Nachdruck Konferenzbeitrag

Henke, M.; Yang, B.; Grotstollen, H.

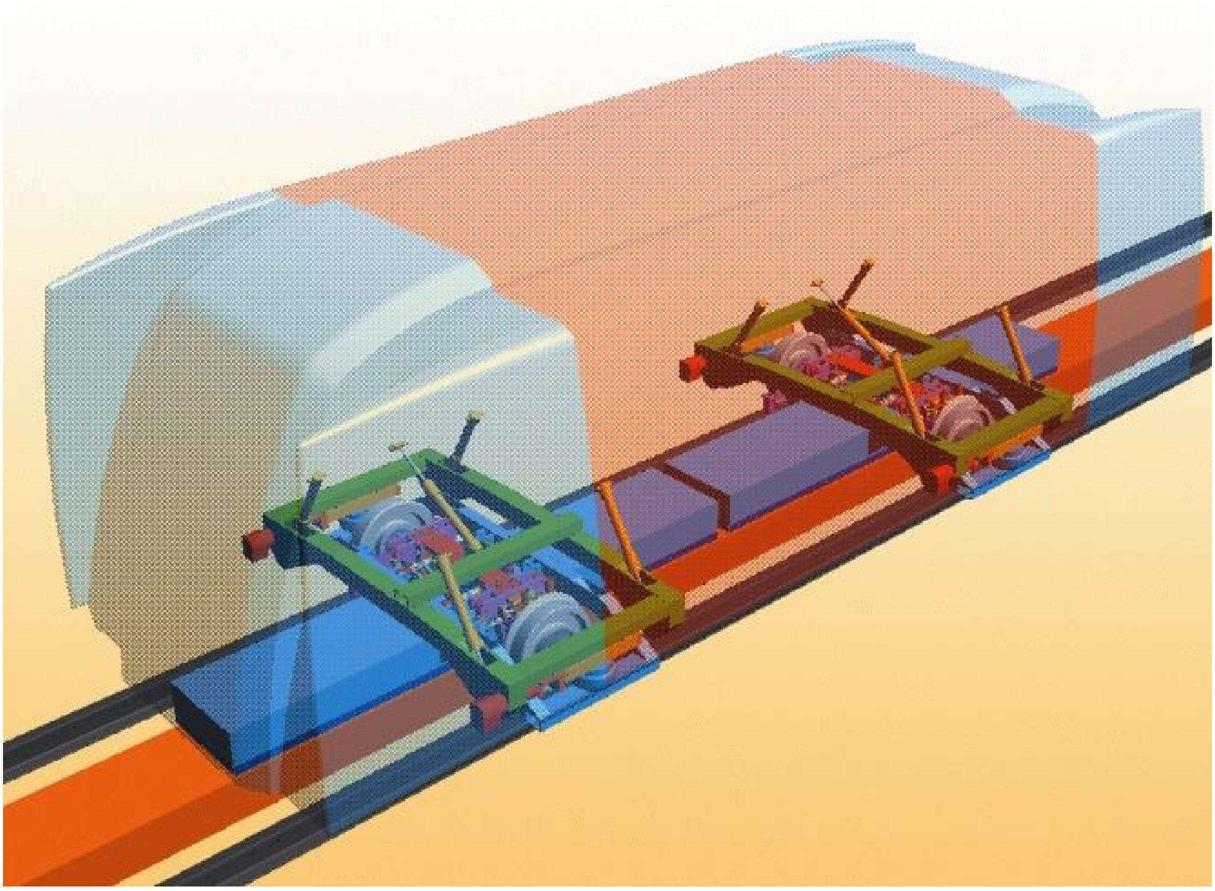
Linear Drive System for the NBP Railway Carriage,

World Congress on Railway Research, WCRR 2001, Köln

Linear Drive System for the NBP Railway Carriage

Markus Henke, Bo Yang, Horst Grotstollen
Department of Electrical Engineering and Information Technology
University of Paderborn

