depends on the x- deviation. Now there are two forces:

a vertical repulsive force and
a horizontal driving force – a cross force.

As shown in Fig. 3 the first one decreases with increasing x- shift and the other one increases.

That means: the magnetic suspension with repulsive forces is a *instable system.*

As Fig. 3. shows the cross force is zero at the exact symmetric position. That means it is necessary only a rather small power to hold the magnetic system in a symmetric position.

The repulsive system demands for very a simple mechanical design. Lat but not least the two opposite positioned magnets can be permanent magnets. Thus there is not necessary an electrical excitation with coils and power- supply. Only two rows of permanent magnets are to be positioned in opposition. The magnetic poles in opposition must have the same polarity north- north ore south- south as well.

Now the repelling force can be used to carry the moving part of the drive- system.

III. GEOMETRY AND REPELLING FORCE

As Fig 4. shows there are different possibilities to arrange the permanent magnets. The levitation force depends on the following quantities

thickness (t) of the magnets
width (w) of the magnets and
distance between to magnets.
and magnetic data of the
permanent- magnetic material.

The practical design of a permanent- magnetic suspension is given in Fig. 5.

There are to rows of permanent- magnets in parallel to each another at the upper side of the stator part and once again to rows in parallel at the bottom of the moving part. The magnetic polarity of the two rows is unimportant.

IV. THE STABILISATION OF THE INSTABLE SYSTEM

In principle there are two possibilities to stabilize.

- stabilization with a mechanical guide
- stabilization with a active magnetic guide

In the first case roller bearing can be used. There are types on the market which are clean- room proved. Their load is in the range of some Newton. Therefore they are suited for the application especially if the mechanical load of the moved part only is in the range less 100 kg.

In the second case there is used a electromagnetic system that's force is perpendicular to the moving direction (Fig. 6). It is called "electromagnetic stabilizer".

It consists of a U- shaped electromagnet, a position sensor and a control electronic. Thus it is a position controlled electromagnetic system. Since the instability can react in either direction it is necessary to use two stabilizer positioned at the left and right side of the levitation-rail (Fig. 7). With the described stabilizers now the moving part can be guided without any mechanical contact.

V. THE PRESTRESSED LEVITATION SYSTEM

There are applications with interrupted permanent-magnetic rail. Passing the interruption decreases the levitation height.

To limit these motions a prestressed magnetic system is used. In this case there are according to Fig. 8 two permanent- magnetic rails. One at the top and one at the bottom (see. Fig. 9). Now the moving part is fixed in vertical direction an the vertical motion when passing the interruption becomes less.

VI. THE CONTACTLESS DRIVING SYSTEM

It is the task to move the carrier without any mechanical contact. This can be achieved with a linear motor. There are different types of linear motors like "tubular motors" or flat types. The second one are of interest for the above described solution. It consists of a flat stator which has the three- phase winding and a secondary made of cupper or aluminium (Fig. 10). The so- called single-sided linear motor produces a magnetic travelling field. This excites a voltage in the secondary which drives an eddy- current. Now there is an interconnection between magnetic field B and eddy- current I both perpendicular to the others. They produce a thrust once again perpendicular to B and I as well. The thrust is transmitted to the carrier without any mechanical contact.

The mean problem now is to involve the stator and secondary into the carrier design. This is shown in Fig. 10. There is the flat stator on the right- hand side and the secondary in the middle. If the stator is supplied with a three- phase current the thrust appears and moves the secondary. If the total length of the trace is longer than the secondary – as it may happen if the trace is subdivided in sectors – more than one linear stator is needed. This is shown in Fig. 11.

VII. Speed control

The power- supply makes an inverter.
Thus it is possible to drive the motor with vector- control and variable speed. There is no mechanical contact and according to this no wearing and no contamination of the clean- room atmosphere.

VIII. The carrier- train

If there are several containers in the system it is necessary to let run them in a demanded distance between the leading and the following carrier. To achieve this it is necessary to signal the position of the leading carrier to the following. Now the following carrier must start. This control- signal starts the inverter for the following carrier in that mode, that at the beginning of the motion there is a high speed to approach as soon as possible to the leading carrier. If close enough the speed is decreased in finally the following carrier runs with the same speed as the leading one. Even more it runs with a fixed distance to the first one.

