Modeling of Influences affecting a Linear-Drive-System

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Abstract - For the systematic model-based optimization of complex mechatronic systems models are required, describing not only the basic function of subsystems, but instead reflecting the influences from one subsystem to another. This paper presents the modeling of influences on a doubly fed long stator linear drive of a railway system, used as demonstrator for self-optimization methods.

INTRODUCTION

In order to apply a hierarchical optimization scheme, the conventional model of a doubly fed linear drive is improved by modeling parasitic influences. Not only local mechatronic functions of the subsystem being optimized cause these influences, modules of the entire vehicle may cause it.

In this contribution a cognitive and reflective operator and a controller (chapter I), which is implemented for a long stator linear motor driven railway vehicle (chapter II). Parameters of the motor are given in chapter III, while effects of varying air gap and pitch angle on the thrust and normal force are investigated, resulting from an imperfect track or steering are outlined in chapter IV.

I. SYSTEM DESCRIPTION FOR SELF-OPTIMISATION

In many cases, adaptation will be a proper way to improve the behavior of a subsystem subject to influences of the environment, user or the system itself. In most cases, the combination of adaptive subsystems will lead to systems with a proper behavior. However, the behavior of the entire system does not necessarily represent the optimal one for a special target. In cases of varying requirements, it is necessary to readjust the specification for the adaptation. This leads to optimization. The decision to readjust the objectives makes the difference between optimization and self-optimization: Self-optimization strategies for complex mechatronic systems are in the focus of the "Collaborative Research Centre 614" (SFB 614) [4], which is the underlying long term project of this contribution.

Many different targets have to be considered for the optimization of dynamic mechatronic systems. In most cases, these different targets lead to contradictory solutions. Then, it is helpful to separate the total system into subsystems, especially if it shows a complex building structure. A strategy for structuring mechatronic systems into subsystems belonging to different hierarchical levels is presented in [1] and [2]. Cross-linked mechatronic systems (CMS) are members of the highest hierarchical model-level. They have no physical link among each other and other hierarchical levels. Instead, they just transfer information from one CMS to another. Autonomous mechatronic systems (AMS) interact with users, environment and other systems. The AMS belong to the second hierarchical level containing the mechatronic function modules (MFM) at the lowest and fastest level comprising sensors and actors together with the electromechanical structure.

Within this framework, "self-optimization" of a mechatronic system means the endogenous adaptation of a target vector as response to altered environmental conditions. This can lead to an adaptation of controller structures, system behaviors and parameters. Such concepts of self-optimization go far beyond known control- and adaptation strategies, since it enables autonomous systems with inherent "intelligence".

