PROPULSION AND CONTROL SYSTEM FOR HIGH-SPEED MAGLEV TRAINS

Uwe HENNING
Dr.-Ing. habil
Siemens Verkehrstechnik
Erlangen - Germany

Rainer KNIGGE , Verena FREITAG
Dipl.-Ing. , Dipl.-Ing.
Siemens Verkehrstechnik
Braunschweig - Germany

1. SYNCHRONOUS LONG-STATOR PROPULSION SYSTEM

1.1. Introduction

The synchronous long-stator propulsion system for the TRANSRAPID has proven its operational reliability at the TVE test facility in Emsland in Northern Germany. The concept has been systematically refined for service maturity. The propulsion system envisaged for revenue service is based on the staggered arrangement of motor windings. The motor stator sections on the left- and right-hand sides of the guideway are offset (staggered) relative to each other in the direction of travel. They are fed by separate feeder cable systems which are supplied at both ends from converters in the adjacent substations. The converter system used features state-of-the-art GTO thyristors.

1.2. Propulsion system featuring neutral-point-clamped inverters with GTO thyristors

1.2.1. Converter system

A study of various concepts featuring 4.5 kV, 3 kA GTO thyristors culminated in a design solution based on neutral-point-clamped inverters and output transformers. Fig. 1 shows the block diagram of the converter system which is to be used in future revenue service and produces output voltages of variable magnitude and frequencies of up to 270 Hz. The motor voltage is max. 10 kV (phase-to-phase), the output per converter 14 MVA.

The input converter is fed by rectifier transformers and consists of four 3-phase bridges connected in 12-pulse sequence control. In addition to smoothing reactors and back-up capacitors, the DC link circuit features braking choppers and resistors to absorb the energy generated in braking mode.

Each neutral-point-clamped inverter supplied with two DC link part-voltages essentially comprises four GTO thyristors and six diodes per phase. The output voltage is adjusted by variation of the DC link voltages, while the inverters are operated in the lowest frequency range. Between 0 and 32 Hz, the primary winding of the output transformer serves as a current dividing reactor for parallel connection of the inverters. In the 32 to 270 Hz range, the transformer increases the inverter output voltage to the required motor voltage of 10 kV.

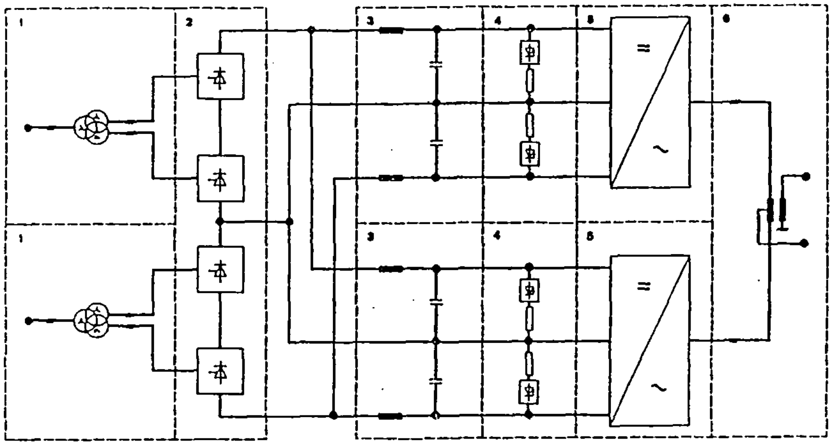

Fig 1: Block diagram of converter system

1.2.2. Test results

To verify the operational reliability of a converter featuring a neutral-point-clamped inverter, a test converter system was set up and tested under simulated revenue service conditions in Erlangen as part of a joint project of ABB and Siemens. The results obtained provide the necessary basic data and knowledge concerning the response and operation of the system [1].

In order to reduce the fundamental frequency of reactive power, the two voltage sources needed for the neutral-point-clamped inverter each comprise two fully controlled rectifier bridges. Fig. 2 shows the control angle curve a_a for the outer rectifier bridges, as well as the control angle curve a_i for the inner bridges as a function of output voltage U_{st} of the current controller. The rectifier bridges always operate in set pairs, i.e. the two outer rectifier bridges are always controlled together while the two inner bridges remain at their maximum control limits, and vice versa.

