Redundancy Aspects of an Electromagnetic Guiding System for a Vertical Transportation Vehicle

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ABSTRACT: This paper deals with an electromagnetic linear guiding for a vertical transportation vehicle such as an elevator. An omega shape actuator [3] (Fig. 1) with permanent magnets and coils on its lateral arms is used to create attracting forces in three directions. Four of these actuators mounted on top and floor of the cabin enable a degree of freedom (DOF) control of the vehicle in the shaft. The system is over determined since eight coils control five degrees of freedom. Due to safety aspects the linear guiding should remain stable even in case of the breakdown of its components. Therefore a strategy is developed to control the guiding system with a one coil failure situation, exploiting its over determination.

1 INTRODUCTION

Nowadays, an increasing number of high-rise buildings are constructed in Asia, the Middle East and other parts of the world. An efficient traffic infrastructure for these buildings is an essential requirement. The focus on improvements of the buildings' transportation systems rests on the elevator systems since the design of such a system for very high buildings is always a challenging task. Additionally, new elevator systems have to be efficient, comfortable and have to possess low-maintenance.

A new concept to reduce the drawbacks of conventional elevators is the employment of electromagnetic guides to elevators. Hereby a wear resistant ride is possible since no physical contact exists between the guides and the guiding rail. These systems promise faster passenger transportation due to the frictionless operation and at least the same riding comfort as state of the art elevator systems. In addition, these guide ways have no consumption of lubricants, which is a further advantage compared to mechanical guide ways.

Figure 2 presents a prototype test bench of an electromagnetically guided elevator constructed at the IEM. In former works [1,5], the assembling and operation of the test bench is presented, which shows a well running system. The introduced system demonstrates an electromagnetic guiding system controlling five of the six spatial degrees of freedom (DOF) [2]. Equation 1 defines the spatial vector q containing the DOF:

Figure 1. Omega actuator without permanent magnets.

$$q = \begin{bmatrix} x & y & \alpha & \beta & \gamma \end{bmatrix}^T \tag{1}$$

Figure 2. Electromagnetically guided elevator test bench.

The elevator car is assumed to be a rigid body. It is fixed in one DOF by its propulsion device, which is a rope in this case. This is the DOF in vertical z-direction. The other five DOF are the translatory movements in x- and y-directions and the rotary movements α, β, and γ around the axes of a Cartesian coordinate system located at the center of gravity of the elevator car. A DOF control system is created to stabilize the elevator car. Figure 3 defines the DOF, resulting forces and dimensions of the elevator car.

Regarding the safety of the system a redundancy of the linear guiding should be built up. Hereby the guiding remains stable even in case of the breakdown of one of its components such as the DC-DC controllers operating the coils or an insulation fault in one coil.

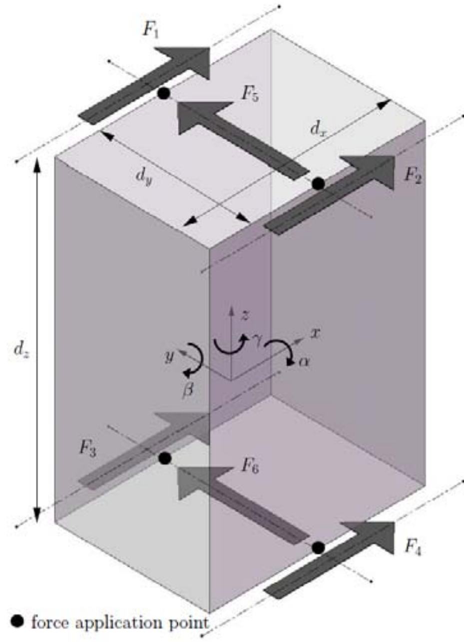

Figure 3. Definitions of the DOF and forces resulting from the omega actuators.

The solution presented in this work enhances the existing state space control by additional supervising algorithms, which detect failures in the guiding system. Hereby an online modification of the control algorithms to stabilize the system in fault condition is possible.

2 NORMAL OPERATION

2.1 Modeling

A degree of freedom control is established to control the elevator car. This method promises a more robust control strategy compared with a single air gap control. Local quantities i.e. the air gaps are measured and transformed to global DOF. A state space control keeps the elevator car balanced in its neutral position in the middle of the shaft [1].

