Power Supply Concept of the Longstator Linear Motor of the NBP-Test Track

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Abstract

The NBP (Neue Bahntechnik Paderborn) project has been established at the University of Paderborn five years ago and a test track will be used for investigations on railway vehicles (shuttles) driven by linear motors. The linear drive is part of a complex mechatronic system with a modular design. The control structure of this railway system is based on the operation of autonomous shuttles which are fitted with individual power management on board. The power supply of all track sections is decentralized, so reference values have to be sent directly from the shuttles to the local power supply units distributed along the track sections.

Introduction

This contribution describes the concept of power supply and communication structure of the linear drive used in a mechatronic carriage fitted with fully active mechatronic components. The modular concept of the undercarriage is based on a drive- and brake-module, a power supply module, an active suspension- and tilt-module and a support- and guidance-module [1]. All of these modules are based on the consistent use of information and communication techniques. In combination with actuators and sensors a novel mechatronic system with special performance is designed. By using active suspension/tilt technology the ride comfort will be improved and in combination with an active steering device the wear of wheels and rails can be reduced.

Propulsion Concept

The drive and brake module of the NBP system consists of a doubly-fed longstator linear motor. The primary is installed between the rails and the secondary is fitted below the undercarriage. Both motor parts are equipped with a three-phase winding. By realizing an independent power supply of primary and secondary, which implies independent alignment of the current vectors, it is possible to operate the vehicle in synchronous and asynchronous mode.

The construction of the mechanical parts of the linear motor is based on an air gap of 10 mm length. In Fig. 1 the structure of the linear motor with primary and secondary magnetic fields is shown.

In order to make the carriage motion flexible, a relative motion between different coaches on the same stator has to be made possible. The asynchronus operation allows relative motion between shuttles running on the same primary segment. This further enable the shuttles to form convoys, without taking into account problems like arcing and oscillating of overhead lines [2]. The convoy build-up optimizes the power consumption of the system by minimizing wind resistance and allows to create an intelligent energy management between the different shuttles.

One main advantage of the longstator motor is based on contact-free energy transfer into the shuttles. If the speed of the primary field is higher than the mechanical speed of the shuttle (asynchronous operation), electrical power is transferred from the primary to the secondary. No overhead lines or contact rails are necessary.

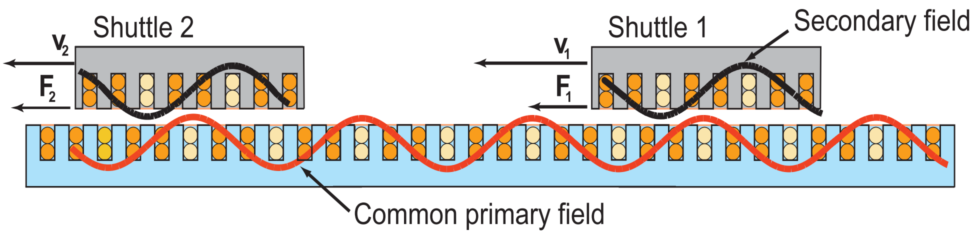

Fig. 1: Principle of the doubly fed longstator línear motor

Further studies have shown, that the absolute value of the power transferred to the secondary depends on the operating point of the linear motor [3]. The transfered power depends on the motor currents and slip. By variation of these values the energy flow between primary, secondary and on-board power supply can be controlled. Since there is no continous energy flow the necessity appears to use an energy storage which is able to store and to deliver electrical energy depending on the operation point. So a continuous operation of the railway vehicle is ensured.

NBP Test Track

Fig. 2a presents the NBP test track, which is built in scale 1:2.5. It is planned as a circuit with straight and curved stretches and with a total length about 530 m. The maximum gradients are up to 6% to realize varying longitudinal load forces along the track. Furthermore it includes one switch for investigations on guidance and steering behaviour in that area. A maximum of three railway vehicles (Fig. 2b), will be operated at the same time. They are designed to drive with a maximum speed about 36 km/h. The length of a shuttle is about 3 m. The body has a height and a width about 1.2 m. One shuttle has a weight of nearly 1000 kg. With this kind of test vehicles numerous tests will be performed also to optimize the energy management of the whole track. Rendezvous-manoeuvres of several shuttles and their thrust control require high performance control and communication technology.