For sequence control of the reactor bridges, the fundamental frequency of reactive power curve was calculated for the conditions of the test converter as a function of limiting control angle (Fig. 2). The comparison with normal control shows a considerable reduction during the rectifier mode in question (first quadrant), particularly in the low-voltage range.

On the output side, during operation of the neutral-point-clamped inverters on the common output transformer, the phase angles of both inverter voltages are adjusted so that, when the voltage are added up in the output transformer, a motor voltage is obtained with minimum harmonics.

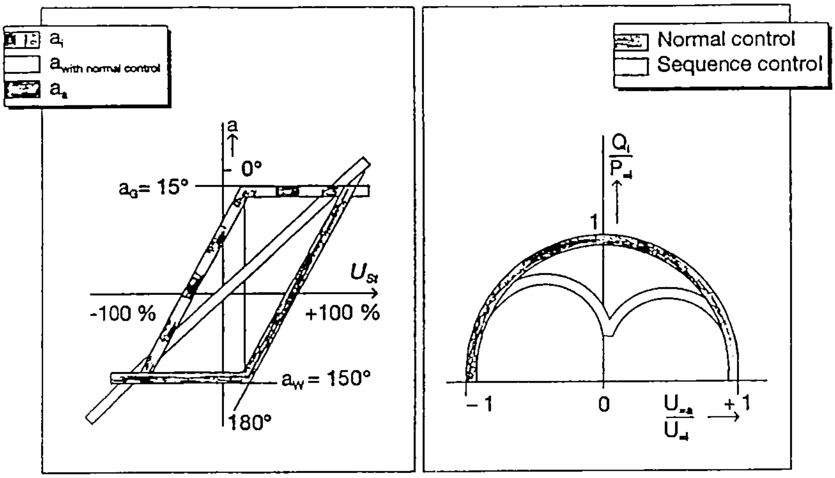

Fig 2: Control curve and fundamental frequency of reactive power for sequence control of rectifier bridges

This is necessary to limit resonant currents in the cable system of the longstator motor. A method was developed so that once the resonant frequencies of the individual feeder sections are established, the phase-shift angle can always be controlled to minimize the magnitude of the resonance-exciting harmonics (Fig. 3).

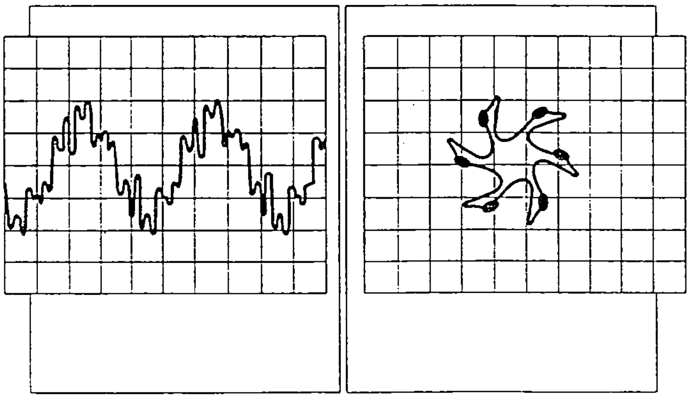

Fig 3: Inverter current at $\gamma = 18.7°$, $f_1 = 240$ Hz, $f_{Res} = 1680$ Hz, $U_d = 2 \times 200$ V, (20 A/T, 1 ms/T)

1.3. Digital drive control

1.3.1. Overview

The digital drive control system (DDC) developed by Siemens in 1989, has proven itself at the TVE test facility in Emsland [1]. The main functions are (Fig. 4): Vehicle position detection, speed control, current control, serial data communication with BLT II operations control system, target braking with reference value generator and constant distance control.

