FEBIS: Communication-based electronically controlled brake

by
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Introduction
The system FEBIS (Freight Electronic Brake and Information System) is being developed within a DB/SNCF co-operation. This research and development activity has been assigned to ALSTOM – SAB WABCO Consortium, known as SWAT. A major development target is to realize an interoperability specification for an open communication system on the basis of which various applications can be implemented and the electronically controlled brake is put into action as primary application. With the electronically controlled brake is intended to be technically possible to run longer trains (up to 2250 m) in Europe too and thus to reduce the longitudinal compressive forces through simultaneous braking and improve the braking characteristics of freight trains in particular.

1 The limits of conventional pneumatics
With the indirectly acting air brake the target brake value can only propagate as a pressure wave in the main brake pipe at 250-280 m/s. This results in a time lag for the response of the last distributor valve in the train unit, the propagation time. Because of the air outlet only available at the driver's brake valve, the gradient of the pressure reduction also gets flatter towards the end of the train, so that the brake force demanded can only build up there with a time lag.

1.1 Train length
With increasing train length
- the longitudinal compressive forces in the train increase, since the rear section of the train which is braked later and more weakly, will buff onto the front section. There is danger of derailing and damage to the buffing and draw gear.
- the braking distance gets longer, as the equivalent braking build-up time of the train increases and thus the mean deceleration occurring for the given brake equipment decreases.
- the release time gets longer, since there are analogous conditions during release, aggravated by the fact that the air is needed to refill the R reservoirs and to increase the main brake-pipe pressure.

One possibility of reducing the differences in the brake force and thus the possible longitudinal compressive forces is by extending the filling and release times of the brake cylinders, since this distributes the available brake force more homogeneously in the train, more so for long freight trains (brake position G) than for shorter passenger trains (brake positions R and P), i.e. the standard time constant of the system becomes large in comparison to the signal travelling time of the control commands. At the same time, this however also extends the equivalent braking build-up time and thus the braking distance. This ultimately leads to a reduction of the maximum speed. Within a distance of 1000 m between the distant signal and the main signal this leads to a maximum speed of only 90 km/h in brake position G.

If one wants to realize primarily a braking distance which is as short as possible, equipment is useful which counteracts the flattening of the pressure gradient and allows air to escape from the main brake-pipe: brake-pipe emptying accelerators which open a wide diameter locally at each distributor valve. This does not affect the propagation time.

Numerous measurements show however that such equipment, contrary to common opinion, has also negative effects on the longitudinal compressive force level. In brake position P, the compressive forces can assume critical values for trains longer than 500 m, depending on the configuration of the train.

If one wants to have longer trains even at the expense of a lower maximum speed and considerably poorer adjustability, the brake position G controlled purely pneumatically seems to be the only way out. Tests of the French state railway SNCF have shown however that even then only trains of approx. 1000 m in length can be reached. This was also confirmed by measurements...
of the Swiss federal railway SBB, which also made it clear that with lengths >750 m the train has to be homogenous as regards wagon types and loading.

1.2 Train mass
The longitudinal dynamic forces increase for a given train configuration when the mass of the vehicles increases. The practical compromise to achieve reasonably short braking distances and an uncrirical longitudinal compressive force level at the same time consists for heavy trains of brake position "P" in driving the first vehicles in the train unit in brake position "G", so that their full braking effect comes later than with the vehicles at the rear. This keeps the train stretched out at the start of braking. This reduction of the brake performance for reasons of longitudinal dynamics is called train mass restriction. With this procedure, too only train lengths of up to 700 m can be mastered.

1.3 Conditions in America
Outside Europe, considerably longer and heavier trains are operated successfully with conventional air brakes today already. In North America for example, freight trains with 25,000 t total weight and up to 200 wagons with a train length of 3,000 m are not uncommon. This is however only possible under the following general conditions which are not to be found in Europe in this form:

- use of centre buffer couplers for compressive and tractive forces up to 1,000 kN
- exclusive use of bogie vehicles in mostly homogenous block trains
- existence of a low overhang or a short distance between the coupling level and the neighbouring wheelset
- filling times of brake cylinders up to 60 s and a distinctly lower braking ratio
- use of synthetic brake blocks with low dependency of the friction coefficient on the speed as compared to the cast-iron brake blocks
- no load-controlled braking/hardly any empty.loaded changeover
- as a rule single-track lines without mixed traffic consisting of passenger and freight trains, which leads to distinctly lower effects of incidents and thus to lower demands on safety and availability.

