TRAIN CONTROL SYSTEMS FOR HIGH SPEED RAILS

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Contribution to the State of the Art

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Abstract: The article provides an overview of train control and protection systems used on high-speed railways in given European and Asia-Pacific region countries. Particular attention is paid to currently operated and future means for the transmission of safety-related information to the trains.

Keywords: HSR; Train control systems; Automatic train protection; Cab-signalling; ERTMS; LZB; TVM; BACC; ATC; CTCS.

High-speed rail (HSR) has developed rapidly worldwide in recent years. Over the past 5 years alone, their length has increased by more than a third from 44 thousand km to around 59 thousand km. China has put into operation more than 40 thousand km which was the greatest contribution to this expansion. The HSR operating experience shows that high-speed passenger transportation is a very popular service. According to the International Union of Railways, about 2 billion passengers travel by HSR every year [1], and the number of the passengers is expected to increase.

According to the international classification, the lines newly built to handle speeds above 250 km/h or upgraded conventional lines operating at speeds of more than 200 km/h are considered as HSR [2]. Each country individually determines the maximum speed, which currently does not exceed 350 km/h. The global evidence shows that there has been no regular passenger service with speeds above 350 km/h by now; however, individual test runs have confirmed the possibility of this service.

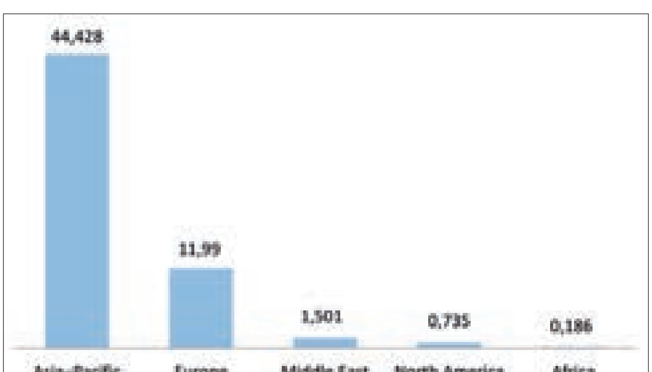

Fig. 1. *Length of the high-speed network in operation by regions (km/h)*

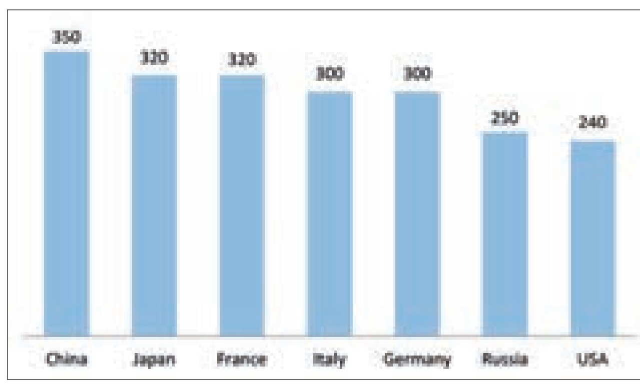

Fig. 2. *Maximum speed of high-speed rail network by country (km/h)*

Increased travel speeds require higher safety level and upgrading of conventional signalling systems. Since the driver is not able to perceive the aspect of trackside signals when running at high speeds, train protection on the HSR is ensured by train separation systems operating without trackside signals.

Despite the communications-based train control systems are widespread, the majority of countries with large HSR network still use track circuits to transmit the information and monitor the occupancy of the track and the integrity of trains.

For example, the TVM train control system deployed on French HSR is based on track circuits. A line equipped with this system is divided into blocks that are 1500 to 2000 m long. Based on information received from the trackside equipment, the onboard computer continuously calculates the braking curve for each block depending on the length, weight and braking capabilities of the train. If a train enters the occupied block, its speed is limited to 30 km/h, and if speed reaches 35 km/h, the train is emergency-braked. The TVM system is backed up by an intermittent cab-signalling system in some areas.

A similar approach is applied on HRS in Japan, where the ATC system is implemented. This system sends audio frequency signals to the track circuits, ensuring the transmission of information about speed limits for each track section to the locomotive. After receiving these signals, the current speed of the train is compared with the maximum permissible speed for the section, and if it exceeds, the train is emergency-stopped. As opposed to the French TVM system, the length of the block is about 3000 m. One block comprises two track circuits. An improved system with digital codes (DS-ATC) is being deployed on newly constructed HSR sections.

