Operation of a vertically levitated ropeless elevator: Interaction of linear drive and magnetic guiding

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***Abstract*—The operation of a ropeless elevator driven by a linear drive and vertically levitated by an electromagnetic linear guiding is described in this paper. A contactless, wear-free movement of the cabin within the shaft is possible. The topology of the elevator system including propulsion and guiding actuators is presented. From measurement at an elevator test bench in scale of 1 to 3, the interdependencies between drive and guiding are discussed.**

***Index Terms*—ropeless elevator, magnetic levitation, linear drive.**

I. Introduction

More and more high-rise buildings, skyscrapers are built nowadays, due to rising land prices in urban areas, especially in Asia and the Middle East. Herewith challenges for the building's vertical transportation infrastructure, i.e. the elevator systems arise. The velocity of the elevators limits the service quality, as well, since the waiting time for passengers will be too long. Moreover, in very high buildings, there are no non-stop elevator shafts. The maximum travelling distance is limited by the tensile strength of the cables [1]. This fact means further delay for the vertical transportation of the building, since passengers are forced to switch elevator cabins at sky lobbies distributed over the building [2].

Considering a ropeless elevator system with a linear drive and an electromagnetic linear guiding, actual limitations can be overcome [3]. Steel cables and mechanical guiding shoes can be omitted. Herewith the proposed novel concepts can be realized.

II. Ropeless Elevator System

At the Institute of Electrical Machines (IEM) of RWTH Aachen University, a ropeless elevator test bench is built up. Figure 1 gives an overview over the system. The cabin is propelled by two long-stator permanent magnet linear synchronous motors on the diagonal corners of the shaft [4]. To eliminate normal forces, an air gap winding with no back iron is applied, a so-called ironless linear motor. An increase of the air gap flux density and therewith of the thrust of the motor is achieved by a double layer permanent magnet arrangement, enclosing the stator winding coils. For thrust ripple reduction, the permanent magnets are skewed. Due to the limited length of the shaft of approximately 5 meters, a segmentation of the stator windings is not realized. In a real application, the segmentation would be obligatory. The linear motors are connected in series and supplied by a single frequency inverter. A field-oriented control is used.

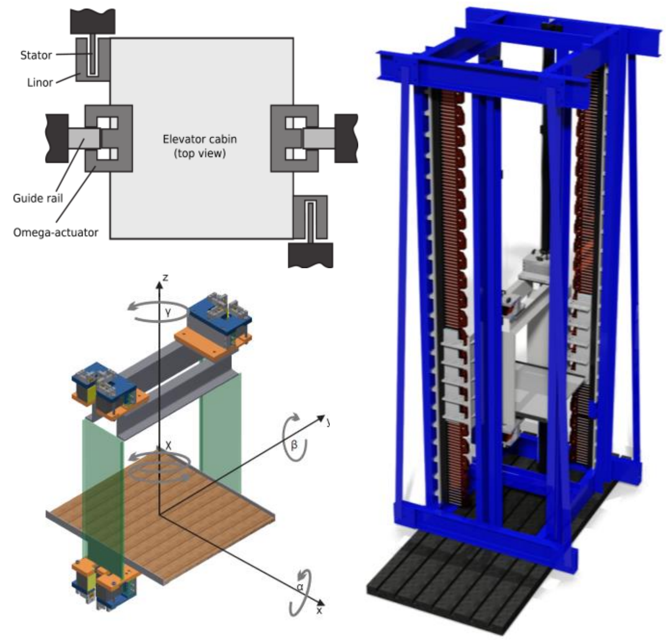

Fig. 1: Overview of the ropeless elevator system.

To eliminate friction and wear, an electromagnetic linear guiding is constructed and implemented on the elevator car. Four omega-shaped hybrid actuators [4] are placed adverse on top the roof and under the floor of the cabin. Permanent magnets on the pole faces of the actuator excite a bias flux within the yoke. With two coils on the lateral arms, superimposed flux components are created to manipulate the attractive forces between the actuators and the guide rails. Each omega-shaped actuator can produce attracting forces in three directions. The air gap forces are calculate as

$$F_{x,y} = \frac{\phi^2_{\delta_{x,y}}}{2\mu_0 \cdot A_{x,y}}. \quad (1)$$

Where $\delta_{x,y}$ is the flux penetrating the air gap in x or y direction, respectively. μ_0 is the magnetic permeability constant and $A_{x,y}$ are the pole areas of the omega actuator.

A degree of freedom (DOF) control [6] is applied to stabilize the cabin in its equilibrium position at the center of the shaft. The local air gaps are constantly measured by eddy current sensors and transformed to global DOF, which are controlled to maintain zero. After a reverse transformation, the currents of the coils around the guiding actuator are determined to apply the guiding forces. Table 1 summarizes the parameter of the test bench.