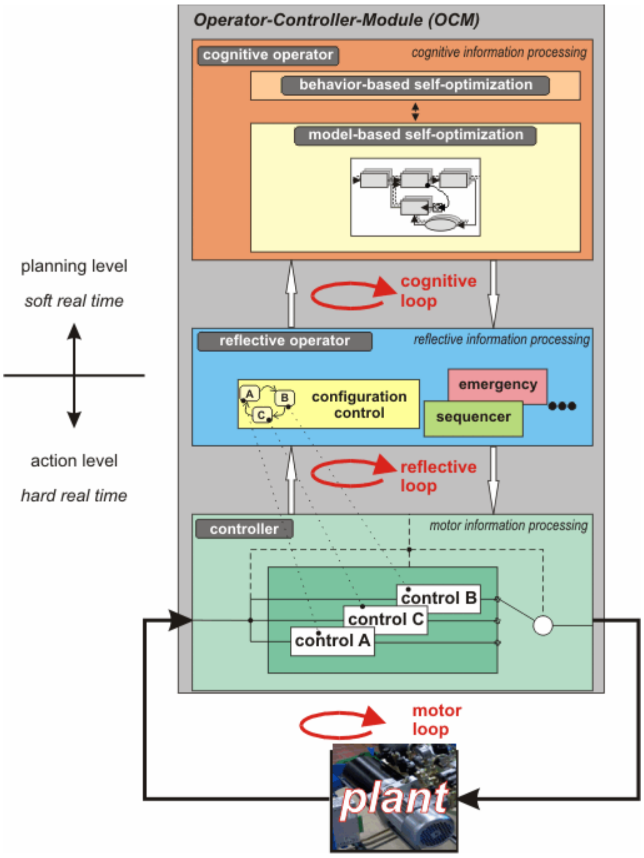

Fig. 1. Operator Controller Module

A framework aiding first the structuring and second representing the means to accomplish self-optimization in complex mechatronic systems is called "Operator-Controller-Module" (OCM) outlined in [2] and illustrated in Fig. 1. A physics based mathematical model forms the core of the operator and supplies the optimizer, which determines optimal controller structures, feed forward and controller parameters. After an evaluation of the optimization targets by an objective monitoring at the operator module, the resulting controller can be downloaded to the controller level, which controls the physical plant. As such, the OCM is useful to combine different levels of subsystems for the optimization of a complex system.

At the highest level, termed planning level, the cognitive operator contains the optimization and generates proposals for new control structures. These proposals will be transferred to the second level, which handles a state-machine for activating the new controller structure. The third level, which is directly linked to the plant, includes the active controller Fig. 1. Self-optimization can be performed by the coordinated dataflow between these three hierarchical levels.

Subsystems containing a physical system as plant will be optimized conventionally based on models. Therefore, the model quality of the plant is important for the quality of the optimization result. Nevertheless, due to the aforementioned structuring the model also has to consider influences of other subsystems, too OCMs with their own optimization.

II. LINEAR-DRIVEN VEHICLE AND UNDERCARRIAGE FUNCTIONS

The selected validation base for the self-optimization scheme within project SFB 614 is a novel linear-motor driven railway system, developed by a project called "Neue Bahntechnik Paderborn" [3]. Fig. 3 displays the test vehicle used by this project. This vehicle belongs to a test bed with a track length of about 530 m. The track contains an artificial hill with an altitude of about 2.5 m and one switch.

The vehicle consists of a superstructure that carries the load and two undercarriages. Fig. 4 shows the concept of the undercarriage module, which is one of the basic modules of the vehicle.

Fig. 3. Vehicle of the demonstrator

The undercarriage consists of three modules: The driving and breaking-, the active suspension- and the guidance-module based on one single wheel set. These key modules have influences to the functions inside and outside the undercarriage.

The doubly fed linear drive module serves three functions: The energy transfer from the primary to the secondary, the control of the pitch angle Fig. 5, Fig. 6 and the generation of thrust described in more detail in [7].

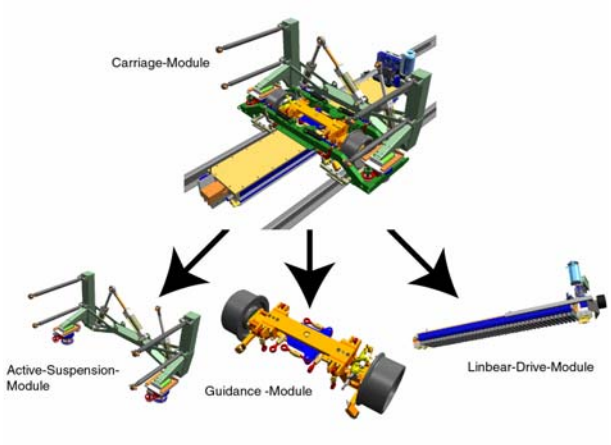

Fig. 4. Concept of the drive module

The single wheel set in an undercarriage allows a pitch of the undercarriage. Under normal circumstances, a pitch control eliminates the pitch angle and provides a constant air gap between the primary at the track and the secondary at the vehicle. In cases of a poor rail track, it is very likely that the pitch angle changes the operating point of the linear drive. This requires an angle depending model of the generated normal force.