As for Italy, lines designed for speeds up to 200 km/h are equipped with the national BACC system based on coded track circuits and cab-signalling system that displays the aspects of the trackside signals. The system makes it possible to continuously monitor the train speed and calculate the braking curve. In BACC system, a block of the open line consists of 4-5 track circuits that are on average 1350 m long. HSR designed for speeds up to 300 km/h are equipped with signal-free ERTMS level 2 that operates without overlaying with other systems. Only trains equipped with the ERTMS operate on such lines.

Fig. 3. *Types of European train control systems*

Cable loop is the least used means for continuous transmission of signal aspects to the train, since, compared to track circuits, the loop is quite damageable and its installation and maintenance costs are higher. Cable loops are used mainly in Germany, Austria and Spain (LZB system) [3].

The LZB system is a computer-aided continuous cab-signalling system for HSR with speeds up to 300 km/h. It is overlaid onto the national signalling system. Train movements on the section are controlled by LZB control centre. It stores data about the section and receives the information about vacant blocks and the switch positions coming from interlocking, as well as the data about current train position and braking capabilities coming from the trains. Based on this data, the distance to a point ahead where the speed is to be changed is calculated upon which the information about maximum permissible speed on the section, the distance to an obstacle, etc. are transmitted to the train via the loop. The LZB cable loops are crossed every 100 m, which allows train position and speed to be determined by counting the phase changes by means of onboard equipment as the train passes over the crossings. Track occupancy/vacancy is monitored by interlocking systems with the aid of track circuits or axle counters. The LZB system is also backed up by intermittent cab-signalling.

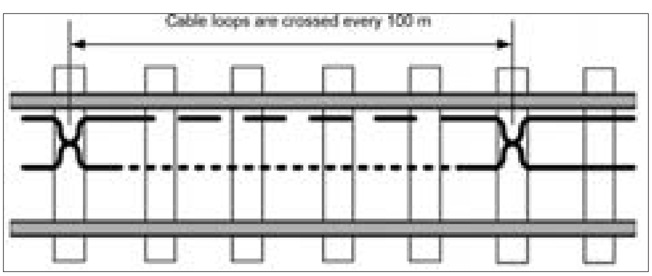

Fig. 4. *LZB cable loop*

In order to ensure interoperability within the European Union, a communication-based ETCS/ERTMS was developed. There are three ETCS/ERTMS levels. The ETCS level 2 is the most applicable system for HSR in Europe, since ETCS level 1 is considered to be unreliable for speeds above 160 km/h. Level 2 implies that train movements are controlled via radio communication (GSM-R standard). Positioning of the train is based on balises, while the track section occupation status is detected with the help of track circuits or axle counters. Level 3 combines the functions of the previous level and onboard train integrity control. This level is under development and is not yet widespread on main railway lines.

The main component of the ETCS/ERTMS is the radio block center (RBC) that controls all vehicles in controlled area and issues movement authorities via GSM-R channels, taking into account the current train situation, permanent and temporary speed restrictions, track profile and braking capabilities. At the same time, the trains transmit the information about their current position and speed to the RBC via a radio channel.

ETCS/ERTMS level 2 and 3 implies using the national onboard protection unit in addition to the European Vital Computer (EVC) in order to ensure interoperability with the national signalling trackside equipment [4].

The ERTMS level 2 is currently being rolled out on HSR not only in Europe, but also in other regions around the world. Based on the technologies used in this system, the Chinese train control system (CTCS) was designed. Similar to the ETCS/ERTMS, there are three levels of CTCS application.

The lines designed for speeds of 200-250 km/h are equipped with CTCS-2, where track circuits are used to control the section occupancy status and transmit information to the train which is similar to TVM system. The CTCS-3 is used for lines which allow speeds above 250 km/h. The main means for transmitting the information to the train is a GSM-R digital radio channel. CTCS levels 2 and 3 include redundant systems, for example, track circuits and active balises are used as a redundant system to CTCS-3.

Another level of the CTCS (CTCS-4) is under development and is considered as a promising one for a new generation system. It involves such features as moving blocks, an integrated navigation module based on the data from the BeiDou system and a digital map for high-precision positioning, as well as the new types of wireless communications (LTE-R and 5G) for safety-related information exchange between the train and the RBC [5].

As regards to Russian HSR it is planned to use the Russian Train Control System (RTCS). The RTCS is designed as a hybrid control system and includes a signal-free train separation system (cab-signalling system) for open lines, an IXL for stations, RBC and a digital radio communication system.