TABLE I
PARAMETER OF THE ROPELESS ELEVATOR TEST BENCH

Driving force	6 kN
Guiding force	2 kN
Rated speed	0.5 m/s
Maximum speed	1 m/s
Driving distance	2.7 m
Total height	5 m
Cabin weight	682 kg

III. Operation of the Elevator

The simultaneous operation of linear drive and magnetic guiding system is discussed in this chapter. With active linear guiding the elevator cabin levitates with a nominal air gap between the actuators and the guide rails of 3 mm. Starting the linear drive, the cabin is accelerated against the gravitation force and moves according the position control scheme of the linear drive.

The air gap displacement during the movement of the cabin is depicted in figure 2. It can be observed, that the air gaps are disturbed. However, the maximum air gap deviation remains within 2 mm, which is the tolerance of the levitation system. The cabin never contacts the mechanic safety guiding during the ride.

The two air gaps in y-direction are disturbed less than the four air gaps in x-direction. It can be explained with the diagonal placement of the two linear motors (compare fig. 1). The normal forces of the linear motors lead to the stronger interference of the air gaps in x-direction.

Analyzing the degrees of freedom of the cabin, a major deviation occurs in the DOF χ, which is the torsion around the vertical axis of the cabin. The other five DOF are only slightly disturbed. The torsion DOF χ principally acts against the other DOF, since it deforms the structure of the cabin around its vertical axis. Due to this fact, χ is controlled weaker when compared to the other DOF [7].

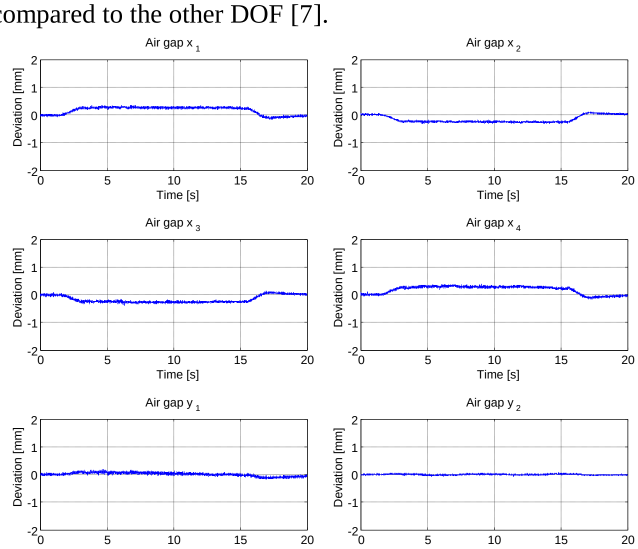

Fig. 2: Air gap displacement during movement of the cabin.

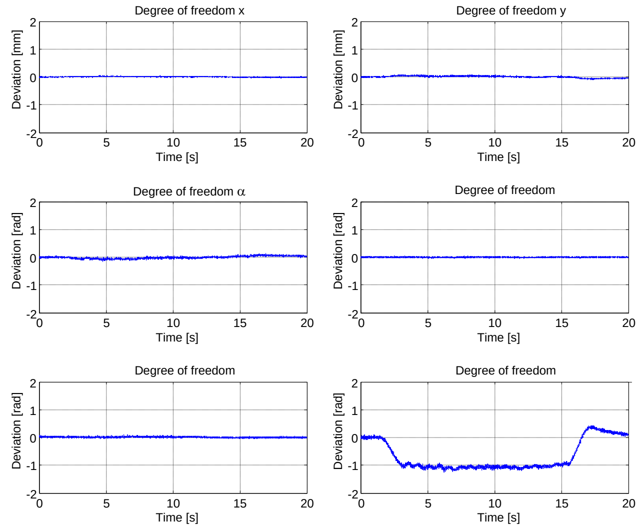

Fig. 3: Degree of freedom displacement during movement of the cabin.

IV. Conclusions

In this paper, the operation of a ropeless elevator at a test bench at the Institute of Electrical Machines is presented. A linear drive propels the elevator cabin without steel cables. An electromagnetic guiding system levitates the cabin vertically in the center of the shaft. The mechanical guiding system is substituted this way. The interdependencies of drive and guiding are discussed. The torsion around the vertical axis of the cabin is identified as the critical degree of freedom, since its stiffness is low. From measurement at the test bench, the contactless and wear-free operation of the elevator system is demonstrated. Detailed analysis of the operation as well as extensive measurement results will be presented in the full paper.

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