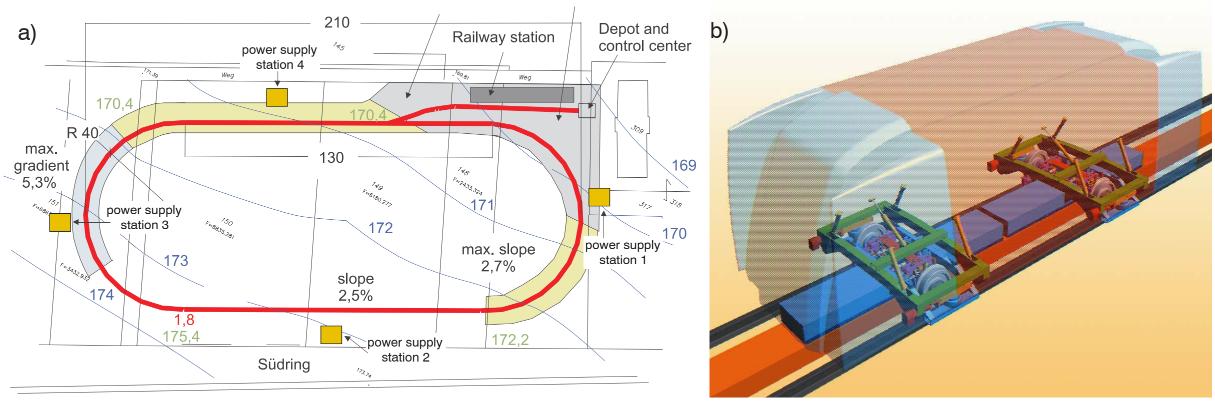

Fig. 2: a) Overview of the NBP-test track
b) Shuttle on a railway section

The modular approach leads to a special electrical design of the primary power supply. The track is devided into segments that are individually connected to power supply units (converters). These segments have a length about 6 m and the converters for every segment are centered in four substations along the track. The main advantages of this concept are:

- minimal energy consumption of the entire track is realized
- flexible control of stator currents along the track becomes possible
- motor design and power supplies can be adapted to landscape topology

Vehicle power supply system

This chapter presents the on-board energy supply system of the shuttle. As mentioned above the transferred power depends on the thrust force. While braking or accellerating a lot of energy can be stored on board. The emerging power peaks cannot be stored in on-board-accumulators, so that braking resistances are necessary to equalize the power balance. Another more efficient possibility is the usage of a combination of accumulators and power caps [4] to increase the maximum instantaneous output power.

Fig. 3 describes the on-board power supply which has been designed especially for the demands of the doubly-fed drive structure. Each drive module is fitted with two secondaries. So five converters supply the motor secondaries and the hydraulic unit. They are coupled via a DC link.The DC link voltage U_D is controlled by a converter connecting the energy module with the main circuit. This converter ensures a DC link voltage of $550\ \mathrm{V} < U_D < 750\ \mathrm{V}$ and also controls the energy flow between the main circuit and the energy module. This module comprises the combination of a Ni/Cd-battery and power caps. The battery consists of 280 cells connected in series. It is loaded via an industrial converter which runs in current control mode. This design allows the investigation of different charging techniques.