IX. Realized examples

A. Transportation system with two magnetic bars

Fig. 12 shows the system. it includes besides the linear- trace a revolving table. Thus the carrier can run in two different directions.

The linear- motion make linear stators which are pulsing according to the impulse- law

$$m \times v = F \times t$$

with m = to be moved
v = speed
F = thrust
t = operating time of thrust

The carrier is pushed though the trace. Reversing the direction is made by changing two phase-connections of the motor. Since there are used pulses to control the speed no inverter is necessary. The linear- motors are to connected direct to the power grid.

The speed is about 0,2 to 1 m/s.

B. Transportation system with a mechanical guide and a linear- motor

The linear- motor has a flat ironless design.
It is a long- stator. The stator coils are positioned on the surface of iron joke. The secondary is a permanent- magnetic component (Fig. 13) which is positioned on the underside of the carrier. This is a synchronous linear drive. The carrier is made for a load of about 0.5 kg.

Since there is a demand to vary the speeds between 1 mm/ s and 1 000 mm/s it was necessary to apply a sufficient noise- poor measuring system. A magneto-strictive sensor war used. It was possible to move the carrier within the demanded speed range. The motion is free of ripples.

C. Transportation system with one permanent magnetic guide

This solution was discussed already in detail. Its maximum speed is about 2 m/s whilst the minimum speed is 6mm/s. This one can vary in a range of 6 mm/s till 60mm/s. The train mode is realizable in this speed- range.

X. SUMMARY

Using a permanent- magnetic levitation in combination with a linear motor it is possible to run carriers without any wear in a high vacuum. Examples of realized equipment are discussed.

