WHAT IS COMMUNICATION-BASED TRAIN CONTROL?

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This article addresses various types of traditional train control systems relative to train location, speed determination, and enforcement, and compares these functions to a communication-based train control (CBTC) system.

Communication-Based Train Control

In today's railway industry, there are many different types of train control systems. The principal intent of a train control system is to prevent collisions when trains are traveling on the same track, either in the same direction (trains following one another) or in the opposite direction (two trains

Digital Track Circuits for Train Detection and Cab Signaling

moving toward each other). These systems also permit safe movement of trains as they cross from one track to another.

Early train control systems were very simplistic in architecture. As train technology and operation evolved over time, these control systems grew to have more and more complex architectures. The latest architecture is known as CBTC. As will be discussed, CBTC uses bidirectional radio frequency (RF) data communication between the trains and control locations distributed along the tracks (wayside).

Where Is the Train?

Various types of train control systems have a common ingredient: the location of the trains must be known by the system at some level of granularity.

To appreciate the concept of CBTC system, one must first understand some of the concepts of traditional train control systems.

Traditional Train Control Systems

The use of a track circuit to determine the location of a train is called waysidecentric. Waysidecentric means that there are devices located near the rails that are employed to detect the presence of trains.

Wayside Signal Control

A simple but safe train control system can be built using track circuits and wayside signals (similar to traffic light signals). Figure 1

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THE ATS STATION IS A MEANS OF MONITORING AND CONTROLLING THE SYSTEM AT A SPECIFIC WAYSIDE LOCATION.

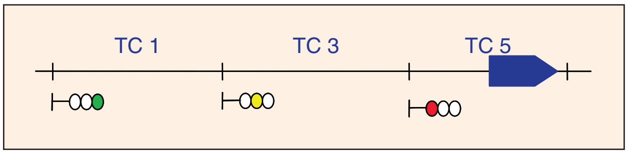

FIGURE 1 Three-aspect signaling system.

illustrates this architecture. If track circuit TC5 is occupied (shunted by a train), the signal at the entrance to TC5 displays a red aspect. If block TC5 is occupied and TC3 is unoccupied, the entrance signal to TC3 displays an yellow aspect. If TC3 and TC1 are both unoccupied, the entrance signal to TC1 displays a green aspect. These signals are separated by the train's safe braking distance (SBD), which is calculated and set at a sufficient length for a train to stop safely from the maximum operating speed specified for the track section.

The train driver knows that a green aspect means two blocks (or at least twice SBD) are clear ahead of the signal. An yellow aspect means one block (at least SBD) is clear ahead of the signal. A red aspect means the block ahead has a train occupying the track circuit. The track circuit permits a train control system to be independent of timetables.

The systems that use wayside track circuits to determine the location of trains have become known as fixed block (FB) systems, i.e., the blocks cannot move. The wayside logic does not know the exact location of the train in the track circuit, just that the train is located somewhere in the circuit. This is sometimes called the granularity of train location, as mentioned previously.

Signal Enforcement with Cab Signaling

As train control systems evolved, electronic cab signal equipment was put on board the train. The track circuit was now used for train detection and cab signaling. The track circuit transmitted coded energy in the rails to display continuous signal aspect information (and later speed information) to the driver. The coded energy is communicated to the train's onboard equipment by pickup antenna coils located in front of the lead axle of the train. The pickup coils convert the coded energy of the track circuit into coded voltage existing across the pickup coils, which is then used by the onboard cab-signaling equipment.

Cab-signaling systems such as these no longer required the driver to remember the signal aspect once the train passed the entrance of the track circuit. The first system required the driver to acknowledge a less-permissive aspect than green. If the acknowledgment didn't occur in 8 s or less, the train was put into full-service braking by the onboard cab-signaling equipment.