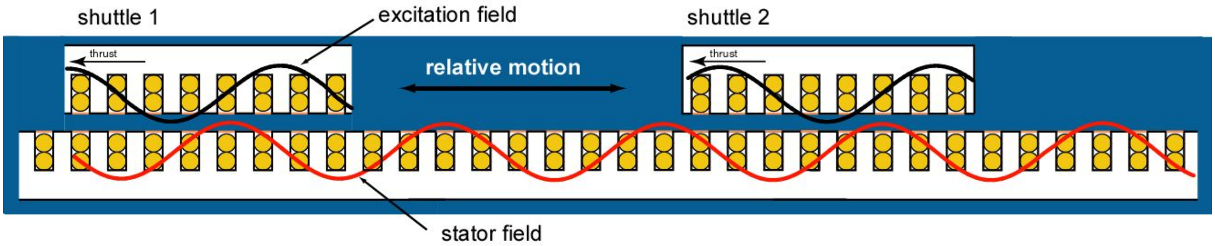
Abstract
At the University of Paderborn, a mechatronic railway system (NBP, Neue Bahntechnik Paderborn) is designed, which means the operation of small vehicles in a large railway network [1]. These shuttles are fitted with active suspension-/tilt and steering modules to ensure high ride comfort and customer support. The vehicles are driven by a linear motor [2] and they operate without magnetic levitation in order to use the simple structure of the existing railway lines for guidance.
The technical concept of the NBP is embedded into an overall logistical structure and a fully automated shuttle is built up useable for the transport both of passengers and goods.
In this presentation the drive system is described including the thrust control of the shuttles as well as an advanced pitch control system for the secondary part of the linear motor.



NBP Shuttle Concept

Drive Module