2 Approaches for overcoming the limits of pneumatics

2.1 The electro-pneumatic (ep-) brake
Ep-brakes offer the possibility of minimizing the influence of propagation times and pressure gradients and thus to reduce both the longitudinal compressive force level and the equivalent brake build-up time. Driver's brake valve and distributor valves work in the same way as with the pure air brake. However when a braking or releasing process is initiated via the driver's brake valve, the solenoid valves on the individual wagons are excited at the same time. This leads to the main brake-pipe being controlled nearly simultaneously along the train before each distributor valve. This means that there is no time lag during release because of the air transport in the main brake-pipe, the R reservoirs are re-filled via a separate main air reservoir pipe (8-10bar) (separation of control and feed pipe). An ep-brake therefore can be better regulated and leads to shorter braking distances and minimized longitudinal compressive forces.

One must distinguish between two executed systems:
- the so-called DB ep-brake as used on DB passenger coaches uses the IS or loudspeaker cable for giving signals, the switching energy for the solenoid valves comes from the power supply of the vehicles. Their functioning is not monitored during running, so it is not a safety-relevant brake.
- the so-called UIC ep-brake as per Leaflet 541-5 uses the UIC control line according to the specification mentioned and transmits besides the braking, releasing and emergency brake override signals also the respective switching currents. It can therefore also be used for vehicles without their own energy supply such as freight wagons and can also be credited for its braking distance reducing effect because it is permanently being monitored.

The installation of a second main air reservoir pipe and a cable on all the wagons of the train unit is a disadvantage, just as the missing answer to failure scenarios, if one wants to run trains with
critical train dynamics which are not mastered by the conventional brake system, which still represents the fallback level.

### 2.2 Additional ventilation points

Essential improvements of the propagation time and the air transport in the main train-pipe have already been achieved if one could actuate at least one ventilation valve in the rear section of the train. This idea was taken up especially in the USA where one has radio-controlled access to traction units distributed in the train unit or to an End of Train device (EOT) installed at the end of the train.

Tests by SBB as well as by DB with the system Locotrol® from GE Harris have shown that the position of the ventilation point in the train unit is decisive in this context. If there is a ventilation point in the front section of the train, it causes in the main brake-pipe analogously to a train with brake-pipe emptying accelerators a faster ventilation of the front section of the train with the possible consequence of higher longitudinal compressive forces. If it is at the end of the train or ideally in the rear section of the train, the ventilation will cause the lowering of the longitudinal compressive force.

Here too however the critical case is the radio disruption, after which only a traditional pneumatic system subject to the propagation speed is available which ultimately predetermines the train lengths and mass limits.

### 2.3 Databus– or trainbus– based brake actuation

With trainbus-based electronic brake systems, it is possible to reach a separation of the signal and the operating medium and to accommodate the intelligence for actuating the brakes at the individual brake controls distributed in the train. In this way a number of additional functions (automations, diagnoses, remote operations) can be carried out besides actuating the brakes. The control and the fill function of the main brake-pipe is separated and an independent signal path established by means of electronic target value transmission so that the propagation time for actuating the individual brakes can be eliminated or at least clearly reduced, depending on the trainbus system. Since the vehicles to be equipped for freight traffic do not have a main air reservoir pipe and it is also to be possible to retrofit old vehicles, the principle of the directly acting ep-induction brake is used for this field of application in the well-known solutions. In such systems the main brake-pipe assumes, if at all, only a back-up safety function (backup), is kept constantly at the standard pressure of $p_{HL} = 5.0$ bar and feeds compressed air to the brake systems.

The local electronic controls regulate the brake cylinder pressure $p_C$ according to the target values transmitted via the trainbus directly from the supply reservoir $R$ using solenoid valves.

Such brakes realized on the basis of communication systems consist basically of a traction unit control computer with the master functionalities of target value generation and control, of the trainbus on wire or radio basis for transmitting information within the train, of the energy supply (centrally from the traction unit or wagon-based self-sustaining) and the wagon equipment with the slave functionalities consisting of the electronics needed for the communication (gateway), the wagon electronics for actuating the brake and the wagon pneumatics. The gateway electronics and the control electronics for the brake can also be integrated in one hardware unit.