Speed Enforcement Cab Signaling (Step Speed)

The next evolution in cab signaling was to remove the majority of wayside signals (typically, most of the automatic or ABS signals can be removed). This is because the coded information of the track circuit was decoded as permitted speed, eliminating the need to have spacing signals between interlocking. To enforce the permitted speed, a new device was developed that performed brake assurance (BA). The BA device measured the effective braking force of the train using the principle of an initial accelerometer (sometimes called a slosh tube). The first slosh tubes were u-shaped and contained mercury, which conducts electricity. If the train was braking at a specific rate or greater, this caused the mercury to move up in the glass tube and come into contact with a silver contact button inside the tube. The contact being immersed in the mercury completed an electric circuit, indicating to the onboard cab signal equipment that the train was braking; thus, a brake application do not have to be forced.

Distance-to-Go Speed Enforcement Cab Signaling (Profile Based)

The next evolution of cab signaling was the use of digital track circuits for both train detection and cab signaling. The use of binary frequency-shift keying (BFSK) to modulate the coded energy of the track circuit permitted much more information to be transmitted to the train. This ability resulted in the use of a profile or distance-to-go system to enforce speed (Figure 2).

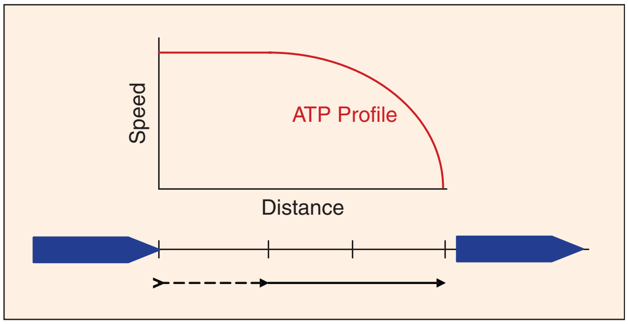

FIGURE 2 Automatic train protection (ATP) with distance-to-go profile system.

The wayside brain, knowing the location of all trains via track circuits, can generate coded messages to each track circuit. This information contains the permitted line speed, the target speed for the train, and the distance-to-go to the target speed. Using this information, the train's onboard equipment calculates the speed–distance profile for the train to follow. In addition, a track map database with grade, curvature, station location, and civil speed limit information is stored within each train's cab-signaling equipment. The train knows which track circuit it is in via a unique ID of the cab-signaling information. The cab-signaling equipment then uses the track map database to calculate the accurate speed–distance profile.

Interlocking Functions

As stated earlier, another function of a train control system is to ensure safe movement of a train from one track to another. The term interlocking was coined in the early days of train control systems with the Saxby-Farmer mechanical interlocking machine.

This device mechanically interlocked the movement of switch machines and wayside signals, e.g., signals must be made to stop before a switch machine can be moved, and signals could not be cleared until the switch machines are locked in the proper position. With the invention of track circuit, train location was integrated into the Saxby-Farmer interlocking machine (Figure 3).

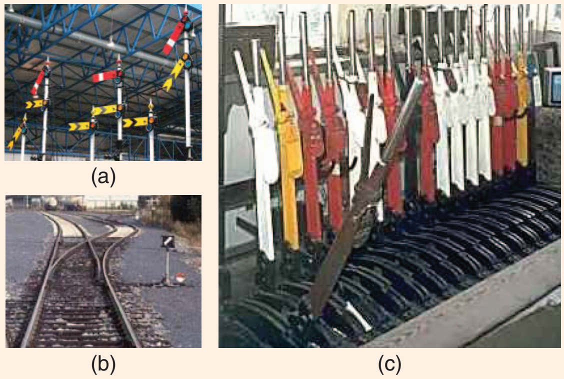

FIGURE 3 Saxby-Farmer mechanical interlocking machine.

As time progressed, these purely mechanical devices were replaced with electromechanical devices and then all-relay devices. Today, computers are frequently used to implement the safety functions of interlocking.

Independent of the signaling architecture (e.g., CBTC or FB), an interlocking must provide certain vital functions, which include approach locking, route locking, detector locking, direction (traffic) locking, etc. These functions ensure that switches cannot be moved under a train and head-on collisions do not occur.

