ECUC

Eddy CUrrent brake Compatibility

DELIVERABLE D.6.2

Engineering guidelines for the installation of ECB in the vehicle

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0	**10 Jul 2015**	**AT**	**Draft – first version**
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2	**30 Jul 2015**	**AT**	**Addition executive summary**
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EXECUTIVE SUMMARY

So far the only existing installation of Eddy Current brake systems has been made on the ICE3 trains of Deutsch Bahn. In order to investigate the compatibility issue of the ECB system, it has been felt that guidelines should be proposed to help the train designer teams to tackle the installation on other trains.

Eddy current brake cannot be considered as a product which is easily installable in a train. In fact it is a complete system both at local vehicle level as it requires the combination of the ECB specific parts working together with traditional brake control and the traction systems, but at train level, and especially when it is intended to use the ECB for service brake, a very sophisticated blending between the different available brakes (electro-dynamic brake, friction brake and eddy current brake) has to be implemented. Therefore it is, in fact, required the complete train brake system to become an eddy current brake system.

The availability of the eddy current brake is a key issue. Obviously this is first due to the availability of the ECB itself that could be impacted due to any failure (even with the best proven design, this can always happen in such a sophisticated system). But there are other reasons that could lead to prevent the use of the ECB:

- restriction due to the track capability to the ECB use,
- restriction due to potential overheating of the rails (due to ECB effect added to a high ambient temperature) that could create a risk of buckling of the track
- too much use leading to overheating of the device,

To cope for all these conditions (some of them being operating rules) the train brake management has to manage the blending between the different brakes to ensure the train braking capability. The dimensioning of the other brakes has to take into consideration additional duties in case of ECB unavailability. The transmission, in a reliable/safe way, of this train braking capability to the signalling (ETCS) system has to be ensured as well.

The proposed guidelines propose ideas to build to corresponding blending strategies.

There are other guidelines in this document for approaching the physical interfaces with the other train subsystems, and working on the monitoring and diagnosis issues.

1. INTRODUCTION

This document proposes design, engineering and operational guidelines for the installation of ECB in a vehicle.

Eddy current brake cannot only be seen as a product installed in a vehicle. This innovative brake concept is to be considered as a full system and both the physical and functional integrations have to be taken into consideration.

As of today there is only one type of train using ECB that have been produced in series (ICE3 for DB).

The ECB which has been studied within this ECUC project, on several points, is adapted to the design of the ICE3 (and alternatively the ICE3 design does take into consideration the design constraints from the ECB concept).

The proposed guidelines cannot be to recommend to copying some features of this train. Therefore the approach will be to remind what has been done on this reference, but to highlight the issues to be solved for a potential future installation in other type of trains. This should enable to understand what are the compatibility issues created by the extension of this brake concept.

2. REQUIREMENTS

The applicable requirements have been listed in the D2.2 of the ECUC project. Refer to this document for more information.

For the new release of the TSI LOC&PAS which has been issued in the meantime, the ECB remains an open point and reference is made to the TSI RST 2008 for the longitudinal efforts.

3. DESCRIPTION

3.1 GENERAL

The following descriptions are based on the design of the current installations on the ICE3 trains. The ECB system consists of 3 main parts:

- the main equipment which provides the braking effort is part of the bogie.
- the pneumatic control module which is car body mounted, provides the control of the mechanical part using pneumatic actuation
- the electric control module, which is car body mounted, provides the electric control and monitoring of the electrical part of the ECB

3.2 BOGIE EQUIPMENT

The Figure 1 shows the basic structure of the eddy current brake main part.

This system consists of the 2 assemblies called "magnets" which include into an integral beam the coils and the end pieces. The 2 magnets are mechanically connected by track rods. The vertical suspension to the bogie frame is ensured by support beams and cantilever arms linked to the axle boxes, and air bellows which control the distance from the magnet to the rail head. Transmission links are used to transmit the longitudinal effort (braking effort) from the ECB to the bogie frame.