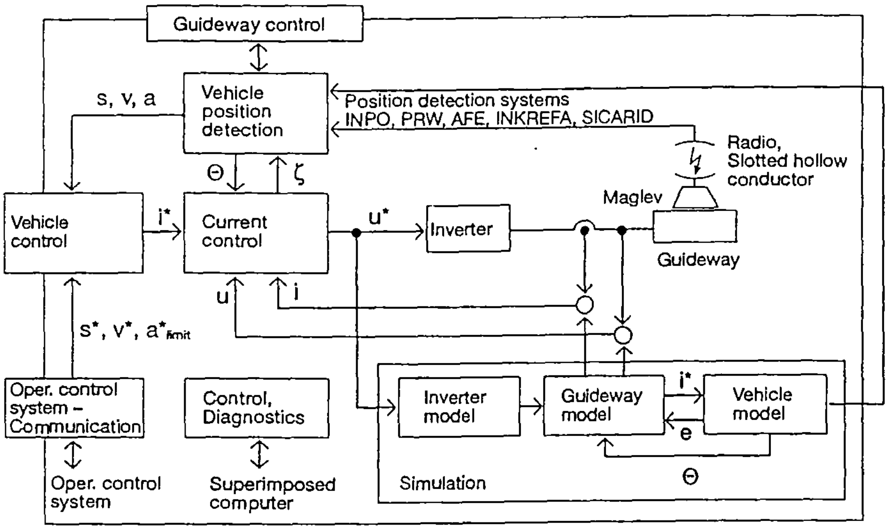

Fig 4: Block diagram of digital drive control

The current control system is based on the principle of field-oriented closed-loop control. To be able to break the current and voltages down as required into components that are parallel and vertical to field orientation, it is necessary to know the angle between motor excitation and the stator (in this case, rotor excitation = the magnetic levitation field of the vehicle). Phase-angle control determines this geometrical, periodic load angle with the aid of a number of measurement methods and also establishes the actual vehicle speed.

The DDC has an enhanced test capability thanks to more accurate inverter simulation, to the inclusion of all switch section parameters, and to the creation of a digital vehicle model including all vehicle position detection and location systems.

DDC is based on the components of the SIMADYN D multi-microcomputer system. The processor modules are designed to perform general open- and closed-loop functions. High-speed current and voltage measurement, current control and setpoint output to the inverter, processing of all vehicle position detection data, as well as phase-angle control and maglev simulation - all these functions are implemented by a special signal processor mudule.

Processor sampling times were selected to meet function requirements. For example, since resonant frequencies of the distributed system (with output transformers, feeder cable and switch section winding) are at approx. 1.5 kHz, a sampling time of 100 μs is needed for current and voltage measurement purposes.

1.3.2. Vehicle control

Vehicle control encompasses the target brake, reference variable generator, and distance-speed control functions.

The target brake constitutes the most significant additional function in the digital drive control system. It enables the maglev to travel over the guideway according to a specified route-speed profile (which makes due allowance for the momentary vehicle status, the position- and-speed-related braking capability of the propulsion system, and the ride quality conditions) and to come safely to a halt at a preappointed destination (Fig. 5).

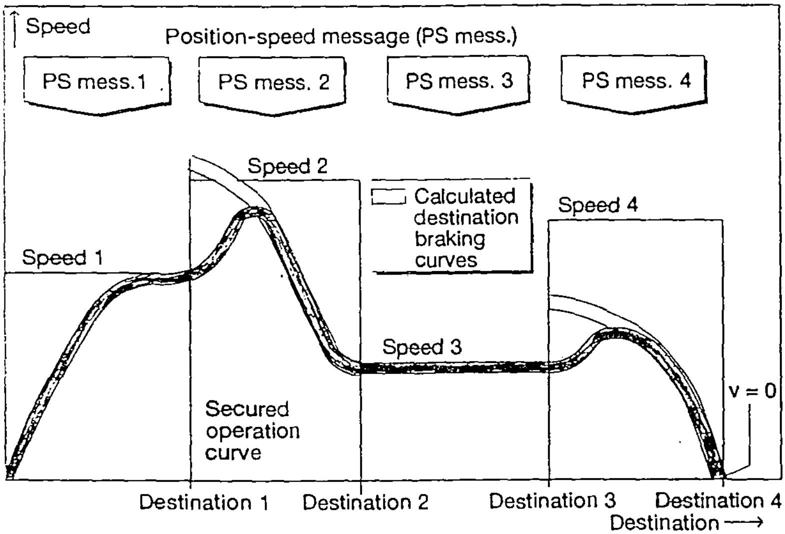

Fig 5: Route-speed profile, target brake curves

1.3.3. Field experience

The functions of the DDC system were demonstrated in high-speed trial runs in mid-December 1989, when record speeds of up to 435 km/h were reached (Fig. 6).