- Approach locking provides for locking of all switches within a route that is governed by a clear signal, prevents the clearing of signals for opposing or conflicting routes when a cleared signal is set to stop and a train is closer than the SBD from that signal, and prevents simultaneous clearing of two opposing signals within an interlocking.
- Route locking (within an interlocking) prevents movement of a track switch before the train enters the route, prevents opposing moves within interlocking, and provides travel direction outside interlocking where traffic is not warranted.
- Detector locking (within interlocking limits) prevents movement of a track switch under a train. Detector locking is in effect when any track circuit containing switches is occupied.
- Direction locking establishes and locks the direction of movement between interlockings. Direction locking prevents the setting of opposing routes into a section of track between interlockings.
- Switches remain electrically locked until this locking is released. Switch locking is only released when applicable approach locking, time locking, route locking, and detector locking are previously released.

To implement these vital functions, train location data is required. In a traditional FB system, track circuits (and/or axle counters) are used to determine the location and direction of a train. Typically, today's CBTC systems are required to provide a backup train-detection system to allow for safe operation of both CBTC trains and non-CBTC trains. These non-CBTC trains cannot communicate their position, and therefore, the system design must rely on a simplified train-detection method. This simplified train-detection method typically utilizes axle counters similar to track circuits of an FB system. These axle counterblocks tend to be much longer than the track-circuit block of an FB system, where the track-circuit length determines the headway or number of trains allowed in a certain area of track.

Train Location with CBTC

The goal of a CBTC system is the same as the traditional system, e.g., safe train separation; however, it has also the challenge of minimizing the amount of wayside and trackside equipment. This means elimination of traditional train-detection devices, i.e., track circuits. With the elimination of track circuits, CBTC systems' communication between the train and wayside must be accomplished by other means than a track circuit.

Vehiclecentric Train Detection

Today's CBTC systems are vehiclecentric systems, where the method of determining the location of the CBTC train is to have the CBTC train (or vehicle) itself; determine its location, direction, and speed; and report this information to wayside equipment.

Some of the devices that are employed by a vehicle to determine its location on the rails include tachometers, accelerometers, gyroscopes, global positioning system (GPS), transponders (or tags), radar, lasers, loop transpositions and digital track maps. Different manufacturers of train-control systems employ different combinations of these devices for train location.

In general, the train has to initialize its location (using tags and/or GPS) on the rails and remember its location and direction as it traverses the line (using track map, tachometer, radar, laser, loop transposition, accelerometer, and/or gyroscope info).

CBTC Interlocking Functions

In a CBTC system (vehiclecentric), each CBTC train's position is communicated to a computer called a zone controller. The CBTC system ensures that the functions of approach, route, traffic, and switch locking are implemented. CBTC systems can implement the interlocking functions in two ways: the first is by having separate devices, i.e., one device for the interlocking function (interlocking controller) and another for CBTC safe train separation (zone controller). The second is to have the interlocking function to be designed into the zone controller. The majority of CBTC systems follow the first method, i.e., using a separate interlocking controller and zone controller.

With the zone controller interfaced to the interlocking controller when required, the zone controller can override specific functions of the interlocking controller. For example, the interlocking controller will not permit two trains in one axle counterblock. However, for CBTC trains, having two trains in one axle counterblock is safe as long as these trains are separated by SBD. In such a case, the zone controller overrides the interlocking controller, permitting two CBTC trains to be in the same axle counterblock.

What Keeps Trains Safely Separated?

The majority of CBTC systems require each CBTC train to communicate its location to a zone controller. This train location information is conveyed to the zone controller via a data communication system (DCS) using both wireless and wired Ethernet. Through these communications, the zone controller knows the location of all CBTC trains within its control area. There are three control methods employed by the various system suppliers to keep the CBTC trains safely separated.

The first method has the zone controller transmitting specific information to all CBTC trains (simulcast transmission) in its control area. This information includes the location of all trains in the control area, all switch positions, all signal aspects, etc. Each CBTC train then calculates its safe movement limit and speed profile using this information.

