ISSN 0005–1144
ATKAAF 44(1–2), 55–58 (2003)

Andreas Pottharst, Markus Henke, Horst Grotstollen

Power Supply of the Longstator Linear Motor of the NBP–Test Track

UDK 621.337
IFAC IA 5.7.2

Preliminary communication

The NBP (Neue Bahntechnik Paderborn) project has been established at the University of Paderborn five years ago and a test track is 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 managements 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.

Key words: energy system management, electrical vehicles, linear drives, motion control, transmission of electrical energy

1 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 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.

2 PROPULSION CONCEPT

An important part of the drive module of the NBP system is the 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 independent power supplies of primary and secondary, which imply 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 Figure 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 enables the shuttles to form convoys and the convoy build-up optimizes the power consumption of the system by minimizing wind resistance and allows to create an intelligent energy management between different shuttles.

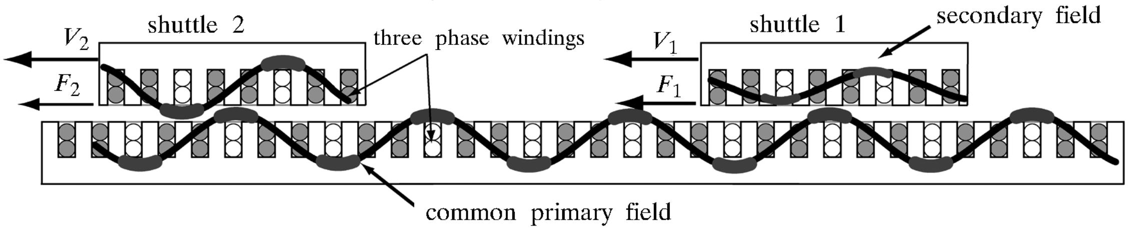

Fig. 1 Principle of the doubly fed longstator linear motor

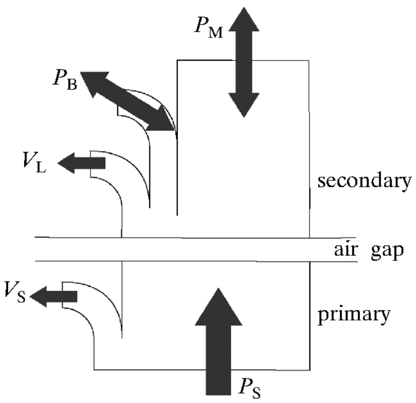

Fig. 2 Energy flow of linear motor

One main advantage of the longstator motor is the possibility of a contact-free energy transfer to 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. This operation of the motor in combination with an on-board energy storage makes overhead lines or contact rails superfluous.

Further studies have shown that the absolute value of the power transferred to the secondary depends on the operating point of the linear motor [2]. The transferred power depends on the motor currents and frequencies of primary and secondary. The energy flow between primary, secondary and on-board power supply (Figure 2) can be controlled by variation of these values. In consideration of the ohmic losses in primary V_S and secondary V_L and the mechanical power need P_M the operating point setting allows even to charge and discharge the energy storage.

3 NBP TEST TRACK

Figure 3.a presents the NBP test track, which was built in 2003. It is realized as a circuit with straight and curved stretches and with a total length about 530 m. The maximum gradients are up to 5.3 % 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 (Figure 3.b), will be operated at the same time. They are designed to drive with a maximum speed of 36 km/h. The length of a shuttle is appr. 3 m. The body's height and width is about 1.2 m. One shuttle has a weight of nearly 1100 kg. With this kind of test vehicles numerous tests will be performed also to optimize the energy management of the whole track.