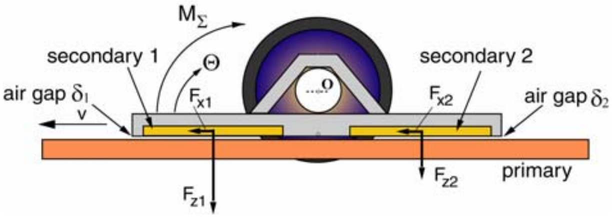

Fig. 5. Linear Drive at the axle

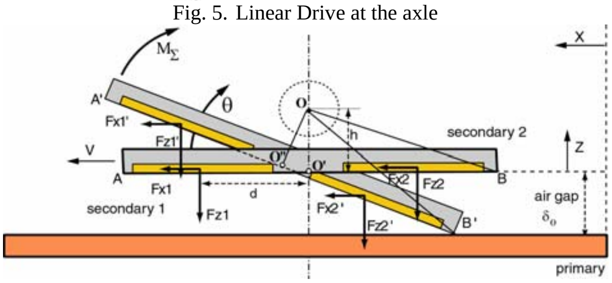

Fig.6. Pitch angle and air gap

A predetermined trajectory for the steering can be calculated by an optimization. This optimization should consider the effects on thrust and acceleration. A correct thrust leads to a precise acceleration and velocity value, which is one requirement for calculating the efficiency. In case of ideal conditions, modeling of these functions is already well done and was presented in [3]. The influence of other modules, e.g. the steering module on the linear-drive module and between functions within, e.g. by the pitch-control, the linear drive module has to be improved for the model-based optimization.

III. MOTOR PARAMETERS

The considered secondary part of the linear motor has a length of about 1.40 m and a pole-pitch of 0.1 m. The nominal mechanical air gap is 10 mm. The specified thrust of a secondary part is 750 N (two secondary parts are used in the test vehicle) at a primary magneto motive force of 1100 A and a secondary magneto motive force of 1190 A. Fig. 7 shows the linear motor in a test bed for measurement of force.

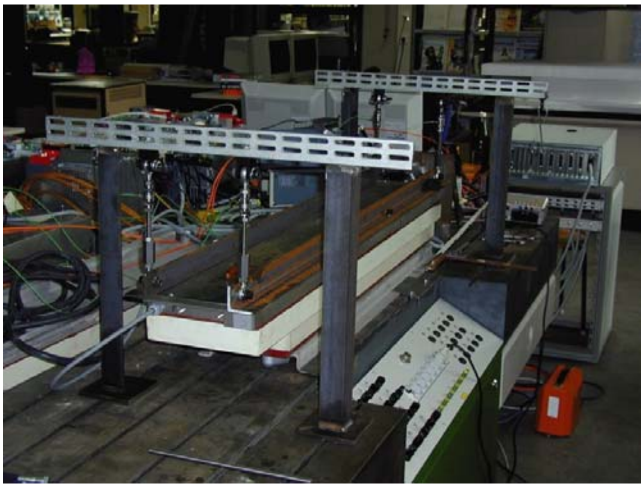

Fig. 7: Test bed for measurement of thrust and normal force

IV. ANALYSES OF THRUST AND NORMAL FORCE

In case of a constant air gap and a constant active surface of the linear motor, the thrust F_T and the normal force F_N are outlined in [8] as:

$$F_T = \frac{9\cdot\mu_0\cdot b_P\cdot\tau_P\cdot N_1\cdot N_2}{\pi^2\cdot p\cdot\delta''}\cdot\hat{\imath}_1\cdot\hat{\imath}_2\cdot\sin(\vartheta)$$

$$F_N = -\frac{9\cdot\mu_0\cdot b_P\cdot\tau_P}{2\cdot\pi^2\cdot p\cdot\delta''^2}\cdot((N_1\cdot\hat{\imath}_1)^2+(N_2\cdot\hat{\imath}_2)^2 + 2\cdot N_1\cdot\hat{\imath}_1\cdot N_2\cdot\hat{\imath}_2\cdot\cos(\vartheta))$$

b_P	active pole width
τ_P	pole-pitch
N_1, N_2	number of effective windings of primary and secondary
$\hat{\imath}_1$, $\hat{\imath}_2$	magnitude of primary and secondary current
ϑ	phase difference between primary and secondary current

If the disturbance from other modules or functions becomes effective, then both forces have to be calculated in a more complex way. Possible influences are for example a not correctly working pitch control or a track depending air gap.