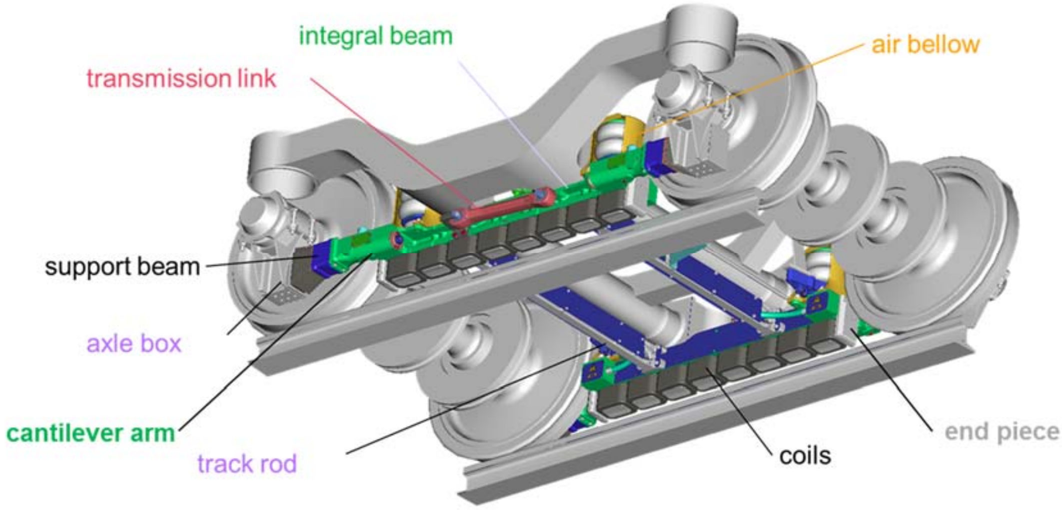

Figure 1: Main bogie mounted components of ECB

3.3 PNEUMATIC CONTROL

The pneumatic control of the ECB is included into the pneumatic brake control module called IBT which also control the friction brake of the corresponding bogies.

The main pneumatic control function adjusts the air gap by controlling the pressure in the air bellows. This pressure control is speed dependant in order to keep constant the air gap during all the speed range, compensating the beam deformation due to the increase of the attraction force while speed is reduced. When not braking, this pneumatic control keeps the ECB in the lifted position.

3.4 ELECTRIC CONTROL

The electric control is split into 2 modules.

The electric power is managed by a DC-chopper included into the traction package (called ASG). The chopper control includes functions to simulate the coil temperature and limit the input current accordingly. Supply current is cut off at a speed below 55 km/h.

The overall electric control is managed by the brake control electronic unit (BSG) located into the IBT module. In addition to controlling the friction brake, additional functions are included to provide the local control of the ECB: building of the ECB current set point which is speed dependant and subject to temperature simulation control.

3.5 SYSTEM INTEGRATION

The overall installation of the ECB system as implemented into the reference train ICE3 is shown in the Figure 2:

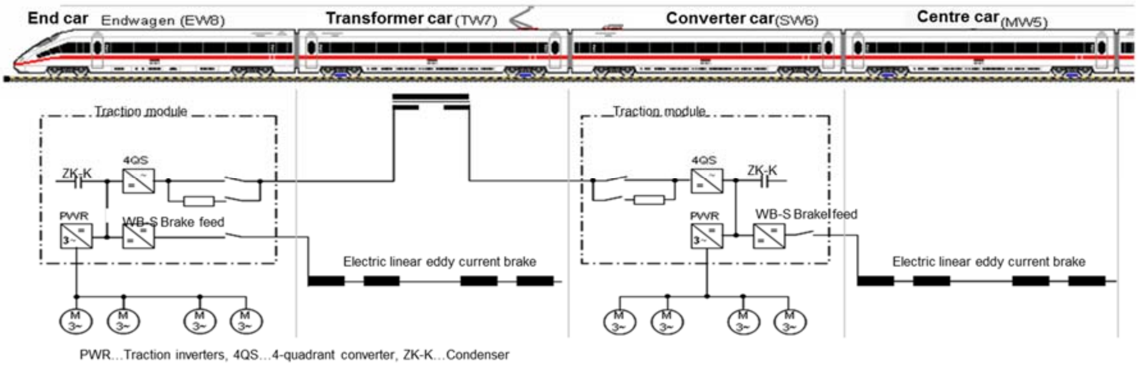

Figure 2: ECB implementation in ICE3

This train is using a distributed power arrangement. ECB equipment is installed in each trailer car (on each bogie for the ECB main part, and control per car for the pneumatic and electric control).