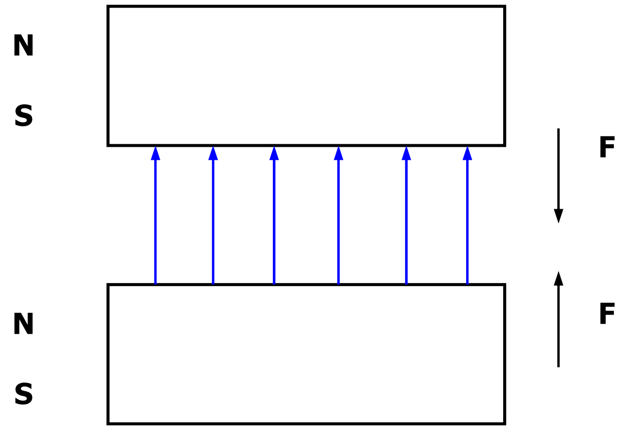


Fig. 1. Attractive force between North- and South- Pole

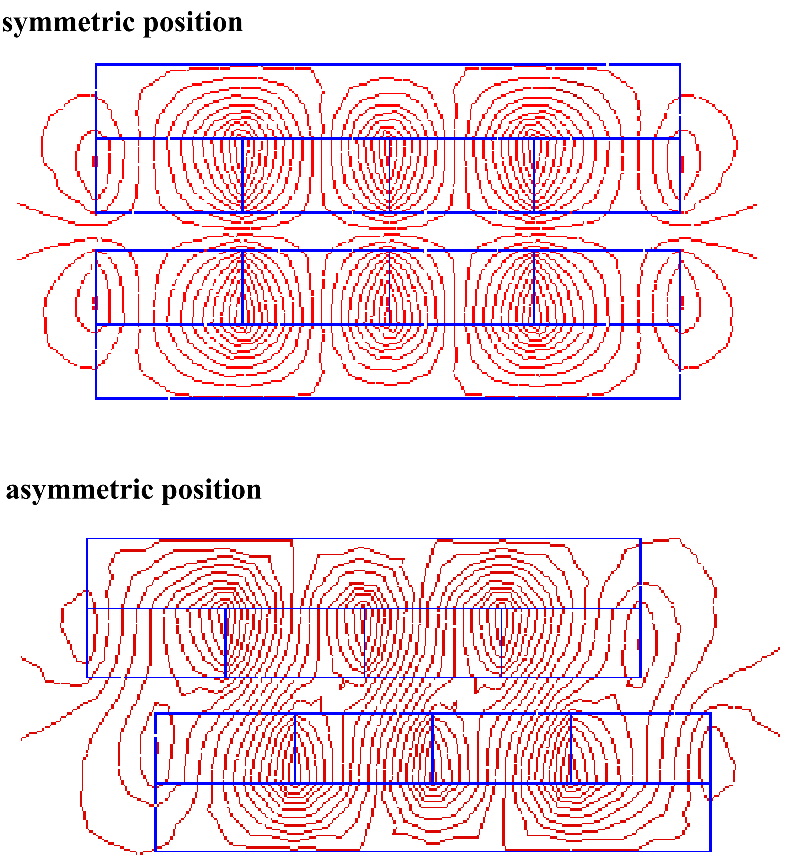
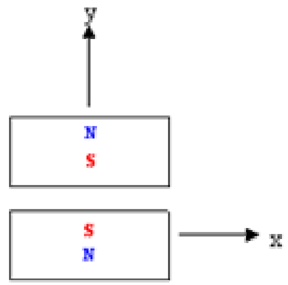


Fig. 2. Repelling force between North- and South- Pole

Magnets:

NdFeB
Br = 1,2T ; Hc = 900 kA/m
12 mm x 5 mm x 60 mm
air- gap δ = 5 mm



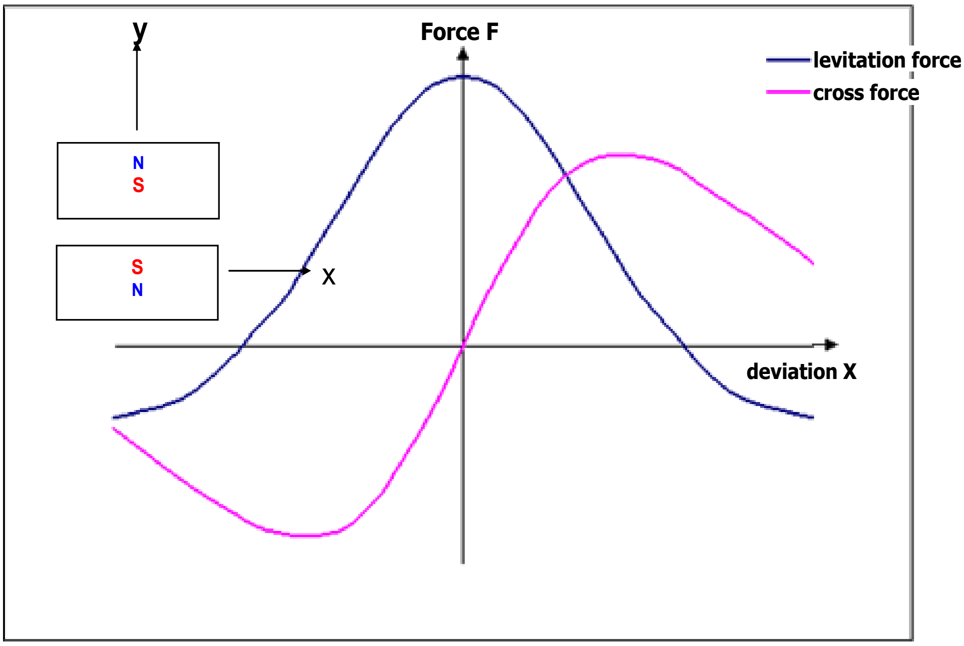


Fig. 3. Forces in an instable system

Impulse – law:

$$F \cdot t = m \cdot V \;; \quad V = \frac{F}{m} \cdot t$$

F = thrust; t = duration of thrust- pulse;
m = weight; v = speed

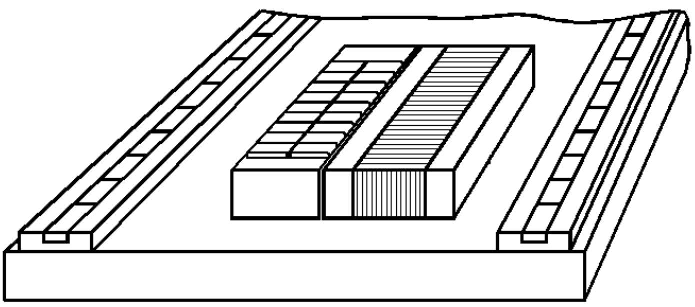


Fig. 4. Arrangement of permanent magnets

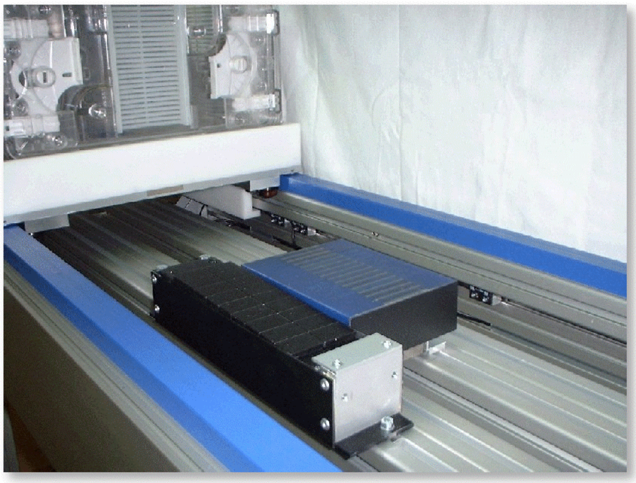