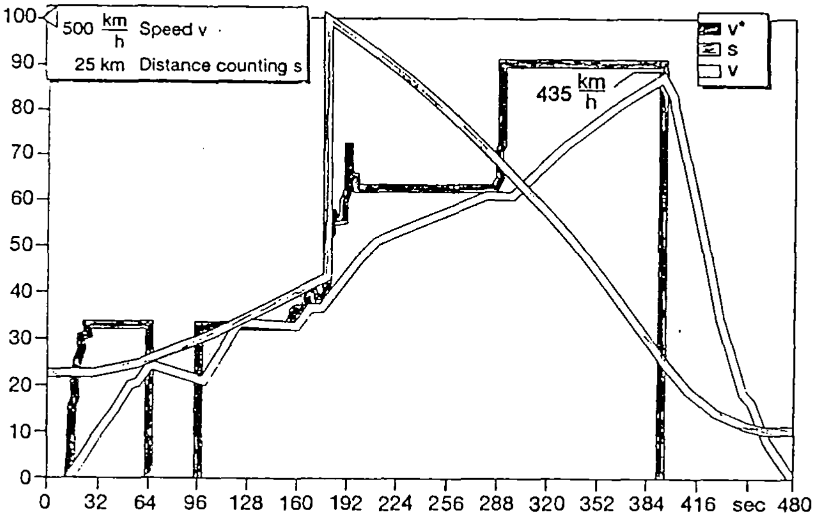

Fig 6: Record run of December 18, 1989

The test runs performed with target braking control showed that the vehicle can be controlled according the setpoints issued by the supervisory level and that preselected destinations can be approached in almost optimum time.

The performance of the DDC system at the TRANSRAPID test facility demonstrates that it is possible and expedient to use a digitally based drive control system for maglev vehicles, as well as the current control system for fundamental frequencies of up to approx. 270 Hz tested with that control system. It has also been proved that, on the basis of the existing configuration, no major problems are to be expected in the development of the system for future applications.

1.4. Outlook

The synchronous long-stator propulsion system for TRANSRAPID has sufficient maturity for revenue service. From a technical standpoint, the basic criteria for the realization of a reference passenger-service line have been satisfied.

2. OPERATIONS CONTROL SYSTEM - MULTIPLE TRAIN OPERATION

2.1. Introduction

The operations control system for high-speed maglev trains encompasses all functions of operational protection, control and management. To verify the operational reliability of these functions, i.e. their interaction and intercommunication, numerous tests have been performed at the TRANSRAPID test facility in Emsland (TVE). For multiple vehicle operation, these functions have been tested under simulated conditions in Braunschweig.

2.2. System Structure

The operations control system comprises mobile, decentral and central components for driverless operation under normal conditions and during disturbances. The safety level, with train-borne equipment and decentralized track installations, guarantees safe operation under all circumstances.

The system, with its many distinct functions, has been subdivided as follows:

BLT II	- current operations control system (TVE)
BLM	- research BLT project for maglev operations control
BLF	- mobile equipment of vehicle control
BLD	- stationary, decentral functional units of vehicle and guideway control
Kom	- communications medium between the BLDs and the BLZ
BLZ	- stationary, central subsystems which are higher ranking to the decentral subsystems

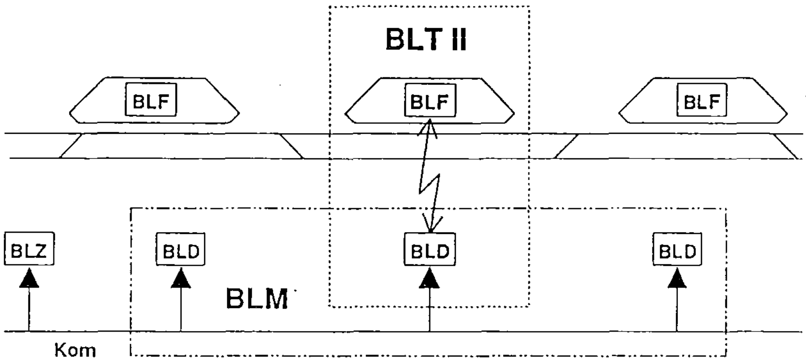

Fig. 7: Components of the operations control system

2.3. Decentral Protection and Control for Multiple Train Operation

The maglev network comprises several lines of up to 30 km in length. These lines are protected and controlled by independent, decentral functional units, the BLDs. As there must be continuous monitoring and protection of trains during their passage through the network, the handover of responsibility for safety from one BLD to the next is of particular significance.