The electric power for the ECB is provided by the regenerated energy from the traction motor in braking mode. In case of catenary power supply disruption, battery supply is used to initiate the regeneration indicated above.

The brake management is carried out at train level to coordinate the use of the different available brake systems.

The Figure 3 is representing for a maximum service brake application the sharing between the different brake systems.

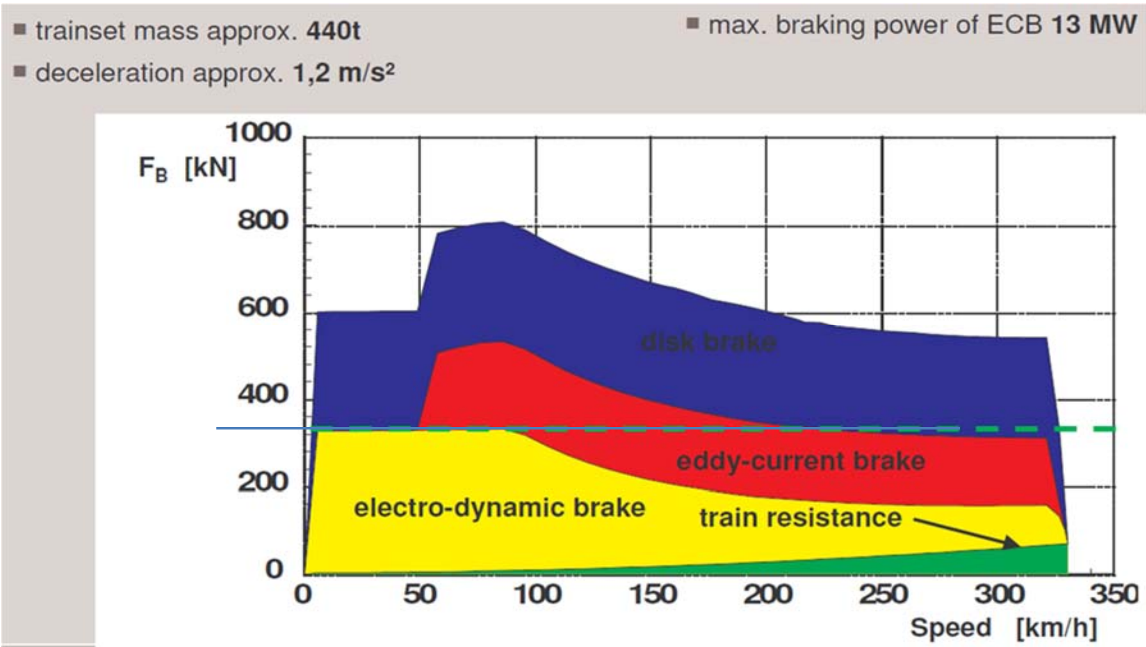

Figure 3: Brake management ICE3

It means that for a lighter service brake application (normal service brake deceleration is circa 0.6 m/s²), the brake management is achieved according to the green dotted line: The electrodynamic brake is used for the complete range and is sufficient to provide alone the brake effort from 90 km/h down to roughly 0. For such deceleration no need for using the disc brakes (blue area) and the eddy current brakes are only used at their full rating from the maximum speed to roughly 200 km/h; and then progressively reduced to be off at 90 km/h.

This train blending is achieved in real time and takes into consideration the real availability of the different brakes. Regarding the eddy current brakes their availability can be impacted by different issues: prohibition to use it on some track sections, reduction of effort due to high coil temperature (too much previous use of the ECB). In that case the total effort requested by the driver can be achieved by using more friction brake (disc brakes).