Fig. 5. Magnetic double- bar system

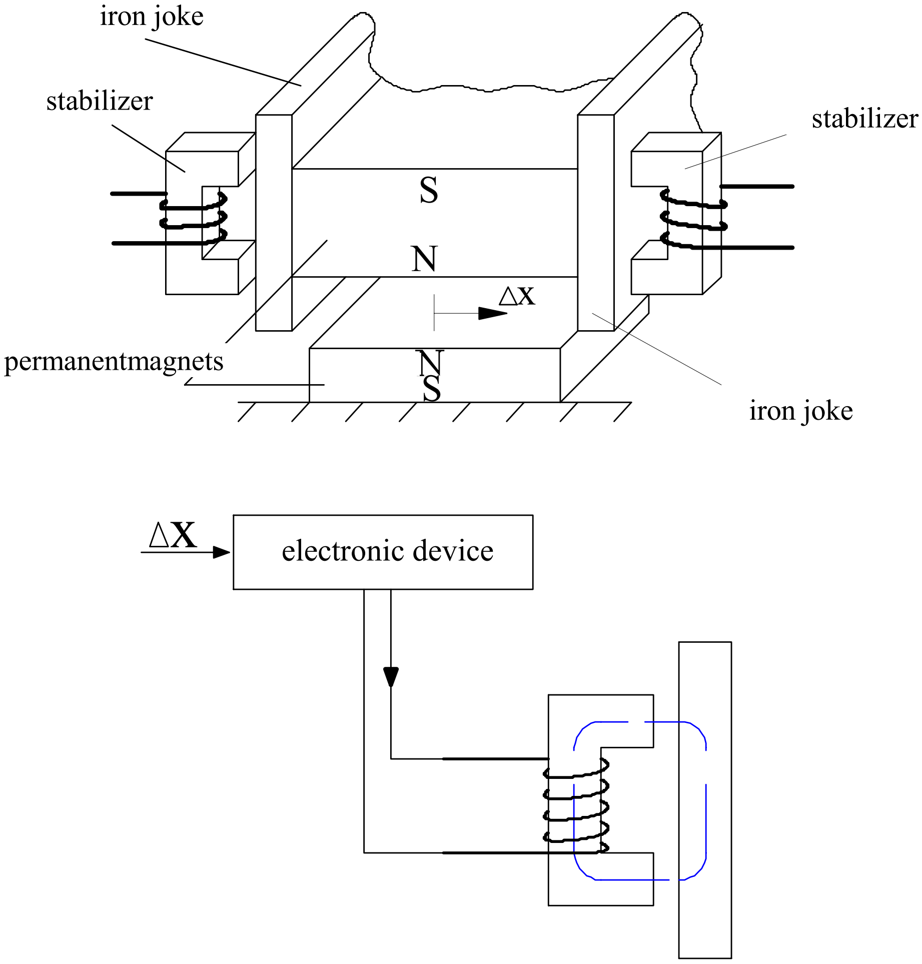


Fig. 6. Electromagnetic stabilizer

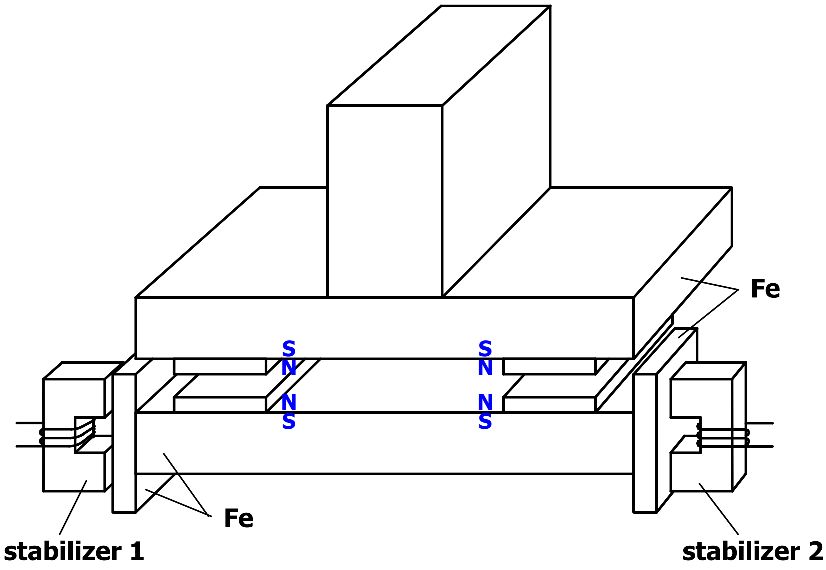


Fig. 7. Two stabilizers

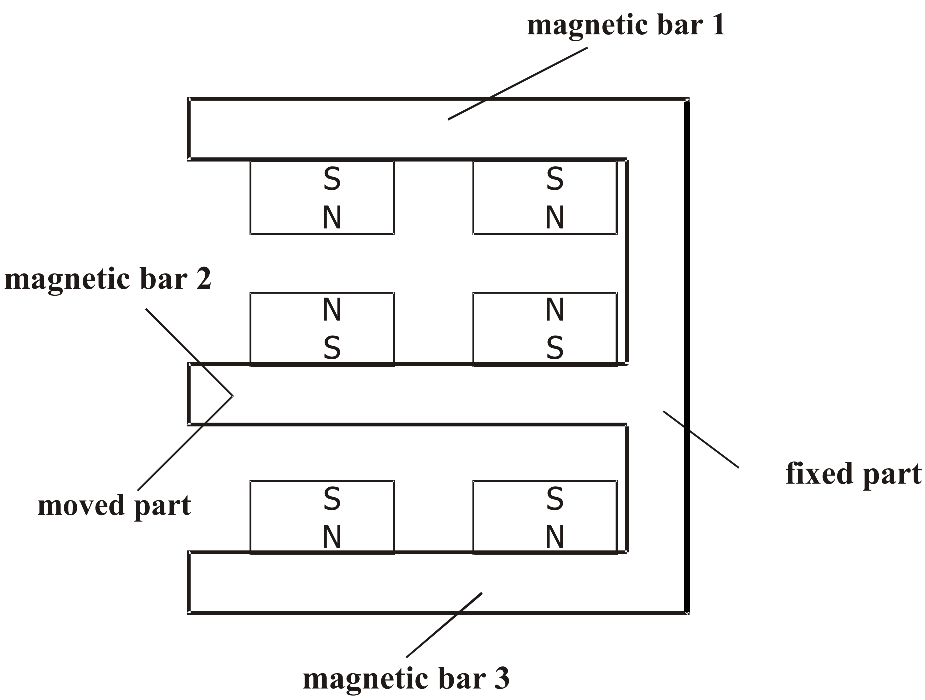