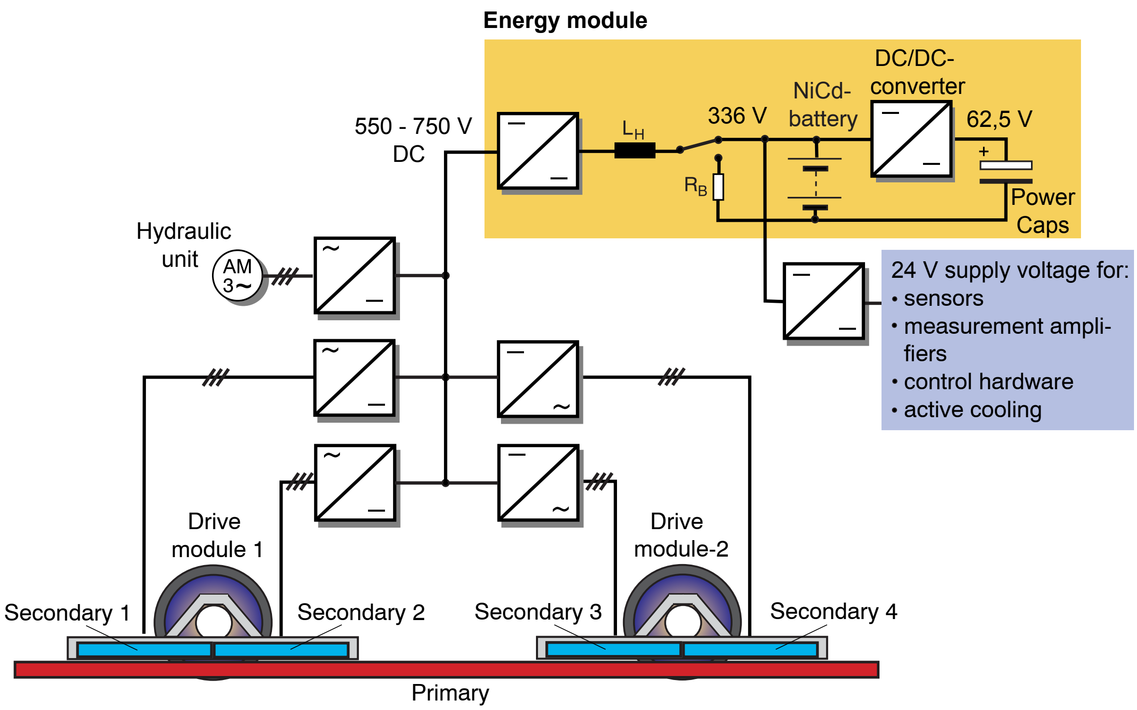

Fig. 3: On-board power supply system

The batteries cannot be connected to the power caps directly, so a DC/DC-converter is used to equalize the voltage levels of battery and power caps. The individual control of the described converters allows the optimization of the energy storage in the energy module and increases the lifecycles of the batteries.

The sensors, actuators and control hardware of the mechatronic carriage are supplied by a separate 24 V - 1.8 kW DC/DC-converter with an input voltage between 250 V (discharge voltage of the battery) and 406 V (charge voltage of the battery).

Communication and drive control structure

Fig. 4 displays the system structure of the test track and the communication channels between different intelligent units. The whole control structure can be devided into three control modules:

- Plant control
- Shuttle drive control
- Primary control

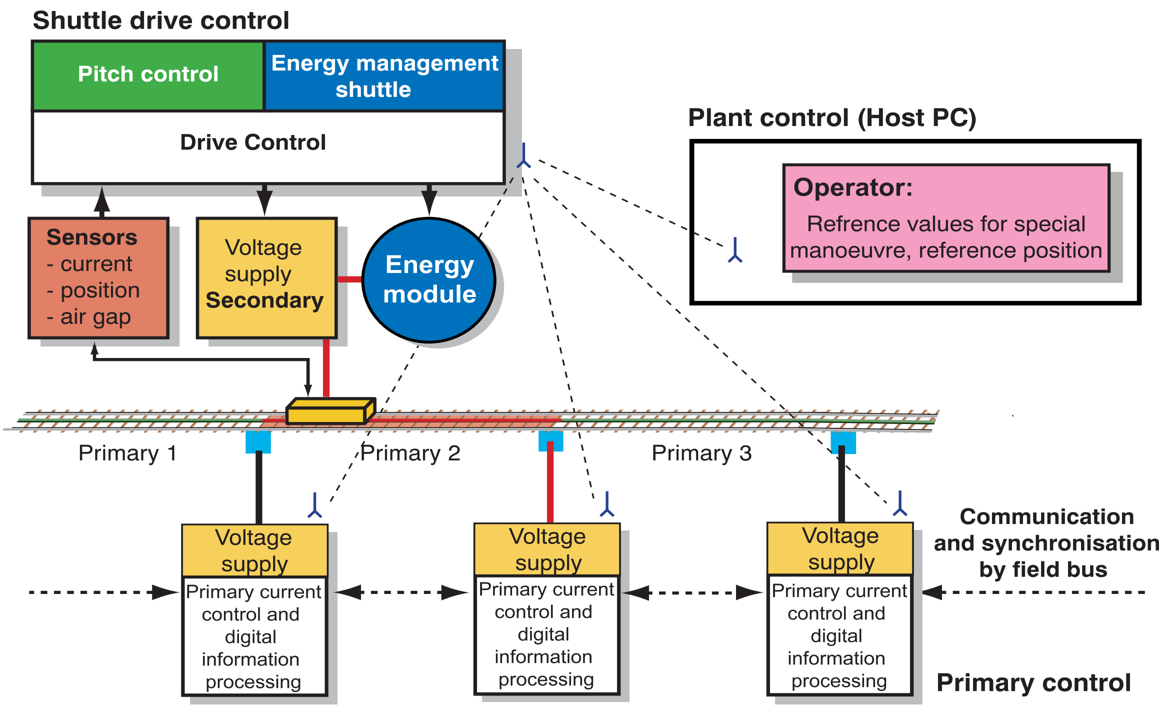

Fig. 4: NBP drive control- and communication-structure

The plant control is used for monitoring the experiment, including global references for special manoeuvres, measurement of significant parameters and fault diagnostics. An operator is able to transfer reference signals to the shuttle by a *Wireless LAN* device. On this way a special software tool enables the possibility to telecommand an industrial PC including prototyping hardware on which the shuttle control is implemented.

The shuttle consists of the mechatronic modules and overlaid digital information equipment (prototyping hardware) which handles different online control structures and the communication between sensors and actuators on board. Depending on the reference position a profile for velocity and acceleration is calculated and used for drive control [5]. For this type of linear motor the control can be built up fairly similiar to conventional field oriented vector control [6].The entire drive control is implemented as a cascaded control structure for longitudinal dynamics, energy management and a separat pitch control which is described in [7].

The shuttle drive control realizes on the one hand the online-communication between the shuttle and the primary power supply units and on the other hand communication between several shuttles when building up convois. In order to obtain an optimized energy management the reference values of stator current amplitude and frequency are transfered. The communication channels are realized by radio modems using bi-directional transmissions in 2.4 GHz ISM band. These modems are linked via serial interfaces with the digital information equipment. High dynamic controllers operate independently of these radio communications local on board respectivly in primary control, so that the demands on the bandwidth of the communication systems can be fulfilled. The main task of the primary control units is to control the stator current vector depending on the commands generated from shuttle drive control.

The electrical position of the stator current vector has to be controlled with high accuracy, so the synchronization of the primary curent controllers is very important for the build-up of a homogenous stator field. So the stator voltage supplies are interlinked via field bus technology (CANopen) on which a master is resposible for this synchronisation task. If the stator controllers do not operate with synchronized time intervals a worst case delay of 1 ms would cause an electrical angular misalignment of up to 40°. So an interrupt controlled software mechanism is applied and in combination with high sample rates the error is reduced down to 5°.

Depending on the vehicles position the stator segments are switched by converters which receive the references via radio commands directly from shuttle drive control

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