4. PROPOSED GUIDELINES

4.1 GENERAL

The ECB brake is a brake system that can be used in addition to the traditional friction brake. Its most interesting advantages are that it is wear free and fully independent of the adhesion. It is a sophisticated system where the control has to cope with the specific behaviour: speed dependent retarding force, speed dependent attraction force.

In addition to that it appears, thanks to this project, that thermal issues have to be considered both at the product itself (repeated brake applications might lead to an overheating of the coils) and at the railway system level (repeated brake applications by different trains on the same track section may lead to unacceptable overheating of the track specially during high temperature days).

Therefore the implementation of such brake in a train needs to have a wider approach than of just installing a product. The train has to be designed from the beginning to integrate such brake system, and this design has to consider the way the train is going to be operated.

The characteristics of the line(s) where the train can be operated (gradient, brake performance requested by the signalling system) as well as the operating conditions have to be deeply analysed to specify the brake cycles to be supported.

The expected brake cycles should be described by:

- brake application, emergency brake, service brake and combinations,
- emergency brake force and service and full service brake forces,
- initial speed of brake applications,
- gradients of the line,
- speed limits,
- duty cycles with delays of driving, braking and stopping and repetitions,
- minimum of deceleration of the train.

When carrying out the design of a train using an ECB system, in addition to the regulation requirements, it is highly recommended to carefully apply the relevant requirements of EN15734-1 and EN16207.

4.2 SYSTEM AND PERFORMANCES

The ECB is only a part of the overall brake system of the train. During the design phase the performances of all the installed brake systems have to be considered and the strategies to activate each one to be defined.

These strategies are different depending on the type of braking (emergency brake, maximum service brake, service brake) and of the different degraded modes that can occur.

They can be represented by charts as in Figure 3.

Regarding the degraded modes the ECB have to be carefully considered.

First there are some cases where the ECB cannot be used or its use is limited

- Depending on the section of the track the use of the ECB may be prohibited, or only limited to emergency brake applications.

- In order to limit the longitudinal effort in the track, the TSI asks for a limitation of the ECB generated braking force per train to 360 kN (emergency brake), 180 kN (maximum service brake and 105 kN (normal service brake = 2/3 maximum service brake).

  Note 1: Based on national rules there could be different thresholds (higher than the TSI's) depending on the type of tracks (slab track, conventional ballasted track). Some infrastructure may accept higher longitudinal brake force (ex: in Germany 290 kN for the max service brake).

  Note 2: These figures are the highest accepted, but depending of the blending management (see Figure 3), the average retarding force during the braking can be lower.

- In case of overheating of the coils (a permanent monitoring is foreseen) there could be performance restrictions. The sizing of the system shall be adapted to the operation of the train, but it shall give a warning (enabling to limit the use of the ECB) in case the coil temperature has reached a level not enabling to achieve a further emergency brake application.
- In case of very high ambient temperature, it has been demonstrated (see deliverable 3.2) that very high rail temperature could be reached. It will lead to restrictions either in the operation of the trains (maximum speed restriction) or the use of the ECB (full prohibition or prohibition of service brake)

  Note: the assumptions for the brake efforts used in this 3.2 task have considered the worst conditions. For a given project more realistic conditions (depending on the real blending used for service brake, and the operation constraints for the train) should be dedicatedly considered.

Secondly the failures leading to the impossibility to use the ECB have to be listed:

- Failure of the ECB control (pneumatic and electric) and their consequences: loss of brake effort on one or two bogies.
- Failure of the electric supply:

  For example for ICE3:

  - If the electrodynamic (ED) brake is taken into consideration for emergency braking performances (country dependent as the ICE3 traction equipment does not include resistors and only regenerates to the catenary), case A corresponds to 1 ED brake module isolated + 1 ECB module isolated, provided that an ED brake module does not provide power supply to more than 1 ECB module during braking.
  - If the ED brake is not taken into consideration for emergency braking performances, case A corresponds to all ED brake modules isolated + 1 ECB module isolated. In this case, power supply of ECB may be provided by ED brake module if this can be performed independently from high voltage power supply.