Fig. 8. Prestressed magnetic levitation system, principle

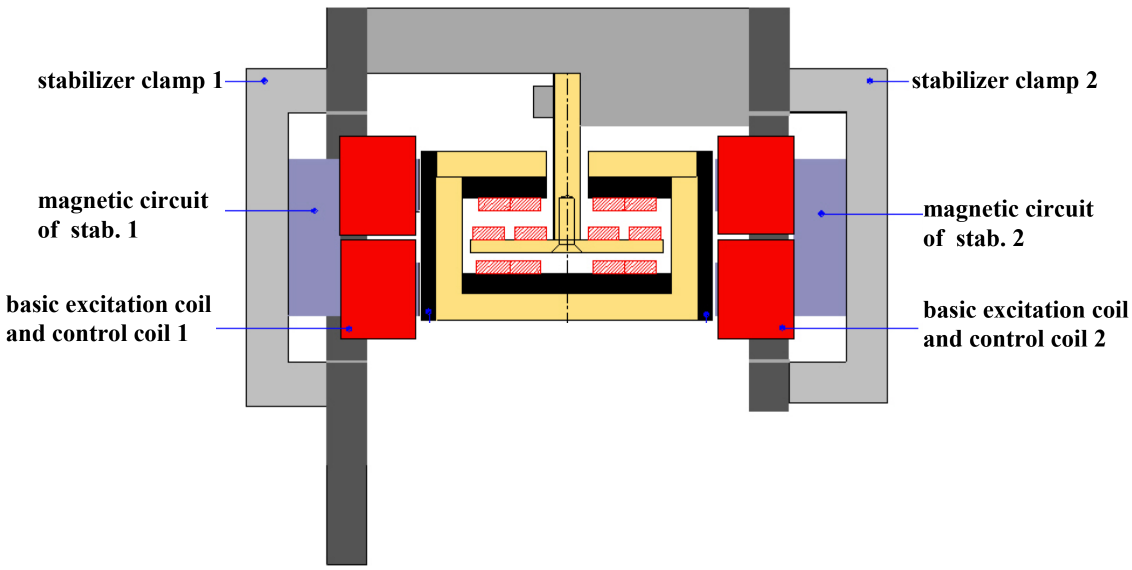


Fig. 9. Prestressed magnetic levitation system, design

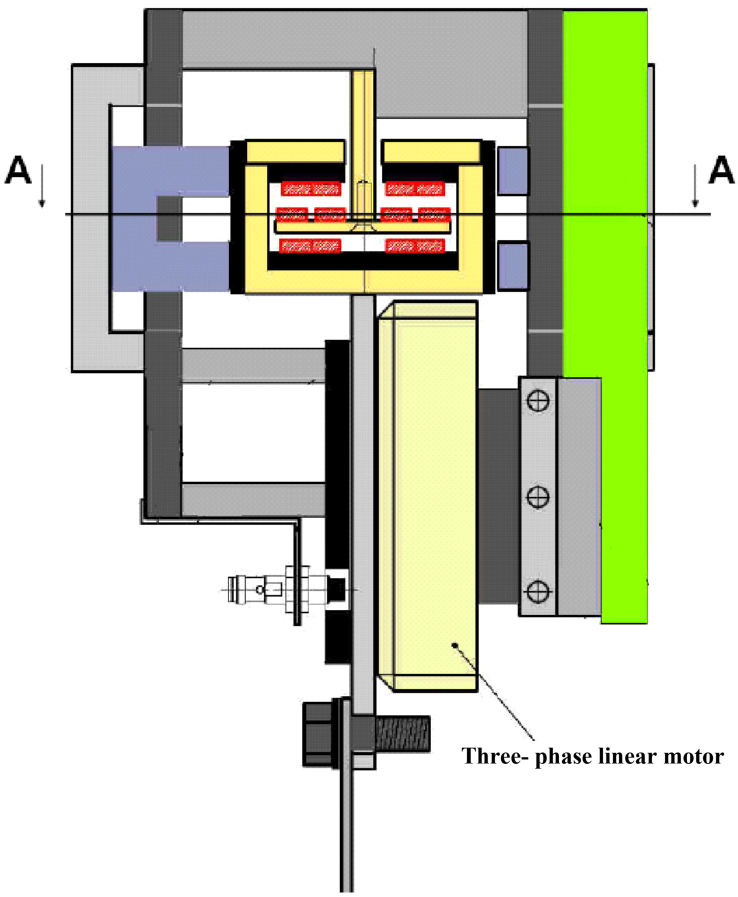


Fig. 10. Magnetic levitation system with linear motor