One of the requirements of the NBP-System is to operate several shuttles in convois of different size, so it is necessary to control several vehicles on the same primary segment. The

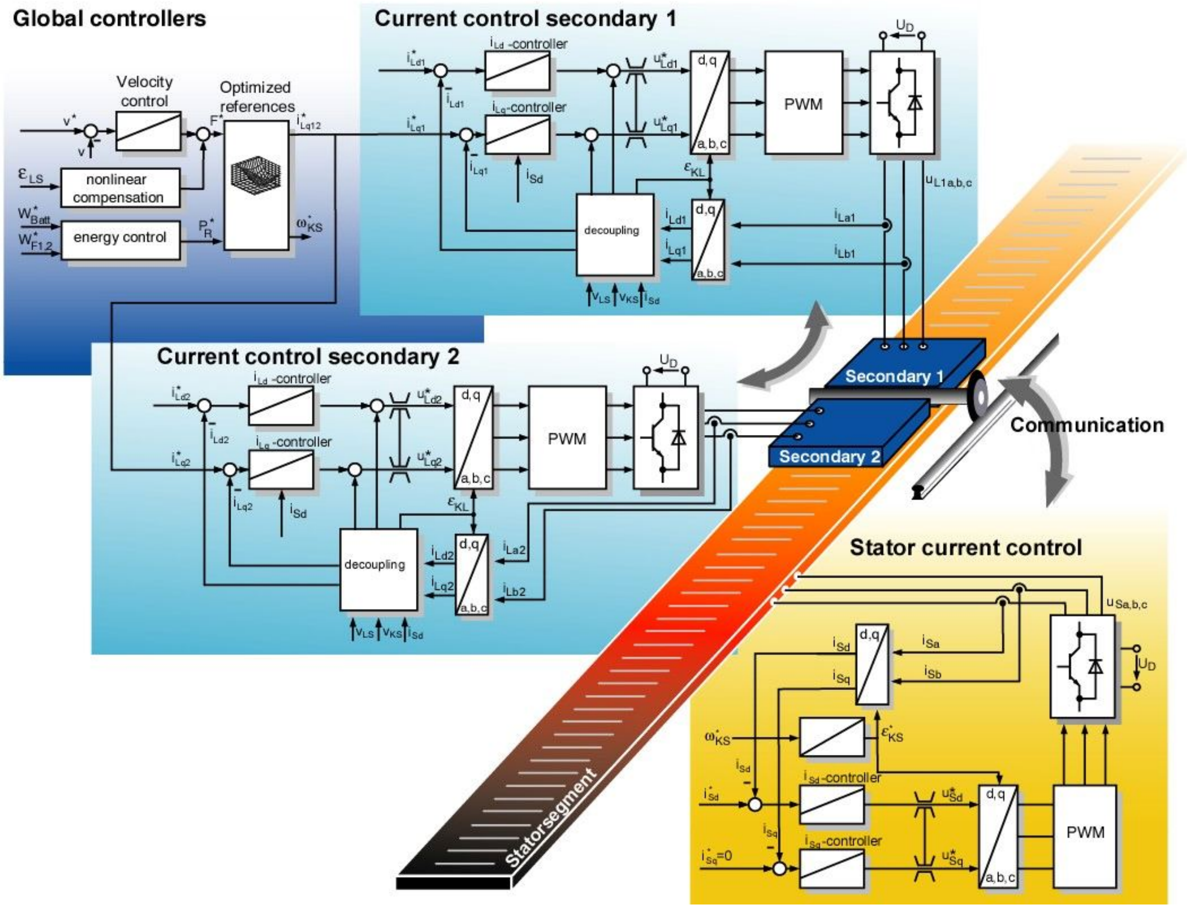
control of the longitudinal motion in general can only be done by the primary (conventional linear longstator motor).
Another main objective of the NBP shuttle is to operate without power transmission lines and without contact rails. Furthermore the shuttles should be able to accelerate and decelerate at any position, they especially should be able to build convois. This can be realised via rendezvous maneuvers between several separated shuttles.
For this reasons, three-phase windings are implemented in the secondary. With this doubly fed linear motor design (fig. 2), it is possible to align the excitation field in the secondary at will, so that the force generation is optimised and several shuttles can perform different thrust forces on the same primary segment [3].