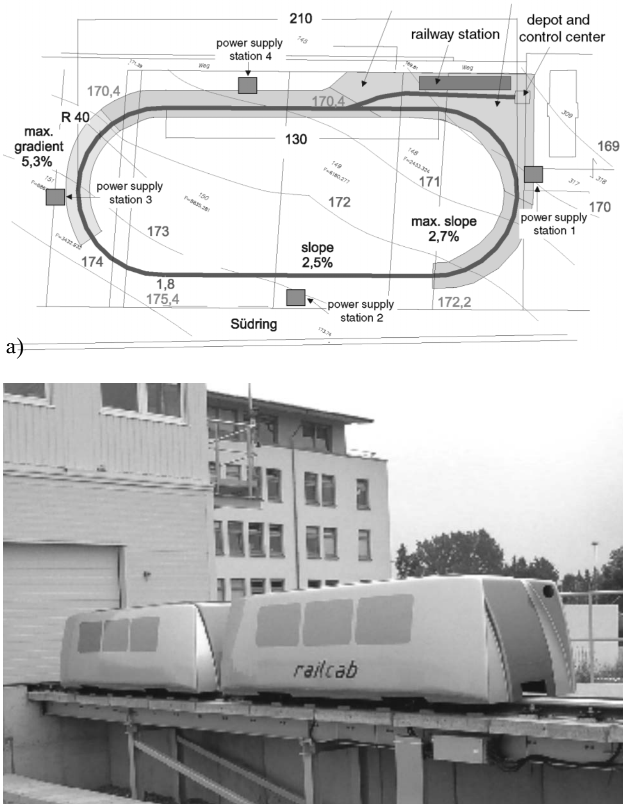

Fig. 3. a) overview of the NBP-test track, b) linear motor driven shuttles on the track

Rendezvous-manoeuvres of several shuttles and their thrust control require high performance control and communication technology.

The modular approach leads to a special electrical design of the primary power supply. The track is divided 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 (Fig. 3.a). 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.

4 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 accelerating a lot of energy can be stored on board. The emerging power peaks can-

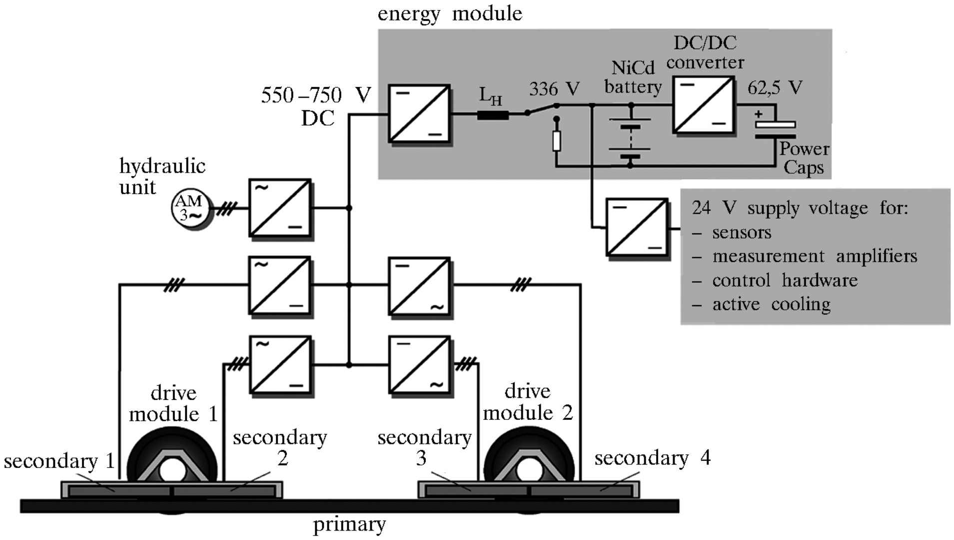

Fig. 4 On-board power supply system

not be stored in capacitors or 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 [3] to increase the maximum short time power.

Figure 4 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. Five converters coupled via a DC link supply the motor secondaries and the hydraulic unit. The DC link voltage is controlled by another converter connecting the energy module with the main circuit. This converter ensures a DC link voltage of 650 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.

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 434 V (charge voltage of the battery).

5 COMMUNICATION AND DRIVE CONTROL STRUCTURE

Figure 5 displays the system structure of the test track and the communication channels between different intelligent units. The whole control structure can be divided into three control modules:

- plant control,
- shuttle drive control,
- primary control.