Note: *Cases A and B refer to the different degraded operation brake modes as specified in TSI HS RST 2008: Case A is considering the worst degraded operation mode defined below:*

> *— One dynamic brake unit, which is able to function independently of the other dynamic brake units, is deactivated if it is independent of the contact wire, or all units on the dynamic brake are deactivated if they are dependent on the voltage in the contact wire.*
>
> *— Or one independent module of the braking system, which dissipates kinetic energy through heating the rails, is inoperable, if this system is independent of the dynamic brake.*

The definition of the corresponding blending strategies (both for emergency and service brake) has a key function. Safety analysis (according to TSI requirements and EN 15734-1) have to be performed in order to assess the consequence on the train brake performance of each of the listed degradations. It shall be demonstrated that there is no single point failure in the whole ECB system that could cause any relevant malfunctions regarding emergency brake application.

The performances are considered in the nominal conditions but deviations (tolerances, failure rates,) have to be determined in order to be used for the computation of the safe deceleration (see ETCS/ERTMS System Requirement Specification SUBSET-026-3).

The way the status of each ECB is monitored and its safety determination and transmission shall also be carefully analysed as it has a direct consequence on the safe deceleration determination used for ETCS.

4.3 TRAIN CONTROL

The complexity of the strategies to be foreseen (as indicated in the previous paragraph) obviously leads to a brake computer-aided train control.

The reliability of this system is of major importance.

The choice of the operation mode for the ECB ("switched off", "only emergency brake operation" or " service and emergency brake operation") is to be provided to the driver but it also may have to be possible automatically for the ATC system.

Permanent information (safety relevant if the ECB performance is considered in the emergency brake performance) about the ECB status is necessary for driver use but for automatic action as well.

4.4 ENERGY SUPPLY

4.4.1 Electric energy supply

If the brake forces of the ECB are to be considered in the brake calculation, the energy supply shall be independent from the main energy supply and shall be split into several units operating completely independent from one another. A failure in one unit is not allowed to cause a subsequent failure in another unit.

The ECB needs a powerful energy supply. If the ECB is considered in the brake calculation the electrical energy shall be provided independent from the catenary supply.

One recognized method is to use the regenerative capacity of the traction system.

Another method is to use a powerful energy storage system, for instance a battery or capacitor. However this method would lead to a specific design and sizing of this energy storage, as current equipment installed on board the trains would not be able to support this type of duty.

The capacity of the energy storage system shall be dimensioned in such a way that the ECB can be activated during three consecutive brake applications from maximum speed at emergency brake storage, without necessity of the energy storage to be recharged, without substantial power loss. At the third emergency brake application, the magnet shall still have no reduction of brake performance due to a lack of stored power at emergency brake application from maximum speed.

An energy monitoring system shall monitor the charge capacity of the energy storage system.

As the power supply will in most of the cases be provided by traction equipment, the following interface information shall be clarified between traction and ECB system:

- nominal voltage of power supply,
- maximum voltage,
- tolerances,
- maximum of voltage rises,
- amplitude of the voltage at operating frequency,
- voltage transient peaks,
- pulse rate of DC chopper,
- pulse voltage rise rate.

As it has been demonstrated during this ECUC project one of the main cause for the high frequency EMC emitted by the ECB is within the power supply (DC Chopper), specific validation actions have to be carried out in order to check the compatibility of the two systems (traction/DC chopper vs. ECB).

4.4.2 Pneumatic energy supply

The ECB shall be supplied with compressed air from a dedicated reservoir recharged from the main reservoir pipe via a non-return valve. The availability of this dedicated compressed air shall be continuously monitored and reported to the train control (safety relevant information if the ECB is planned to be used for emergency brake).

In the event of a loss of main reservoir supply the reservoir for the ECB shall have sufficient volume to be capable to carrying out of emergency brake application three times without refill of the reservoir.

The ECB shall not require a system pressure of more than 6 bar to deploy and shall tolerate pressure up to a maximum of 10 bar.

In case of air supply local isolation, suitable mechanical devices shall enable to keep the ECB magnets in the high position.

4.5 Installation

4.5.1 Bogie

The main part of the ECB is bogie mounted. Its volume and weight lead to a specific design of the bogie.

In release position the ECB is lift up by the bellows and is completely linked to the bogie frame (in this condition the weight of the ECB is not considered as unsprung).