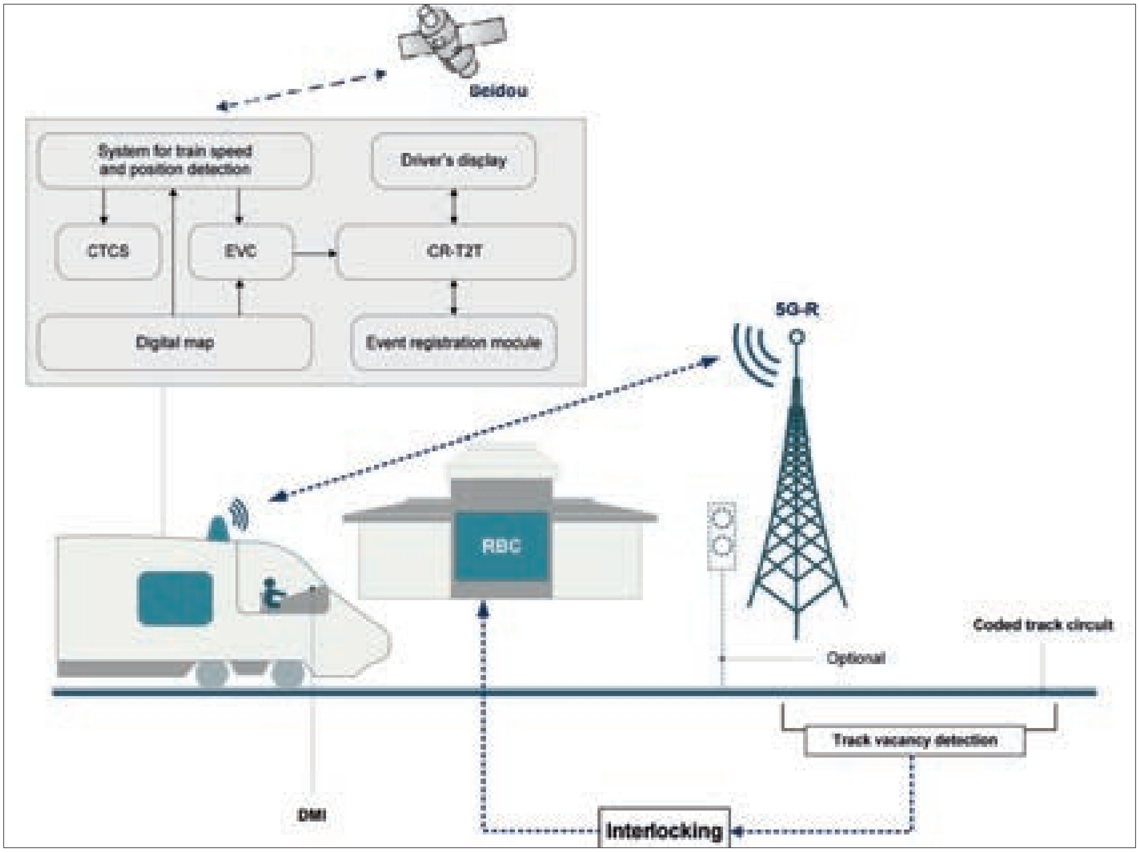

Fig. 5. *CTCS-4 architecture*

RTCS is a dual channel system and enables the regulation of train movements using data received by the train from both conventional block systems via track circuits (ALSN and ALS-EN codes), and the RBC via a radio channel (permitted speed or stopping point).

An important difference between RTCS and ETCS/ERTMS is that the Russian solution uses a single onboard protection unit, which simultaneously communicates with track circuit equipment and the RBC. By comparing the information received via the radio channel with the information received via the track circuit, the onboard equipment builds a braking curve. This approach creates an additional control loop and allows for the implementation of a multi-level protection concept.

If there is no information transmitted to the train via the radio channel, the train does not stop. In this case, the train operates using conventional train control system (automatic cab-signalling). After establishing a stable radio signal, the train automatically continues to be controlled by communication-based train control system along with conventional one.

The train position is detected based on GNSS data and onboard digital maps that are the main source of information about infrastructure facilities when making decisions related to safe train operation.

In order to increase the reliability of the RTCS operation, a new extended audio frequency track circuit (750 m) was designed. This decision is due to the lack of time for the locomotive operating at high speeds to correctly receive information from a standard audio frequency track circuit.

