Radio Based Control of a Linear Motor for the NBP Railway System

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ABSTRACT

In the course of the NBP (Neue Bahntechnik Paderborn) project a testing plant is used for investigations on autonomous railway vehicles (shuttles) driven by linear motors. At the testing plant the linear motors are of the doubly-fed long-stator type which is used to transfer energy to the shuttles. In accordance with the two parts of the linear motor being distributed to the vehicles and the track the drive control hardware consists of different units which are distributed to stationary plants and moving shuttles. Communication between these control units cannot be performed but by radio transmission which is a demanding task because strong realtime requirements of drive control must be fulfilled.
Keywords: Linear drives, motion control, transmission path, radio based synchronization

1. NBP TESTING PLANT

1.1 Test Track

At the University of Paderborn a new railway system NBP (Neue Bahntechnik Paderborn) is under development. The new system is characterized by autonomous shuttles which travel on demand instead of trains travelling in accordance with a fixed schedule. Furthermore the shuttles are driven by linear motors which are of the doubly-fed long-stator type. To make traffic efficient shuttles can form convoys which asks for fast switches without moving parts. Therefore active steering is introduced to the shuttles which are equipped with units for suspension and tilting for better comfort. For investigation of the complex mechatronic system a testing plant in scale 1:2.5 has been built at the University of Paderborn. The test track consists of a circuit with straight and curved stretches having a total length of about 530 m. The gradients are up to 5.3% to demonstrate the great climbing capability of linear motors. Furthermore the test bed includes one switch for investigations on guidance and steering behaviour in this area (Fig. 1).

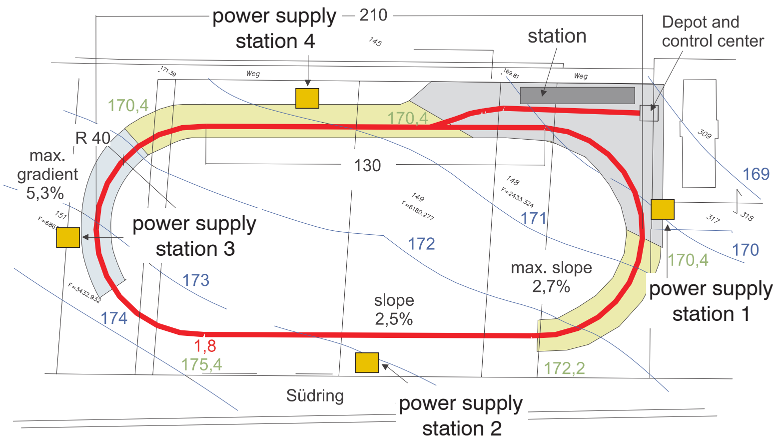

Figure 1: NBP-Test Track

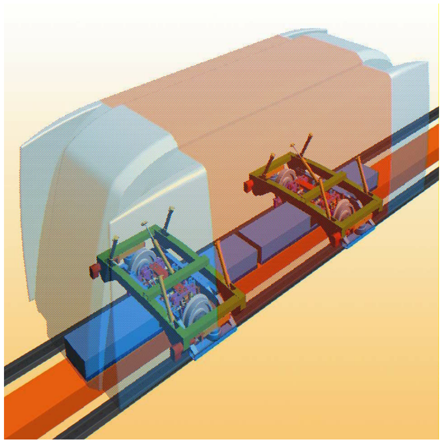

Figure 2: NBP- Shuttle

A maximum of three railway vehicles (Fig. 2), will be operated at the same time with a maximum speed of 36 km/h. The length of a shuttle is appr. 3 m. The body has a height and a width about 1.2 m. One shuttle has a weight of nearly 1100 kg. The above mentioned mechatronic modules [1] are overlaid by a digital information system consisting of several prototyping hardwares which handle different on-line control and communication structures.

1.2 Doubly-fed long-stator linear motor

The doubly-fed linear motor used for driving a shuttle consists of two parts. The primary is installed between the rails and a pair of secondaries is fitted below the undercarriages of each shuttle. The primary generates a travelling magnetic field by means of a three-phase winding. To minimize energy consumption it is divided into segments of appr. 6 m length which are only fed where shuttles are travelling. The converters for every segment are concentrated in four substations distributed along the track (Fig. 1).

The secondaries mounted below the undercarriages also have three-phase windings. By this means the magnetic field of the secondaries can be shifted with regard to the shuttle. Operating shuttles in the asynchronous mode has two important advantages: First, shuttles travelling on the same primary segment are able to drive with different speeds, so relative motion between different vehicles becomes possible. Due to this feature convoys of shuttles can be formed to minimize the wind resistance and the power consumption of shuttles driving to the same destination. Second, by asynchronous operation of the motor energy transmission from the primary to the secondary and to the on-board power supply system of a shuttle becomes possible [3] and neither overhead wires nor contact rails are required.