In brake application position the ECB is down linked to the axle boxes. However the gap is controlled by the air bellows, to avoid any reduction of the gap at low speed that would be due to the increase of the attraction forces on the magnet assembly.

The transmission of the retarding forces to the bogie frame is carried out by transmission links.

Therefore 3 sets of interface have to be defined and validated between the bogie and the ECB: upper suspension of the bellows, fixation to the axle boxes, fixation of the transmission links.

The definition of these interfaces shall ensure that the influence on the driving stability of the bogie is not impaired both in release and application modes. It shall also insure that even in the worst case the gauges defined in EN15273 are compliant.

Regarding the maintenance, the design of these interfaces shall enable an easy access for the removal/exchange of the ECB assembly. The gap adjustment (which is to be done each time a remaining of the wheels is made) has to be easily accessible

The cabling should be protected against damage from flying ballast or something similar.

4.5.2 Control

In the current installation the control of the ECB is managed by two different equipment: electronic brake control unit (which control both the electric part and the pneumatic) and traction control for the DC chopper and its control.

The pneumatic brake control of the ECB is part of the pneumatic brake control equipment (brake panel). It means that this brake panel has to be designed to fully integrate the ECB control constraints.

The electric control of the ECB is managed by a dedicated DC chopper supplied from the DC bus of the adjacent motor car. This DC chopper system shall also include the necessary sensors to monitor the proper operation of the ECB (current monitoring, coil temperature simulation, earth fault detection system). Special care shall be taken to ensure the operation parameters of this DC chopper (such as frequency, and pulse range) do not have negative consequence on the EMC behaviour of the ECB.

The cabling from this equipment to the ECB shall be designed in order to avoid that in one bogie only one ECB on one side is activated (e.g. the left ECB) and the other is NOT activated.

The electric control equipment shall also include an auxiliary power storage (dedicated battery) that is necessary to ensure the activation of the ECB in emergency situation even in the case of an electric supply (catenary) disruption.

4.6 Monitoring and Diagnosis

Any event that could lead to a loss of brake performance from the ECB shall be subject to a close monitoring:

The list of devices/functions to be monitored will be an output of the safety analysis to be mandatory done at the design stage (see §4.2 and EN 15734-1).

The eddy current brake shall be monitored in such a way that any reduction in capacity below that required for an emergency brake application shall result in an automatic train speed limitation and/or other operational limitations or if suitable in an information for the driver.

A preliminary list for monitoring is:

- Complete or partial isolation
- Air pressure availability
- Failure status
- Activation of ECB (magnetisation)
- Release position
- Undue activation of ECB (lowering or/and powering on)
- Earth fault detection

Depending on the output of the safety analysis this monitoring shall either only warn the driver (for further action) or automatically have an action on the train (brake activation, speed restriction, information to ETCS)

The key parts subject to monitoring shall also be able to be tested in a reliable way during the train brake tests. The purpose of these tests are to confirm that the ECB is well configured and the communication with the train system is active, to confirm the correct function (which means correct application and release: it means the lift up/down of the ECB and the activation of the circuit shall be fully testable), and to confirm the correct operation of the control chain.

Depending of the RAMS analysis some of the tests will be allocated to the regular basic brake tests (that could be done automatically depending on the TCMS design) or to the full brake test (frequently requested on a daily basis, subject to the operator safety plan).

The result of these tests shall be reported to the driver and in safe way to the ETCS (that will take into consideration the actual available brake capacity to manage the train control).

4.7 Maintenance

The ECB control system shall integrate the means to record the result of the monitoring. All the event shall be classified either for immediate action or for further treatment at the earliest suitable date.

This information shall be available locally by a suitable diagnosis interface but also from a central point in the train via the TCMS.

All the key components of the ECB shall be equipped with the suitable testability means (test points, sensors, …).

The adjusting of air-gap is the most important work. The interval of this maintenance work is depending on the wear of the wheel sets. Other contents of maintenance works items are defined in the maintenance plan.

The access to the main components shall be designed to reduce in a reasonable way the time to exchange the faulty parts.