2.3.1. Requirements of Multiple Train Operation

a) Only one train at a time is permitted in each BLD section (protection against collision).

The distribution of BLDs corresponds to the distribution of propulsion units along the guideway and mode of transmission to vehicle. Only one vehicle per section can be provided with propulsion and transmission, a condition also of operations control.

b) Hazard area protection and brake curve monitoring must extend beyond BLD boundaries.

A train which enters a BLD section in which there is a danger area (e.g. a point still unlocked) must never be allowed to cross the brake curve to this hazard area. The actual speed is compared with the brake curve and, in view of the potential danger, the train's speed is reduced in the preceding BLD.

c) Safe operation must be guaranteed even during transmission failure.

Transmission interference or total transmission failure cannot be ruled out.

2.3.2. Functions of Train Transfer

Train acceptance initiation **BLD 1** --> BLD 2

BLD 1 checks whether sufficient track can be reserved in its own area. If this is not the case, BLD 2 is requested to reserve its track for the approaching train.

Train acceptance BLD 1 --> BLD 2

BLD 2 determines whether the incoming request to accept train can be met by checking

- its section for unoccupied state,
- if request is meant for it and
- whether there is a direct connection to BLD 1.

If all 3 conditions can be fulfilled then BLD 2 notifies BLD 1 of acceptance.

Train Transfer Initiation BLD 1 <-- BLD 2

BLD 2 checks whether the train has been fully driven into its section. If this is the case, BLD 1 is informed that its section is no longer occupied.

Train Transfer **BLD 1** <-- BLD 2

BLD 1 checks this incoming information from BLD 2 to ensure that
- the train concerned had in fact been accepted by BLD 2 in the first place, and
- the vehicle identification is correct.

If both requirements can be made then BLD 1 releases its section for the next train.

2.4. Testing under Simulated Conditions

At present, the propulsion system at the TVE test facility permits one-train operation only. To perform tests on multiple train operation would require a longer guideway with additional substations for propulsion control.

Therefore, a simulation of multiple train operation has been provided at Siemens in Braunschweig to test, in particular, the interaction and coordination of systems when employed on a long stretch of line such as from Hamburg to Berlin.

2.4.1. Structure of Test Station

The fundamental components are 3 BLD units, as would be used in passenger operation, together with intercommunication links:

BLD 1	decentral operations control 1
BLD 2	decentral operations control 2
BLD 3	decentral operations control 3
CP16 ring	data transmission channel
NWM	network manager of the CP16 ring

The following operations control equipment has been simulated for the testing of the decentral components during multiple train operation:

BLZ	operations control centre
Pr-Dr	logging printer
OB-Sim	simulation of local operation
ARS/FZ	propulsion system, vehicles and guideway.

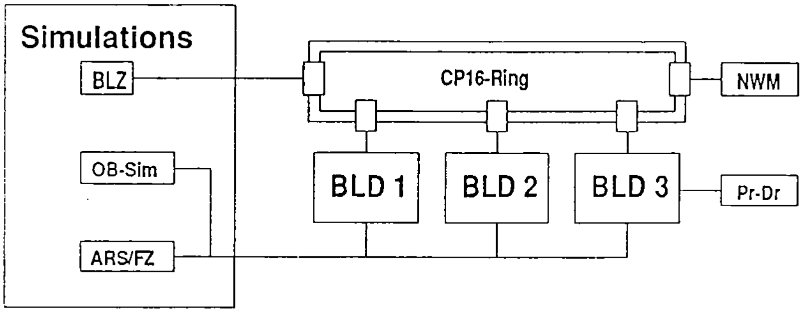

Fig. 8: Components of test station

2.4.2. Safety Requirements

Up to now, 6 different lines have been programmed each of which comprises 3 independent substation sections. As the maglev train passes through each section, it is monitored in turn by the corresponding BLD.

Througout its passage, the train is continuously protected and controlled. At each section, responsibility for safety is transferred from one BLD to the next, a function which is of particular significance.

The safety requirement which are made by the BLDs are:

- only one vehicle at a time is permitted in one BLD section
- hazard area protection and brake curve monitoring must extend beyond BLD bounderies, and
- safe operation has to be guaranteed even during transmission failure.