In this paper the focus is set to the control strategy of the actuator coils. The Matrix θ describes the transformation of the local currents, i.e. the coil currents to global currents, which are modeling quantities. Equation 2 depicts the transformation from local to global currents including the matrix θ. The correction factor 1/8 restores the magnitude of the global values compared to the original ones.

$$I_{global} = \frac{1}{8}\underbrace{\begin{pmatrix} 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\ 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 \\ -1 & -1 & 1 & 1 & 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 \\ -1 & 1 & -1 & 1 & -1 & 1 & -1 & 1 \\ -1 & 1 & -1 & 1 & 1 & -1 & 1 & -1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 \end{pmatrix}}_{\Theta} I_{local} \quad (2)$$

Where I_{global} is defined as

$$I_{global} = \begin{pmatrix} I_x & I_y & I_\alpha & I_\beta & I_\gamma & I_{h1} & I_{h2} & I_{h3} \end{pmatrix}^T,$$

I_{local} is defined as

$$I_{local} = \begin{pmatrix} I_1 & I_2 & I_3 & I_4 & I_5 & I_6 & I_7 & I_8 \end{pmatrix}^T.$$

Each DOF is assigned with a global current. The three last global currents are additional quantities to restore symmetry in to the transformation matrix. The local currents are the eight coil currents.

Depending on the DOF to control, the coils on the actuators are powered to excite attracting forces on the guide rail.

3 REDUCED ACTUATOR OPERATION

3.1 Control strategy

The main strategy to keep the system stable in reduced operation is the principle of equal energy. Therefore, the matrix θ which defines the transformation of local coil currents to global control currents is changed. Obviously the defect coil can no longer be fed by a current, so zeros are set to the matrix at these points. To compensate the force drop another coil is powered with double current, resulting in an equal energy state compared to the full running system. Equation 3 depicts the resulting transformation matrix θ_{red} for a fault condition in the first coil. The matrices for the other fault conditions are similar. As mentioned before the linear guiding system is over determined, so changing the matrix describing the transformation of the currents does not result in an uncontrollable system. Now five DOF are controlled by seven coils.

Other strategies of changing the transformation matrix have been analyzed such as reduced energy per coil or deactivating one actuator. But the strategy described above gives the best results.

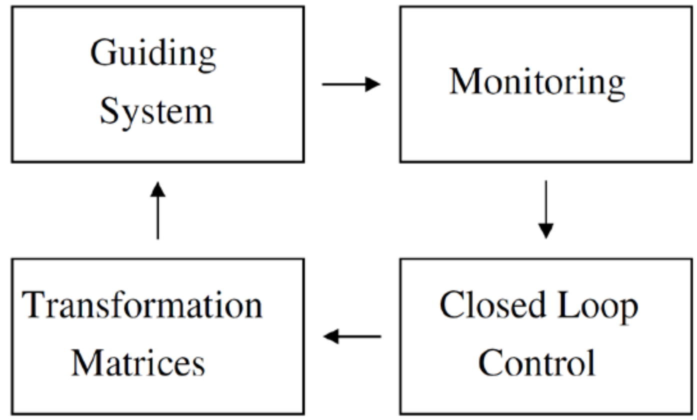

Figure 4. Control strategy of the redundant system.

If this strategy is implemented for every coil, a redundancy for the whole guiding is achieved. Of course the stiffness of the guiding is reduced compared to the normal operating system. Figure 4 depicts the control scheme including the backup level. Depending on the detected failure coil, a different transformation matrix is chosen to enable a stable guiding system.

$$I_{global} = \frac{1}{8}\underbrace{\begin{pmatrix} 0 & -2 & -1 & 1 & 1 & -1 & -1 & 1 \\ 0 & 0 & -2 & -2 & 1 & 1 & -1 & -1 \\ 0 & 0 & 2 & 2 & 1 & 1 & -1 & -1 \\ 0 & -2 & -1 & 1 & -1 & 1 & 1 & -1 \\ 0 & 2 & -1 & 1 & -1 & 1 & -1 & 1 \\ 0 & 2 & -1 & 1 & 1 & -1 & 1 & -1 \\ 0 & 2 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 2 & 1 & 1 & -1 & -1 & -1 & -1 \end{pmatrix}}_{\Theta_{red}} I_{local} \quad (3)$$

3.2 Measurement

On the elevator test bench at the Institute of Electrical Machines IEM a force impulse of 100N is given to the elevator car in x direction. An impulse hammer is used to excite the elevator car on defined places on the chassis. Figures 5 and 6 show the displacement of a local air gap in normal operation and during seven coil operation. It can be seen that the displacement in reduced operation mode is twice the value compared to the fully controlled system. Nonetheless the electromagnetic guiding is stable even with one defect coil. Further force impulses are applied to the elevator car, exciting different DOF. Measurements prove a functional guiding ability in all DOF.