Doubly fed linear drive concept

Control Scheme

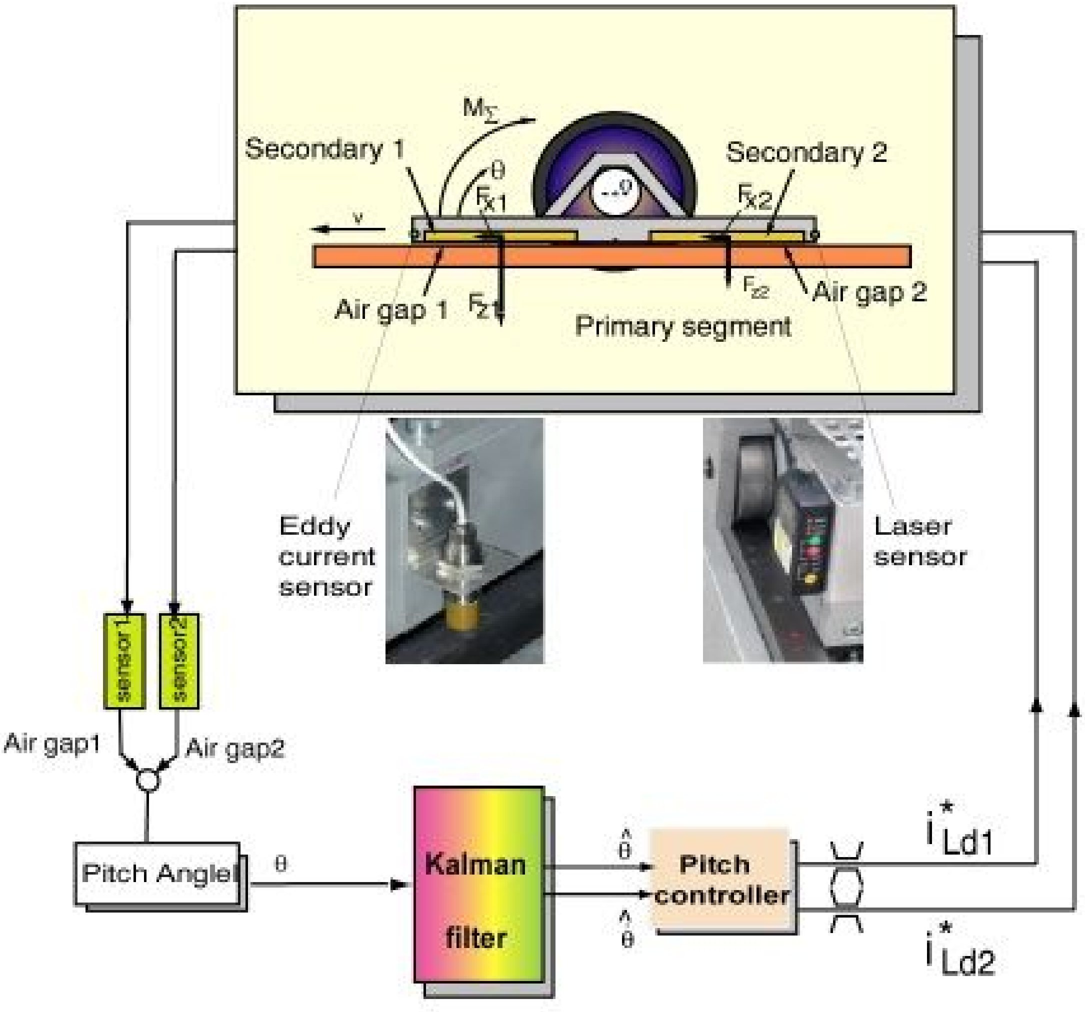
The stator (primary) current has to be controlled independently of the longitudinal movement of the vehicle. So the control of the linear motor can be structured in current control for primary and secondary, velocity control and position control.
Contrary to conventional linear drive systems, the primary current has to be controlled as to constant frequency and amplitude during operation. The frequency depends on the vehicle velocities and effects the energy flow between primary and secondary which can be controlled separately in an upper cascaded control loop. The energy flows between primary and secondary can be analysed via currents and voltages in primary and secondary.
The secondaries of all the vehicles running on the same primary segment are magnetically coupled via the primary windings. Disturbances in primary current control are the voltages induced by each shuttle operating on that segment and error voltages resulting from the feeding converter.
The longitudinal dynamics of each motor are controlled via the electrical alignment of the secondary current. All shuttles use the common primary flux. The switching between different primary segments is taken into account and the segments the shuttle is running into have to build up the current just before the secondary enters the segment.
As the primary current component is fixed at a constant value, the only remaining actuating variable for thrust control is the orthogonal component of the secondary current.
The actual values of the current components are directly determined by transforming the measured primary and secondary currents.
For the control of the carriage (fig. 3), there are thus three remaining variables to be controlled: the components of the secondary current and, superordinated, the velocity of each carriage. All these control loops are realised with PI-controllers. Feedforward control of velocity and secondary current yields a reduction of the position error.
A simulation model has been made for the control shown above. It includes the cascaded vehicle control and the power management of two secondaries.



Control structure of the drive for longitudinal motion

Pitch control

The single axle structure undercarriage is adopted instead of conventional two axle structure. Such a design makes the shuttle lighter than the bogie variant. The thrust and normal forces result in a torque around the axle which has to be compensated to retain a constant air gap between primary and secondary. This concept puts forward new control demand except for linear drive control [4]. In case of non-zero of the resultant torque on the axle, pitch motion is inevitable and the air gap is away from the desired value.



Pitch control of the linear drive module

As well known, the primary and the secondaries are interlinked magnetically by the air gap. Since the air gap of the linear motor plays an important role, it must be kept constant, in other words, this pitch motion should be avoided in any case, consequently, each axle has two secondaries which powers are supplied completely independent.