Each time a vehicle crosses from one BLD section to the next, a series of operational control functions has to be performed: "train acceptance initiation", "train acceptance", "train transfer initiation", and "train transfer".

2.4.3. Simulated Operation

As train proceeds, its movement data is recorded at the test station (Fig. 3: 2 trains on line 1). From the ensuring data evaluation, speed diagrams are produced for each vehicle and from these, the course of travel can be determined.

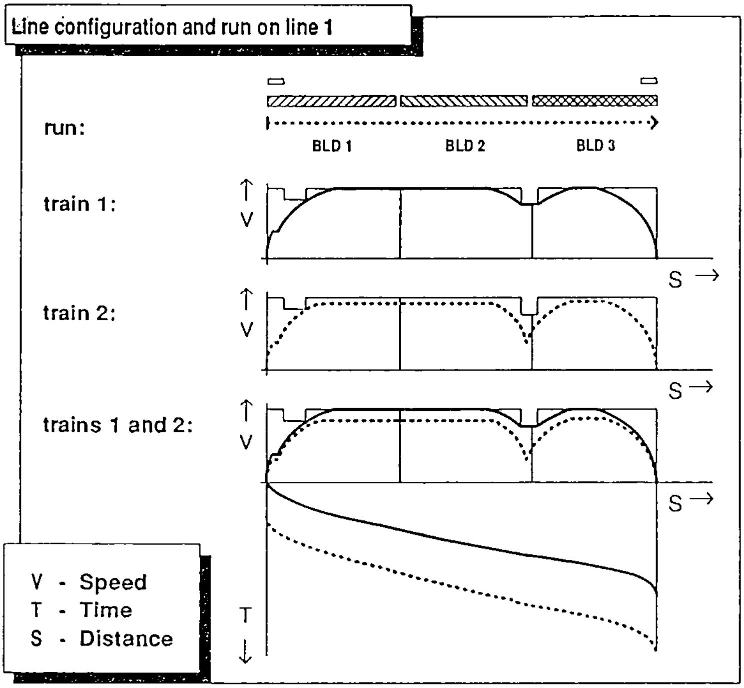

Fig. 9: Line configuration and speed diagrams for two-train operation

With reference to the above, train 1 starts in BLD 1 and travels through BLD 2 to the terminal station of BLD 3; here, train 1 remains. Train 2 follows the first vehicle on the same line: BLD 1-2-3. BLD 2 forces train 2 to stop at the boundary to BLD 3 as BLD 3 is still occupied by train 1. To complete run of train 2, BLD 3 is released by deactivating train 1. Train 2 now picks up speed, travels into BLD 3, stopping at the terminal station.

2.4.4. Test Results

The tests performed under simulated conditions show that the decentral control and protection equipment fulfil the requirements for multiple train operation. By blocking a BLD which is already occupied, collision between trains is ruled out.

These simulated tests have demonstrated proof of the operational reliability of several decentral vehicle controls, i.e. distributed control, protection and monitoring within an information network.

2.5. Summary

To control, protect and monitor vehicles during multiple train operation, many decentral controls are required.

The interaction of these controls, via an information network, has been tested under simulated conditions in the test station at Siemens, Braunschweig.

These tests verify reliability of transfer of responsibility for safety from BLD to BLD.

In the near future, investigations are to be carried out in respect of the interplay of all components of maglev train operation and the resulting operational performance. On the basis of this experience, a forecast will be made on the availability of components and economy of operation in public service.

Bibliography

[1] Henning,U., Friedrich,R., Hochleitner,J., Laber,H., Weller,A., Eikermann,J. and Ruppel,J.: Entwicklungsstand des Langstatorsynchronmotor-Antriebssystems des TRANSRAPID.
Statusseminar Schnellbahnen, Fulda, November 1991 (pp. 18.1...18.23).

[2] Fischer,S., Freitag,V. and Knigge,R.: Betriebsleitsystem für Magnetschnellbahnen - Mehrfahrzeugbetrieb.
Statusseminar Schnellbahnen, Fulda, November 1991 (pp. 19.1...19.17).

[2] Freitag,V.: Betriebsleittechnik für Magnetschnellbahnen in der Erprobung.
Signal und Draht 84 (1992), H.3, S.(wnf).