In America there are also activities corresponding to the AAR with the ECP development. Here an LON powerline is used as communication system. So there is a cable connection between the vehicles with which energy and data are transmitted via the same medium. The American system is mainly designed for the brake control. It is not based on an open communication system that can later be the basis for new applications without modifications of the remaining system. With this solution, trains of up to 3 km in length are run in America. It must be said however that in this solution too the fallback level is still the conventional pneumatic AAR emergency brake, which allows already a sufficiently safe stopping of the train for the train length mentioned independent of the ECP solution. Because of the inadequacy of the conventional direct-release AAR brake, the introduction of an ECP brake in America quickly leads to profitable effects like the introduction of graduated release with effects for speed, track utilization, energy consumption, wear of brake blocks or through brake-related wheel damage and the loss of costly manual
activities before and after running on long gradients, which greatly exceed the necessary investments.

From the above one can see that there is no system development today with which on the one hand today's limits of the pneumatic UIC brake for freight trains can be overcome, and with which on the other hand, through the clear separation of the communication system and applications, an open extendable system is created which can later be the basis for further applications or automation steps in the freight train.

3 FEBIS

3.1 System survey

The development of the FEBIS brake control is based on a communication system for which a line-bound and a radio-bound solution is being developed. This means that, as with all databus-based brakes, a separation of the signal medium and the operating medium of the pneumatic brake is achieved. The specification of the target value for the individual brakes in the vehicle is effected via this communication channel and the conventional UIC brake is constantly in release position and feeds compressed air to the brake units. The development of the brake takes place as a so-called overlay solution, i.e. the vehicles equipped with an electronically actuated brake can also be included in conventional freight trains.

The energy supply needed for the electronics is ensured centrally via cable or locally through wheel-set generators (for radio), and there is a battery for each brake electronics as energy buffer to guarantee autonomy for approx. 5 hours even if the central energy supply breaks down. The line bound trainbus system is being realized on the basis of the LON technology of the American company Echelon with a LON-Powerline-data transmission, i.e. energy and data are here transmitted on the same line. For FEBIS not only one line is used, but two. This offers apart from the line redundancy on the one hand a doubling of the data rate, and on the other hand the energy
provided can be doubled in the individual vehicles, if necessary. The lines are fed with 230 VDC from the leading locomotive (Picture 2).

A master/slave approach with determined behaviour is used for the communication protocol. The multimeter capability of the LON-communication – this means that every subscriber can transmit when it wants to – is used for emergency messages. The availability of two data networks is used to differentiate between "vital" functions such as brake and traction control, and additional applications such as diagnosis and monitoring functions.

The radio-bound trainbus solution (see Picture 2) is based on the TrainTalk protocol from GE Harris and uses hardware components of the company ST2E for transmission in the 5.8 GHz ISM band. The antennae are placed along the two sides of the vehicles, which gives a range of approx. 100 m. The energy supply of the freight vehicles is effected for the radio solution through axle generators and appropriate batteries, so that a vehicle-based self-sustaining system can be realized and tested.

### 3.2 Equipment and functionality of a FEBIS vehicle

Picture 3 shows an overview description of the vehicle equipment for the pneumatic part of the brake. For the brake equipment a clear separation of the UIC brake and the electronic brake control was observed including load correction with advantages regarding the functional independence of the two brake systems.

![Concept of FEBIS vehicle equipment with vehicle-bus](image)

In every vehicle, the FEBIS brake appliance unit with solenoid valves and pressure transducers is installed parallel to the conventional UIC brake. For easier installation without expensive piping and with minimal modifications to the G/P changeover and release cable, it is designed as an intermediate flange. A double check-valve releases the maximum pressure to the brake cylinder: this is either the one from the outlet of the UIC distributor valve or the one from the FEBIS electro-pneumatics. The FEBIS brake also feeds itself with compressed air from the supply reservoir R and regulates the brake cylinder pressure $p_c$ corresponding to the target brake value received via the communication medium, electronically controlled with two solenoid valves (for filling and releasing). For this no controlling takes place, but the $p_c$ value (or a so-called Cv pressure which pre-controls the former) is fed back as a sensor value into the control process. For this the control is parameterised amongst others by the load signal, the T pressure. In the FEBIS mode this allows an even, smoothly gradable brake operation with low hysterizes. The time constants of the cylinder pressure control, i.e. the time constants for setting up and relieving the pressure, are oriented on those of the brake type P of a conventional UIC brake, also for the long freight train.
Besides the sensor for the C pressure, pressure sensors for the R and the main brake-pipe pressure are used for diagnosing the operational condition of the brake unit. The inexhaustibility of the brake, which is ensured in UIC operation by the fact that the UIC brake can only be released if the R reservoir is also filled accordingly, is also controlled electronically for the FEBIS-release process.