The second method has the zone controller communicating to each CBTC train its specific speed requirement. The onboard equipment then follows this speed requirement by controlling the propulsion/braking of the train. This technique reduces the computing requirements for the vehicle's onboard equipment.

In the third method (which is the most commonly used today), the zone controller carries on or conducts individual RF dialogs with each CBTC train and issues a movement authority to each train based on where other trains are in the zone controller's area, as well as switch positions, station stops, etc. A movement authority includes a physical track point or limit, which the train's front end cannot proceed beyond. Under this method, each CBTC train constantly calculates a safe speed/distance profile and moves at or below this profile to the end of its authority.

Movement Authorities with CBTC

The zone controller can employ three techniques of determining the physical separation of CBTC trains in its control area. The first technique uses virtual blocks. The second technique uses moving blocks. The third technique uses a combination of virtual and moving blocks.

Virtual blocks are a software equivalent of having physical track circuits separating trains in an FB train control system. Each virtual block has a specific length (defined in the memory of the zone controller) determined by the headway requirements of the system. Movement authorities are given to the exit of each individual virtual block only. In general, just as actual signal blocks would be laid out, virtual blocks are shorter in length near stations with longer length virtual blocks between stations.

Moving blocks are equivalent to giving the following CBTC train a movement authority up to the exact rear-end location of the lead CBTC train. As the lead CBTC train moves forward, given the movement authority, the following CBTC train is advanced in each communication cycle by and from the zone controller.

The combination of virtual and moving block movement authorities can be very effective in train operation. The virtual blocks are located between stations, with the moving blocks entering, within, and leaving the stations.

CBTC System with Non-CBTC Trains

If non-CBTC trains are to operate under signal control on the same trackage as CBTC trains, then a backup signaling system must be employed. The non-CBTC trains are controlled by traditional means using wayside signals and track circuits or axle counters for train location. Some systems not equipped with standard physical track circuits, and signals instead employ devices called axle counters to indicate track occupancy. An axle counter system has axle counterheads attached at the base of the rail at the entrance and exit of a length of track defined as a train-detection block. Once an equal number of axles of a non-CBTC train are counted into and out of a particular train-detection block, the block is declared unoccupied.

The zone controller safely keeps CBTC trains separated via movement authorities. If non-CBTC trains are operating on the system, the zone controller uses train location information from the backup system to track non-CBTC trains through the system.

When CBTC and non-CBTC trains are running concurrently, the track circuits (or axle counters) of the backup system communicate the location of non-CBTC trains operating on the line to the zone controller. Using this information, the zone controller issues movement authorities to CBTC trains to stop at specific locations defined by the boundaries of the backup track circuits. Note: line capacity may be significantly decreased if non-CBTC trains and CBTC trains must run on the line at the same time.

Characteristics of the First CBTC System

One of the first CBTC systems to be put into revenue service was Aide a la Conduite, a l'Exploition et a la Maintenance (SACEM). This system was an overlay to an existing wayside signal train control system that was deployed in France on an inner-city Paris Metro Line in the early 1980s.

The SACEM system (Figure 4) required an architecture that permitted equipped (CBTC) trains and nonequipped (non-CBTC) trains to safely traverse the same line. The existing interlockings, which employed track circuits and wayside signals, controlled non-CBTC trains, and CBTC trains, were controlled by the SACEM's zone controller. The bidirectional communication between the CBTC trains and zone controller was accomplished using wayside-transposed loops, with carrier frequencies ranging between 20 and 80 kHz. These transposed loops were independent of track circuits.

The SACEM zone controller interfaced with the traditional interlocking system. The existing interlockings performed the vital functions listed earlier for all the nonequipped and CBTC trains operating on the system. The zone controller overrode specific functions of the traditional interlocking for the CBTC trains. For example, a CBTC train was given permission to enter an occupied block (a special aspect was illuminated at each wayside signal) and profiled to a stopping point behind the leading train. This type of CBTC overlay operation increased the capacity of the traditional wayside signaling system.