1.2 Tasks of Drive Control

To achieve a constant thrust force the phase shift between the interacting magnetic fields generated by the primary and the secondary must be constant. Consequently an exact synchronisation of primary and secondary currents has to be realized by the assigned control units which are distributed to the shuttles and the track. So a fast and safe communication structure becomes necessary to admit a high dynamic system.

With regard to shuttle operation control of force is of interest only when shuttles are travelling in a convoy. When shuttles travelling independently speed control is required, and position control becomes necessary when shuttles approach to form a convoy.

2. OVERALL CONTROL AND COMMUNICATION STRUCTURE

The control and communication structure of the test track can be divided into three modules (Fig. 3):

2.1 Plant Control

The plant control, situated at the control center, is used for monitoring the experiments. From here the computers onboard the shuttles and at the track and their associated prototyping hardwares are started, global references for special manoeuvres are generated here and transmitted to the shuttles, parameters significant for control of the plant and for fault diagnostics are received. Communication with the shuttles is performed by means of a Wireless LAN.

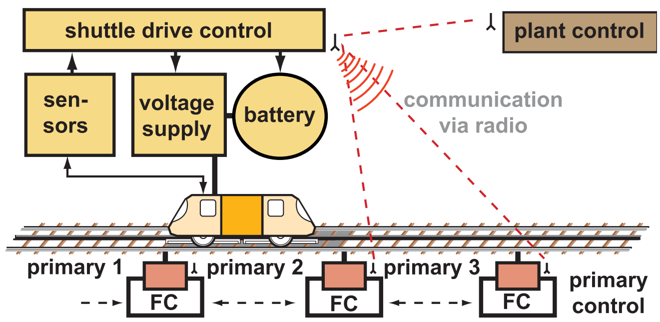

Figure 3: Communication structure

2.2 Shuttle Drive Control

Besides communication with the control center each shuttle has to realize on-line-communication with the power converters feeding the primaries. The actual position of the shuttle and the reference values of stator current's amplitude and frequency have to be transferred. In addition the drive control of a shuttle has to communicate with other shuttles when forming or joining a convoy. The communication channels are realized by radio modems using bi-directional transmissions in the 2.4 GHz ISM band. These modems are linked via serial interfaces with the digital information equipment. Independently of these radio communications high dynamic controllers on board the shuttles are responsible for control of secondary currents, speed and position, respectively.

2.3 Primary control

Depending on the vehicle's position the primary segment on which the shuttle is travelling has to be selected and the current vector of the assigned power converter has to be controlled in accordance with the reference values received from the shuttle's drive control. To ensure continuous transition of the magnetic travelling wave between neighboured primary segments an exact synchronization of the primary current controllers is very important. Therefore the stator power converters are interlinked via field bus (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°.

3. CONTROL STRUCTURE OF LINEAR DRIVE

The control structure of the linear drive used at the NBP testing plant can be seen at Fig. 4. As can be seen from the control scheme the references of the secondary and primary current are established by the shuttle control in dependence of the thrust force reference delivered by the speed and position control. The frequency of the stator current is established depending on the actual speed and the power to be transmitted to the on-board power supply. Due to low repetition rate and great delay caused by radio transmission and synchronisation of primary power converters amplitude and frequency of the primary current cannot be refreshed but every 24 ms. Therefore control of primary current is quite slow and control of force, speed and position must be performed by the shuttle-side current controllers.
For synchronizing the magnetic field of the secondaries the position of the stator field is required. It is calculated from the primary current reference under consideration of the delay time caused by radio transmission. Furthermore the position of the shuttle must be known. It is measured by means of incremental encoders which detect the movement of the wheels, and errors are corrected by evaluating signals of proximity switches when passing markers which are distributed along the track. The actual speed required for speed control is calculated from the change of position.
When a convoy is driving on a segment the primary field is the same for all shuttles. This is why the coordinate system of the motor control is orientated to the stator current vector [2] which is set by a shuttle control serving as master.