Besides the components mentioned the intermediate flange also has another special feature: the so-called EVA valve. This component allows the ventilation of the main brake-pipe. In this way, as will be seen from the further description (see fault conditions, fallback level) on the one hand a support of the main brake-pipe ventilation is realized, on the other hand however a possibility in particular of passing on a signal on the pneumatic line independent of the communication medium. EVA valves therefore are in this function special brake acceleration valves. They assume the function of passing on brake commands by being able to draw air locally from the main brake-pipe.

The second main brake-pipe sensor shown in Picture 3 is not relevant for the actual brake control, but is used in the initialisation phase of the radio system for determining the alignment of the wagons via the evaluation of the running-time difference of a pressure signal in the main brake-pipe.

The release condition of hand or parking brakes is monitored without additional components and the G/P/R position is also determined by using the brake cylinder pressure characteristic, which is not relevant for the pure FEBIS brake.

Via a test button on the sidewall of each wagon, an auto test of the electronics can be triggered - the success of which is shown by in indicator light. Through this initialisation step, it is also possible to release an applied FEBIS brake manually in case of faults. For maintenance purposes an interface is also envisaged for reading the fault memory with various diagnostics data.

### 3.3 Equipment and functionality of the traction unit

In a traction unit, the following can be found: the central control functions across the train (master components) needed for realizing the FEBIS brake control, i.e. the master function for initialising and monitoring the communication and energy system as well as the master functionality of the FEBIS brake function in the train. A precondition for starting the FEBIS-brake is a proper initialisation of the respective communication system (radio, brake) after the sequence, direction and the type and parameters of the vehicles found in the train are known. In addition the electrical energy will be fed into the powerline, at least for the wire variety.
Concept of FEBIS locomotive equipment

The layout of locomotive equipment in principle is shown in Picture 4. There is a FEBIS master computer that contains the central control functions of the communication system and the energy supply mentioned above. This master computer is connected to the communication network (wire or radio) and contains the display interfaces to the driver of the traction unit. After the basic systems of communication and energy have been initialised, the individual applications, especially the brake, is selected, initialised and started by the driver of the traction unit via the display. The master of the brake application can also be implemented in this central unit. Its task is the initialisation of the brake system (brake test), to pass on the brake demands of the driver of the traction unit to the electronically controlled brakes in the train and to keep the main brake-pipe pressure at the nominal value of 5 bar and also to master fault conditions and fallback level.

The actuation of the brake in the locomotive follows the same principle and uses the same components like in the wagons. This makes it possible to brake in FEBIS mode also a locomotive that has not been fitted out and is being towed, which is important for delivery and towing trips.

3.3.1 Initialisation of the brake application

A full brake test today requires a considerable expenditure of time and staff. Guaranteeing safety therefore represents a major cost and time factor. The driver of the traction unit with electronic support can carry out the FEBIS brake test in less than 10 min. The full FEBIS brake test comprises the following functions:

- Automatically executed functions of the UIC brake, diagnosed by FEBIS sensory mechanism
  - condition of hand brakes
  - condition of vehicle brake (G/P/R, on/off)
  - filling of brake systems of the train
  - leak test
- Automatically executed test of the FEBIS brake
  - applying and releasing a FEBIS operational brake stage
- Backup-test supported manually by the driver of the traction unit
  - Lowering the main brake-pipe by activating the driver's brake valve
- Pick-up of the pressure wave by the first EVA valve and onward transmission (passing on of signal) through all EVA valves
- Release of the pneumatic brake by means of the driver's brake valve

- Automatically executed brake calculation via determination of the ratio of operable brakes, their actual braked weights and saving of the established weights of vehicles and brakes

As can be seen from the sequence already, it is not sufficient to test only the UIC system, but the full backup system including the EVA functionality must be tested. Only in this way can the mastering of the longitudinal dynamics of long and heavy trains, for which today's UIC limits are exceeded, be guaranteed.

3.3.2 Operational phases of the brake application

The operation of the FEBIS brake (target value specification) is effected without change via the driver's brake valve. For all other FEBIS functions, the keyboard on the traction unit display is used. In the FEBIS mode, the signal transmission between the brake lever of the traction unit driver and the main brake-pipe must be separated, since operating the brake lever should not lead to a decrease of the main brake-pipe pressure.

When using driver's brake valve units which transmit the target value purely electrically, separation is possible in a "very simple manner": the target value is passed on from the operating lever to the FEBIS master and the analogue transformer of the driver's brake valve unit does not use it as up to now for influencing the main brake-pipe, but keeps the main brake-pipe at its nominal value of $p_{HL} = 5.0$ bar. With conventional guide brake valves, which generate a pre-control pressure directly with the operation of the lever, this must be read as an electrical signal via a pressure sensor for picking up the brake demand in order to get the FEBIS target value and to build up simultaneously and independently a constant pressure of 5 bar at the relay part. The separation of the signal path is tied to the existence of additional hardware signals between the FEBIS master computer and computers available in the locomotive such as the HSM.