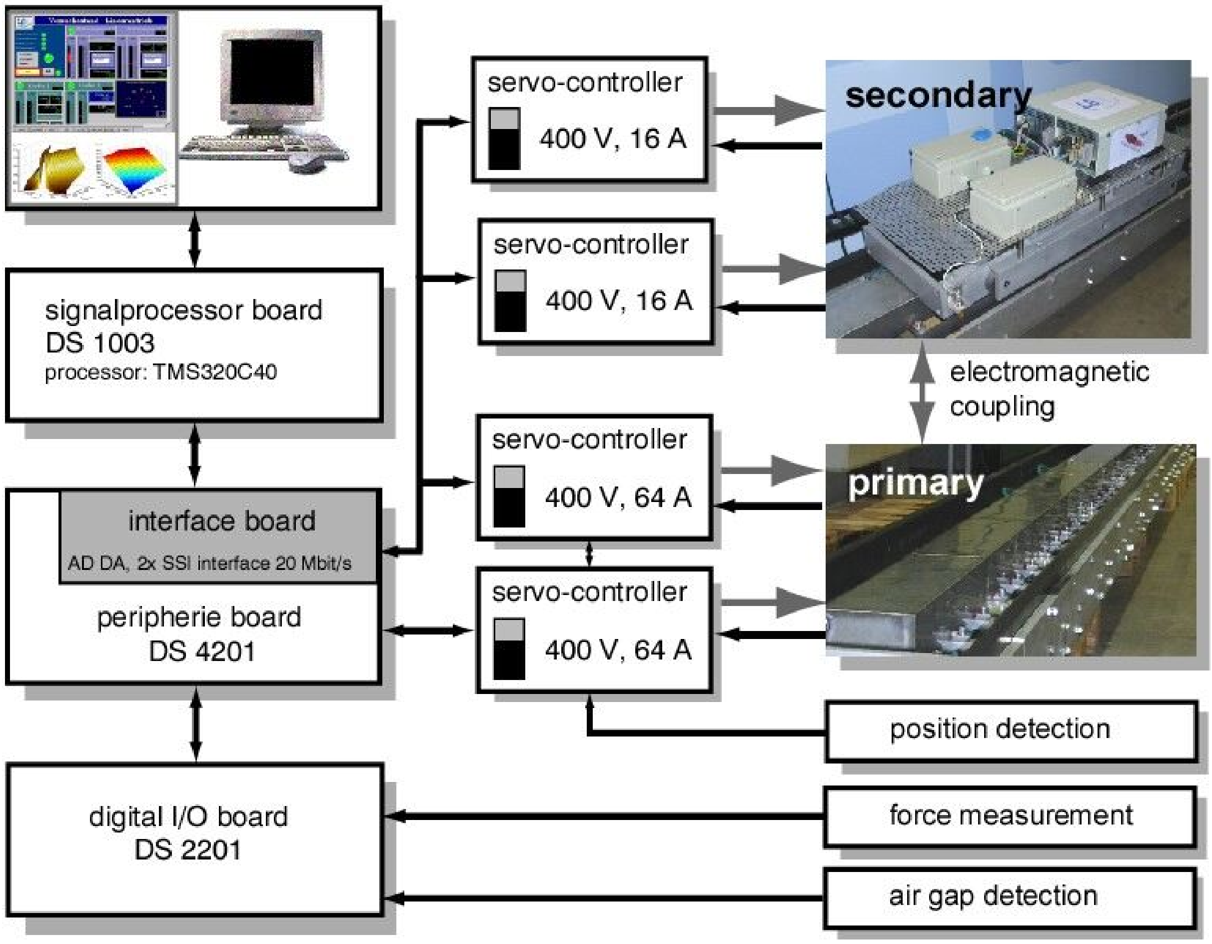
From the point of view of drive control, the system modeling and the control structure are based on a primary current oriented coordinate system, which is common to all secondaries. Linear drive control and pitch control can be decoupled completely by using the orthogonal components of the secondary currents as control variables.