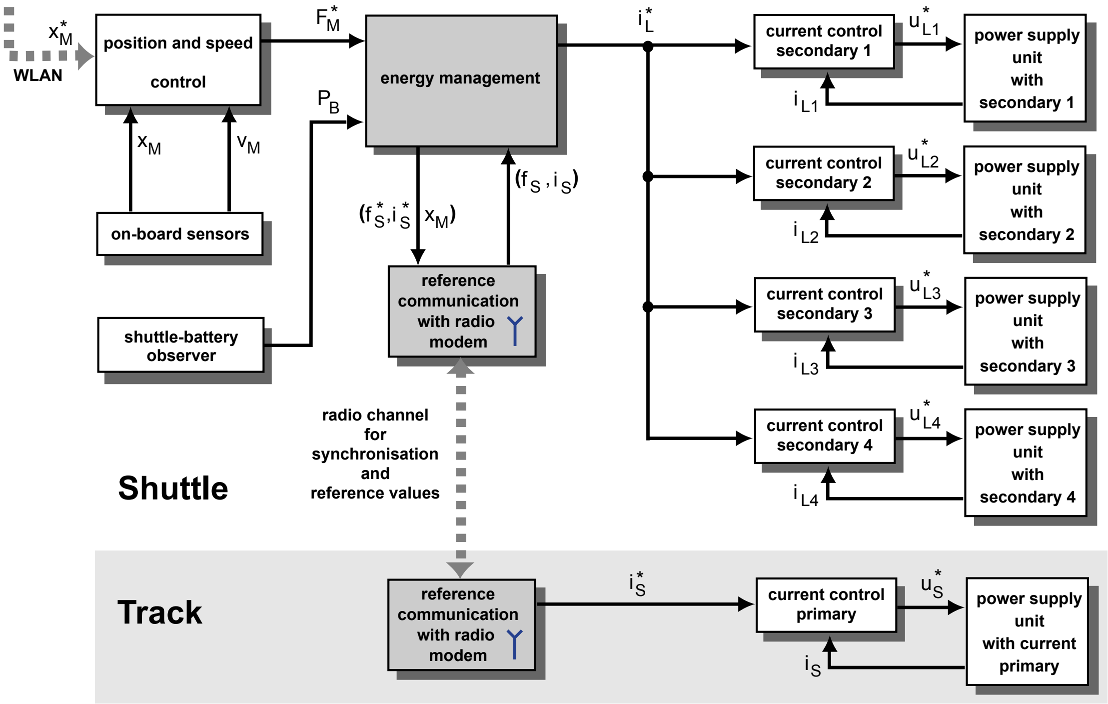

Figure 4: Control structure of the linear motor

The last module to be mentioned is a shuttle-battery observer which estimates the state of charge and determines the power which should be transferred to the battery. This value is applied to the energy management where the reference optimum values for the stator current and frequency are calculated [3] under consideration of the required thrust force. As already mentioned the stator references are transmitted to the current control of the primary to adjust the reference stator field via a synchronized communication channel realized by radio modems using bi-directional transmissions.

4. SYNCHRONIZED RADIO CHANNEL

The synchronization of this radio channel is very important for a save operation of the whole track. On the one hand it is important to know exactly the position of the shuttle to activate the correct primary on which the shuttle is at this very moment. On the other hand the momentary position of the stator field has to be known on the shuttle to calculate the wanted position of the secondary field. If incorrect values are used for this calculation the stator field orientation for the motor control can no longer be guaranteed and in the worst case the shuttle will drive in the wrong direction.
For this technical reasons mechanisms for error detection and synchronization are implemented in the communication system. The transmitter on the shuttle sends the position of the shuttle and the reference values for stator current and frequency encoded in a data record (Fig. 5). This data record consists of 4 data bytes, a startbyte and a stop byte with an error detection consisting of an modulo 256 byte. The transmission of this data record is polled by the track-side receiver by a single byte. The transmission of this polling byte is driven by a timer task and the byte is encoded to enable the receiver on the shuttle to notice transmission interferences. This error detection is necessary to appropriate the current stator values for the energy management in the control structure of the shuttle (Fig. 4).
Driven by the before mentioned timer task also a synchronization process data object (PDO) is sent to all power supplies via CANopen field bus. Driven by this synchronization message the old stator references in the primary control are replaced by new values. In this way a deterministic system behaviour with known dead times becomes possible (Fig. 6) and also the primary controls are synchronized to avoid an angle error by switching the stator field.

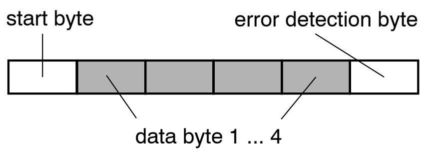

Figure 5: Data record

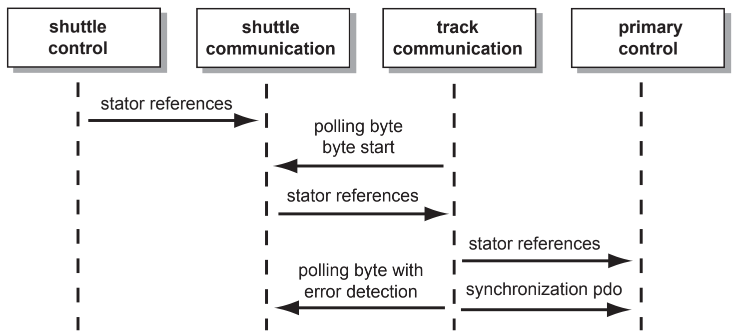

Figure 6: Sequence diagramm

Due to short stator sections distances between the shuttle-side and the track-side communication systems are short. Considering also that electromagnetic disturbances of the linear drive are negligible small [4] best presumptions for a failure-free and save radio communication are existing.

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