A FEM-2D model for MAXWELL-2D is used to investigate the letter effect on the normal and the thrust force.

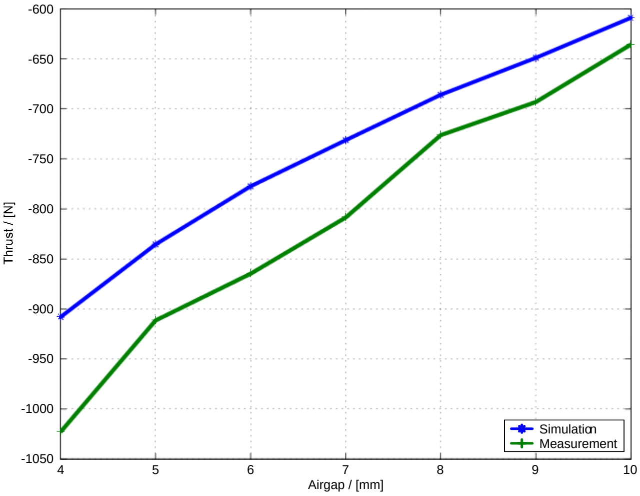

Fig. 8: Comparison of measured and simulated thrust

Some MAXWELL simulation results are validated by measurements on the comparable linear drive of the described vehicle. Fig. 8 shows a comparison of the thrust with a maximum difference of about 11 %, although only a coarse simulation model was used neglecting the laminated structure of the core and saturation effects. The simulations for high pitch angels and low air gaps are limited by the contact of the secondary on the primary part of the linear motor.

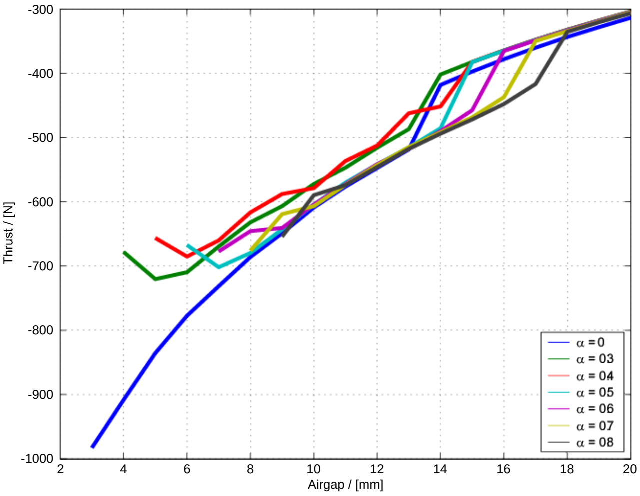

Fig. 9: Air gap depending thrust versus varying pitch-angle

The simulations of an air gap depending thrust at a pitch angle between 0° and 0.8° show that the thrust is nearly constant at different pitch angles, s. Fig. 9. This is also illustrated at a fixed mechanical air gap of 10 mm in Fig. 10.

Fig. 11 shows that pitch angel has more influence on the normal force as on the thrust, which is to expect from equations above. However, the illustrated forces are the mean values, resulting from alternating current phasor. The alternating current phasor is necessary to consider the influences of poles and notches of the core especially on high pitch angles at low air gaps.