The equipment available in a locomotive which enable the driver of the traction unit to trigger an emergency brake application in critical situations remains unchanged as far as effect and operation are concerned, i.e. the ventilation of the main brake-pipe takes place as before, is however recognized in these cases and supported and passed on through the EVA valves.

Apart from this target value specification across the train just mentioned it is also possible to brake individual vehicles selectively in individual operating conditions (e.g. initialisation, stoppage), for example via the display interface, to secure the train for example during a brake test to be conducted on a gradient.

3.3.3 Reaction in case of faults

As already explained above, the developments of trainbus-based electronically controlled brakes to date are based on using the back-up pneumatics as a fallback level and are therefore ultimately subject to the limits of the respective system. If we are to create in Europe the technical possibilities of considerably longer trains, then this means that we have to overcome the limits of today's UIC brake system in particular also for the fallback level, but we must at the same time guarantee that the traction unit driver can take control as far as possible in case of a fault. Even in case of a fault it should be at his discretion as far as possible where the train will come to a stop, so that for example stopping in a tunnel will be avoided.

In case of a fault, a breakdown of communication or initiated by a special data telegram, the FEBIS brake of an individual vehicle changes into a mode from which the EVA valves are actuated when a pressure wave is recognized in the main brake-pipe. They assume the function of passing on the brake command, by drawing air locally from the main brake-pipe. The pressure wave can be initiated by the driver of the traction unit (brake position, Ackermann) or for example by a train separation. The recognizing FEBIS vehicle brake (LCU) then sends immediately asynchronically a message via the network and informs all LCUs it can reach of the rapid braking demand, which leads to the activation of the EVA valves and the build-up of FEBIS brake cylinder pressure. As long as FEBIS is used in addition to the UIC system as overlay-system, the main brake-pipe lowering also leads to a parallel braking by the UIC distributor valves. In this way it is
possible to get also extra long and heavy trains into a safe condition at any time, since the response of the brakes of the individual vehicles will only be retarded by the propagation time in those places where no communication is possible any longer between two vehicles. This provides a segmented synchronism. This approach is the basis for running any trains beyond the length and mass limits of today and to allow on the other hand train configurations of today without restrictions. The braking capacity of the train would thus become nearly independent of the length of the train even for the fallback level, and a train then behaves more or less like an individual wagon from the point of view of braking technology. A supplement of approx. 10-15% can then even be given for the inscribed UIC braked weight, which can be used for increasing the speed.

3.4 Status of development

Essential parts of the FEBIS developments have been completed and the railways and industrial partners (ALSTOM – SAB WABCO) are starting with experiments and tests. For this purpose a test rig, was set up in Piossasco, where the entire system for a train length of 2250 m is being installed and tested, before investigations are carried out in the train (Picture 5). This brake system Test Bench has been developed and manufactured by SAB WABCO – Italy with new and original criteria and it is unique by its size in Europe.

Lay-out of test rig in Piossasco (SAB WABCO – Italy)

The time planning envisages that the installations of the system in the train will start in spring of 2001, and first results from measurements and investigations on the train also as regards the technical feasibility of very long trains in Europe should be available in 2001. The target date for concluding the development with the release of the interoperability specification is 2002. These results are to find their way into corresponding UIC specifications or standards on a European level.
4 Comparison of FEBIS with other brake systems

The connection between longitudinal compressive forces occurring and braking distances occurring in relation to the brake control used can be seen qualitatively in Picture 6. These were based on simulations with E-Train, in which train configurations chosen at random were examined in the various brake control variations for rapid brake applications from 100 km/h for the braking distance and from 3 km/h for the longitudinal compressive forces.

Longitudinal pressure forces for different brakes (qualitatively)

Braking distances for different brake controls (qualitatively)
It becomes clear that with ep- or a FEBIS brake actuation distinctively smaller longitudinal compressive forces and braking distances can be reached in comparison to the conventional UIC mode. The forces occurring when a distributed main brake-pipe ventilation is used depend on the position of the second ventilation point. The examination of a greatly simplified model of the AAR brake, for which only the brake cylinder build-up time was increased and the deceleration reduced, makes it clear that the low level of the longitudinal compressive forces was achieved through a considerable extension of the braking distances.

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