Today, a majority of new CBTC projects include a backup signaling system of one of the varieties discussed earlier. This requirement usually leads to a CBTC system architecture that has the interlocking functions implemented in a separate computer that is interfaced to the zone controller.

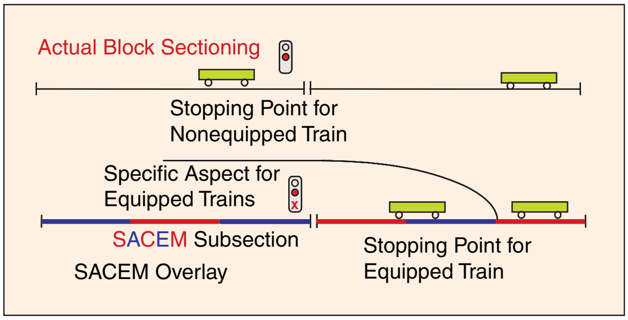

FIGURE 4 SACEM overlaid on existing fixed block signaling system.

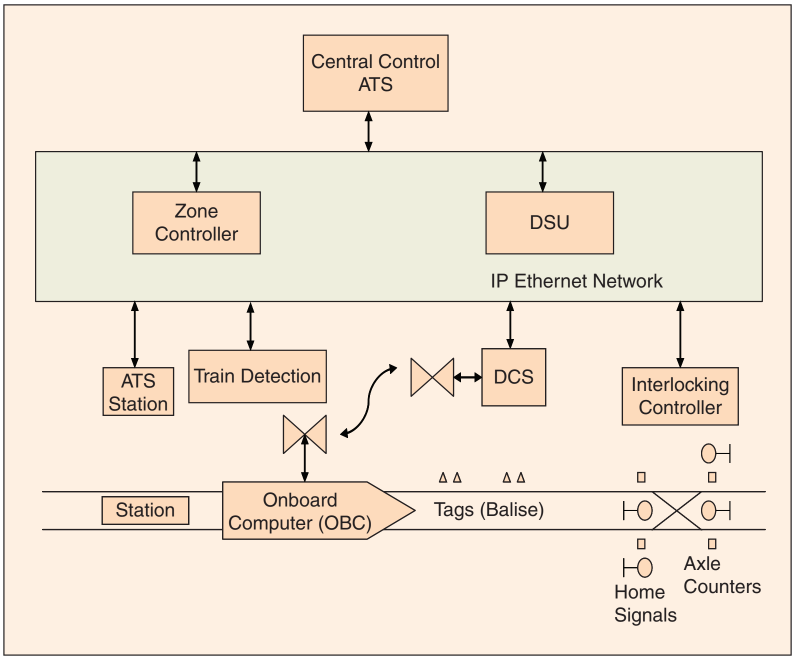

FIGURE 5 Simplified block diagram of a CBTC system.

Typical CBTC Architecture

A simplified architecture for a CBTC system is shown in Figure 5. The interlocking controller performs the vital interlocking functions. Axle counters are used instead of track circuits for train detection of non-CBTC trains. The safe separation of non-CBTC trains is via wayside signals. Central control automatic train supervision (ATS) permits the dispatcher to monitor the entire system and issue commands manually or automatically, to change the routing, performance, and station dwell times of trains according to an operation schedule. The ATS also may have a finer resolution as to where CBTC trains are located at all times.

The ATS station is a means of monitoring and controlling the system at a specific wayside location (most commonly, a station location). The DCS is a wired and wireless Ethernet system that permits bidirectional communications between all devices on the system network. To ensure that all CBTC trains have the latest version of the track map, the data storage unit (DSU) is used to check each CBTC train. Wayside-mounted tags are located throughout the system and are used by the train's OBC for localization, wheel-wear calibration, and to minimize accumulated errors with position/location. These devices are all common devices of today's CBTC system.

Author Information

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