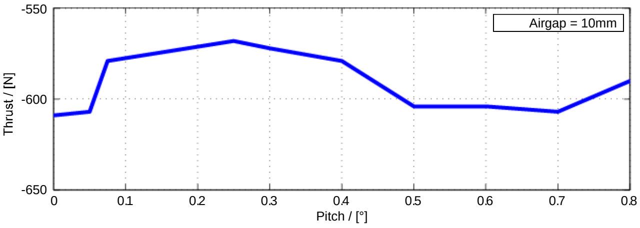

Fig. 10: Pitch angle depending thrust at constant air gap

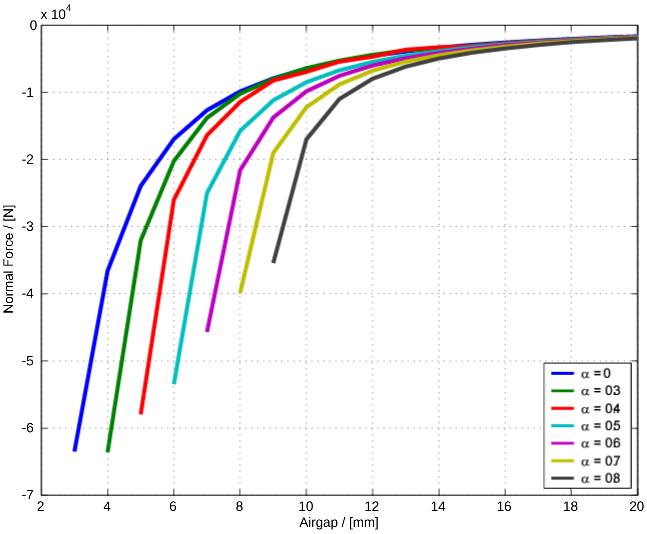

Fig. 11: Air gap depending normal Force at varying pitch angle

It is assumed that the increasing normal force is mostly caused by the influence of the end of secondary part of the linear motor. Especially just before the secondary contact the primary the force rises. Of course, these conditions must be prevented by a pitch-angle-controller.

The presented simulation of forces on a linear motor with variable air gap and pitch angle leads to characteristic diagrams, which can be realized as a lookup-table to support simulations of the whole vehicle (e.g. in MATLAB) and utilize a model-based optimization by an OCM. Fig. 12 shows a presentation of this characteristic diagram. This characteristic diagram will also be the base for an advanced operating point assignment of the doubly fed linear motor [9].

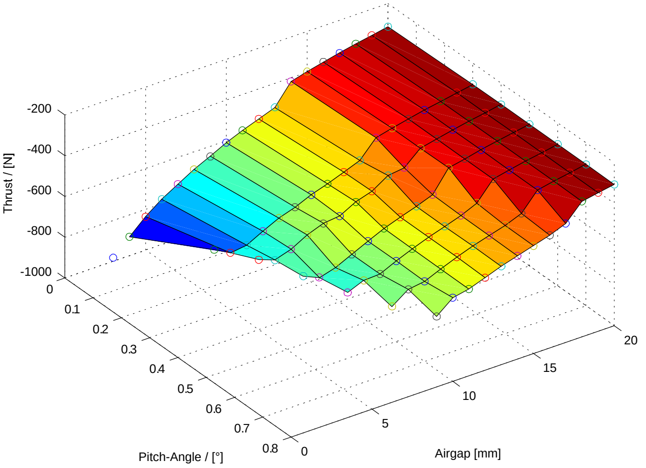

Fig. 12: Characteristic diagram of simulated thrust

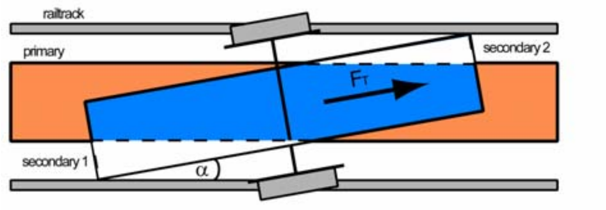

Fig.11. Active linear motor surface at steering

V CONCLUSION AND OUTLOOK

Many influences e.g. from the steering to the doubly fed linear drive lead to an alteration of the air gap or of the active surface of the linear drive, which may decrease the possible and effective thrust. A proper modeling of parasitic effects at all hierarchical levels is an exigency for the model-based optimization of the whole vehicle. So far used models for these optimizations are simple and do not consider influences to the thrust. For many optimization tasks, it proved best to describe influences by characteristic diagrams stored in look-up tables. This characteristic diagram supports the required accuracy for the optimization models to consider influences to linear drive.

The steering, which can decrease the active linear motor surface and turn the main direction has an influence to the thrust. This case is shown in Fig. 12. Calculations for this problem require a three-dimension model of the linear motor. Investigations on these influences are performed momentarily.

ACKNOWLEDGMENT

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