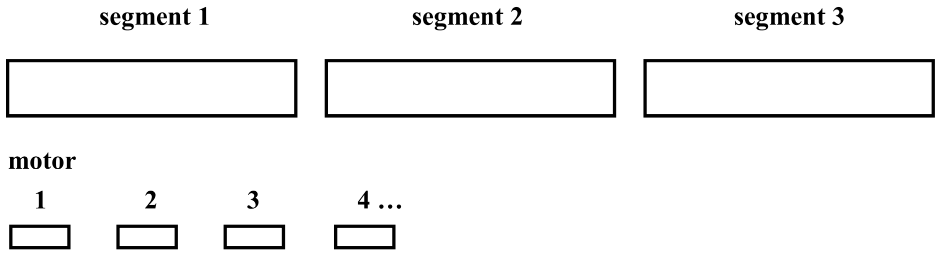


Fig. 11. Multi- motor drive

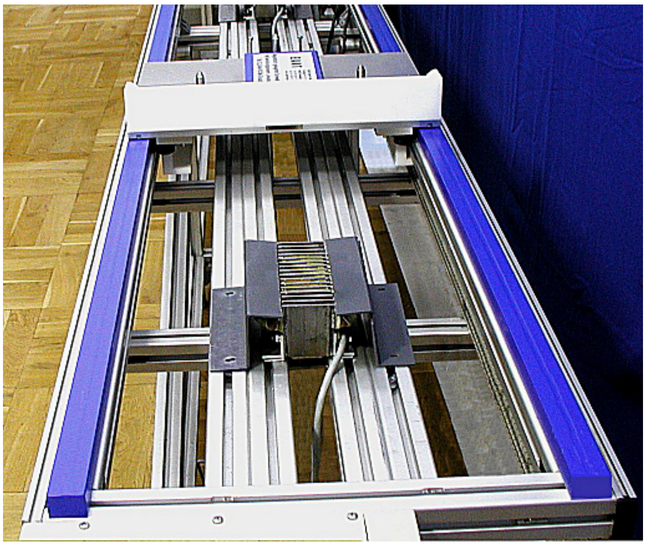


Fig. 12. Transportation with two magnetic bars

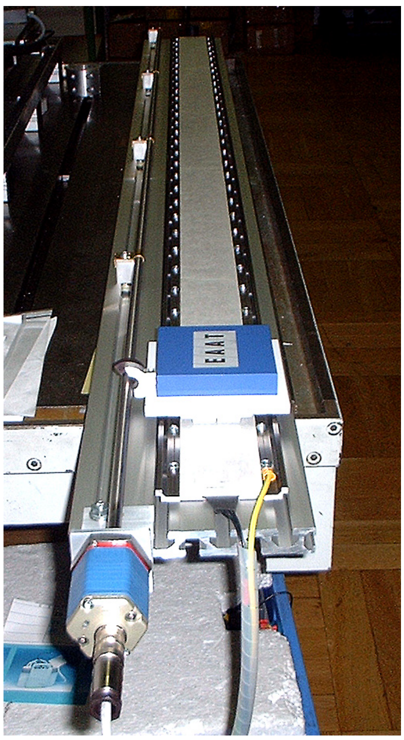


Fig. 13. Ironless linear drive