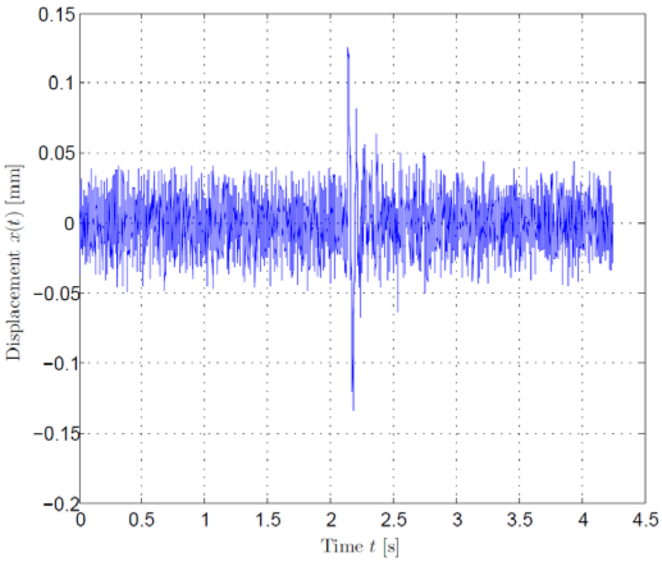

Figure 5. Displacement of one air gap resulting from force impulse during normal operation.

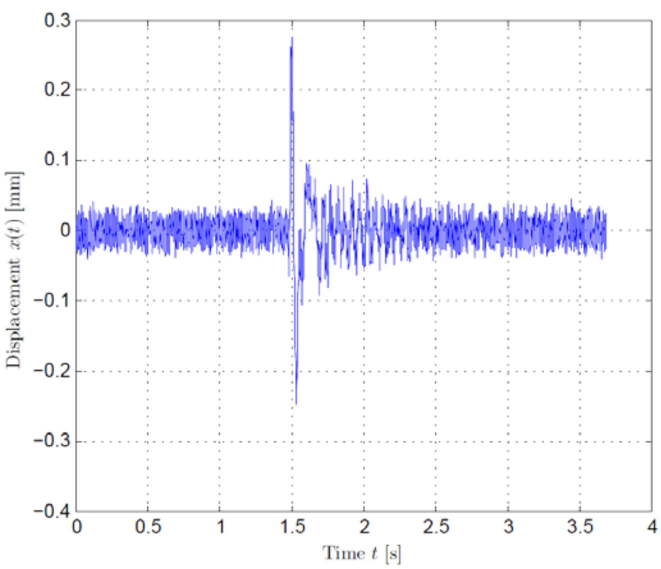

Figure 6. Displacement of one air gap resulting from force impulse during operation with seven coils.

4 CONTACTLESS POWER SUPPLY

Another interesting aspect of this reduced operation strategy is the possibility to deliberately deactivate one coil to use it for other purposes. Since the electromagnetic guiding requires a power supply, an inductive power transfer (IPT) system can deliver the required power. Cables or sliding contacts are not required in this system. Hereby the unused coil can serve as the secondary winding of a loosely coupled IPT system. If the operation frequency of the contactless power supply is high enough, it is decoupled from the electromagnetic guiding and one actuator entity combines the aspects of guiding and energy transmission [4]. Under this operation the redundancy aspect is no longer given since the system is already in the seven coil operation mode. Nonetheless the less required space compared to a separate contactless power transmission system legitimates this purpose.

5 CONCLUSIONS

A backup control level has been implemented to a DOF control for an electromagnetic guiding system of an elevator car. By utilizing the over determined system for redundancy aspects, a safer operation of the elevator itself is achieved. Monitoring of the system and alternating control matrices online is the key strategy for this advanced operation. The functionality of both normal and redundant operation is demonstrated on an elevator test bench at the IEM. The stiffness of the guiding system is reduced compared to normal operation mode, but the elevator car can be operated even with one defect coil.

Ongoing work will focus on the possibility of using the reduced operation mode for an integrated inductive power supply. Hereby the unused coil serves as the secondary winding of the contactless power transmission based on an air gap transformer. The influence resulting from a high frequent alternating flux on the guiding system in reduced operation mode has to be analyzed carefully in future works.

6 REFERENCES

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