Instead of measuring the pitch angle directly, two sensors are mounted on the two end sides of the secondaries. On the basis of the geometrical sizes, the pitch angle can be calculated in an easy way by measuring two air gaps. Pitching velocity is estimated by using a Kalman Filter algorithm.

According to the current pitch angle and pitching velocity, the pitch controller keeps the pitch angle to zero. As a result, the normal forces on the axle will be changed, since they are related to secondary currents.

Test Stand

A test stand of 8 m in length has been built up for one linear drive module including 12 primary elements and 2 secondaries. The primary elements are installed between two rails and divided into two separately fed segments. The maximum thrust force is about 500 N with an air gap of 9 mm.

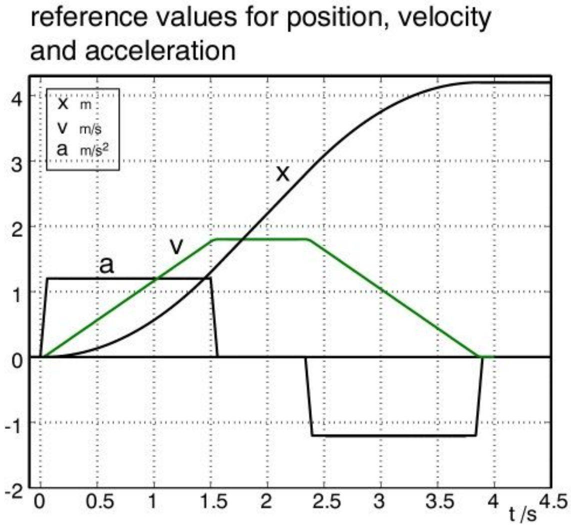


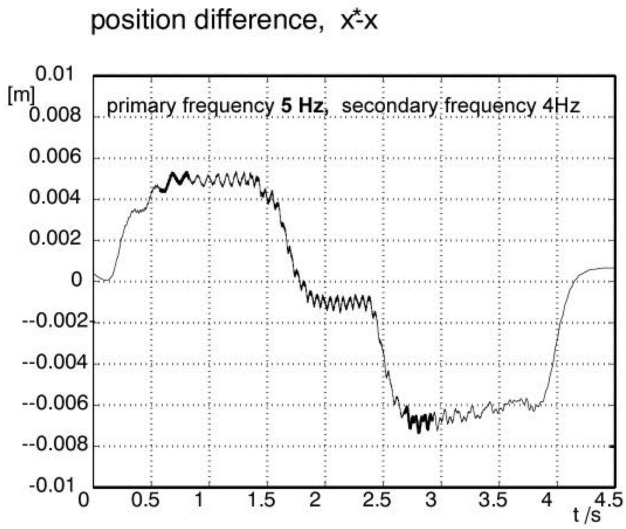
Test stand for the drive module

The experiments are implemented on a real-time digital multi-processor system. The control structure can be implemented block oriented with Matlab/Simulink tools so that the motor behavior can be analyzed in a simple way.

Experimental Results

Fig. 6 displays the result of a test run with maximum velocity of 1.8 m/s . The position controller and the cascaded velocity controller realize a difference between reference and actual position below 5 mm.





Test stand for the drive module

[1] J. Lückel; H. Grotstollen; K.-P. Jäker; M. Henke; X. Liu: Mechatronic Design of a Modular Railway Carriage, IEEE/ ASME International Conference on Advanced Intelligent Mechatronics 1999, Atlanta, GA, USA, 1999, pp. 1020-1025.

[2] Jacek F. Gieras: Linear Induction Drives, Oxford Science Publications, 1994

[3] M. Henke; H. Grotstollen: Modelling and Control of a Longstator-Linearmotor for a Mechatronic Railway Carriage, IFAC Conf. on Mechatronic Systems, MECHATRONICS 2000, Darmstadt, Germany, pp. 353-357 .

[4] B. Yang, M. Henke, H. Grotstollen: Realization of Pitch Control on the Teststand for NBP Wheel-on-Rail System, LDIA 2001, Nagano, Japan .