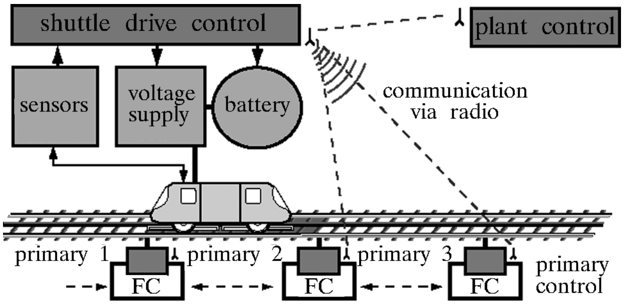

Fig. 5 NBP drive control- and communication-structure

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 [4]. For this type of linear motor the control can be designed fairly similar to conventional field oriented control – in this case on a stator current oriented reference frame [5]. The entire drive control is implemented as a cascaded control structure for longitudinal dynamics, energy management and a separate pitch control which is described in [6].

The shuttle drive control makes use of 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 transferred. 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 respectively 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 current 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 responsible 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.

5 CONCLUSIONS

In this paper the power supply of the longstator linear motor and the concept of the control technology of the NBP test track have been presented. The principle of the doubly fed longstator linear motor, which makes it possible to build up convoys and to transfer energy to the shuttles, has been explained. The presented test track was built to demonstrate the functionality of NBP system and to provide a basis for research and optimization of the automatic control technology.

REFERENCES

[1] J. Lückel, H. Grotstollen, K. P. Jäker, M. Henke, X. Liu, **Mechatronic Design of a Modular Railway Carriage**. AIM, pp. 1020–1025, Atlanta, USA, 1999.

[2] A. Pottharst, H. Grotstollen, **Concept of Contactless Energy Transfer with a Doubly-fed Long Stator Linearmotor**. SPS/IPC/DRIVES, pp. 822–830, Nürnberg, Germany, 2002.

[3] A.-Ch. Rufer, Ravokatrasolofo, **Static Converter for Complementary Energy Storage with Battery and Supercapaitor**. PCIM, Nürnberg, Germany, 1999.

[4] Ketterer, **Automatisierte Inbetriebnahme elektromechanischer, elastisch gekoppelter Bewegungsachsen**. Springer Verlag, Berlin, 1995.

[5] M. Henke, H. Grotstollen, **Modelling and Control of a Longstator-Linearmotor for a Mechatronic Railway Carriage**. IFAC Symp. Mechatronics, pp. 353–357, Darmstadt, 2000.

[6] B. Yang, M. Henke, H. Grostollen, **Pitch Analysis and Control Design for the Linear Motor of a Railway Carriage**, IEEE Conf. IAS2001, pp. 2360-2365, Chicago, USA, 2001.

Koncept napajanja dugačkog statora linearnog motora za novu prijevoznu tehniku – ispitni poligon. Projekt NBP (nova prijevozna tehnika Paderborn) utemeljen je na Sveučilištu Paderborn prije pet godina, a ispitni poligon korišten je za istraživanje željezničkih vozila (u obliku kabine), pogonjenih linearnim motorima. Linearni pogon je dio složenog mehatroničkog sustava i modularne je konstrukcije. Struktura upravljanja tim željezničkim sustavom zasniva se na autonomnom pogonu kabina, koje se točno pozicioniraju individualnim vođenjem snage na priključku.

Napajanje svih sekcija poligona je decentralizirano, tako da se vrijednosti referencija mogu slati direktno od kabina prema lokalnim jedinicama napajanja, koje su distribuirane uzduž poligona.

Ključne riječi: električna vozila, vođenje energetskog sustava, linearni pogoni, upravljanje gibanjem, prijenos električne energije

AUTHORS' ADDRESSES:

Andreas Pottharst
Markus Henke
Horst Grotstollen

University of Paderborn
Institute for Power Electronics and Electrical Drives
D-33095 Paderborn, Germany, Pohlweg 47–49

phone: ++49-5251-605482
fax: ++49-5251-605483
e-mail: pottharst@lea.upb.de
henke@lea.upb.de
grotstollen@lea.upb.de
URL: http://wwwlea.upb.de

Received: 2003–10–20