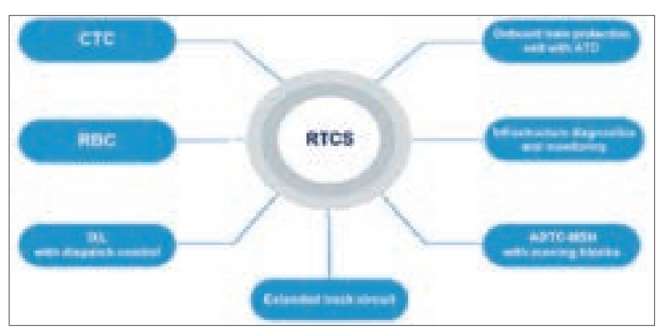

Fig. 6. *RTCS subsystem composition*

It should also be noted that the RTCS includes all the components necessary to implement the moving block concept and the ATO.

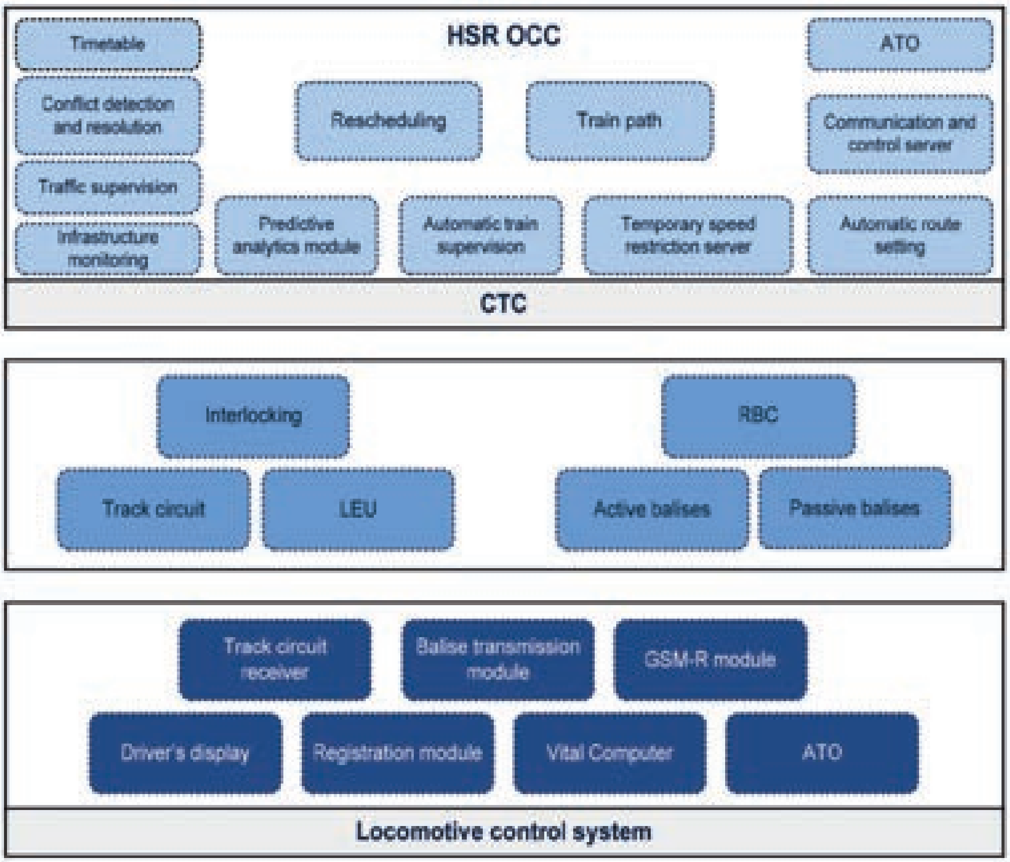

Fig. 7. *Traffic management system for HSR*

The signalling system is an element of the integrated traffic management system for HSR implying that the train traffic on HSR is controlled from the operations control center (OCC). The OCC has the full range of tools to regulate train movements on HSR. In particular, it ensures automatic route setting, real-time supervision, conflict detection and resolution, rescheduling, transmission of updated timetable and information about speed restrictions to the onboard ATO module. The main components of the integrated traffic management system for HSR are shown in Fig.7.

This review shows that modern train control and protection systems for HSR are characterized by individual adaptation of conventional signalling systems in terms of equipment related to interlocking, automatic blocking, cab-signalling, communication. Redundancy of the signalling system components is the basis for achieving high safety level. Therefore the most common train control system for HSR in the world is the one with double control configuration which uses radio communication and a track circuit along with, in some cases, additional redundancy components such as active balises. Dual standard approach additionally provides interoperability with mainlines.

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