ECUC

Eddy CUrrent brake Compatibility

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Collection of previous experiences and know-how

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0.1	05.02.2013	(Partners)	
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1. INTRODUCTION

This document contains the collection and description of previous experiences and know-how of the partners of ECUC project concerning the design, the compatibility with the railway infrastructure and the operation of eddy current brakes (ECB).

Chapter 2 describes the main design parameters of eddy current brakes. Chapter 3 exposes the electromagnetic interferences between linear eddy current brakes and signalling systems. Chapter 4 shows the incompatibilities of ECB with tracks and chapter 5 gives inputs on the actual operating conditions for ECB. Finally, chapter 6 exposes the influence of environmental conditions.

Each parameter will be presented by a short description and - as far as possible – references on further documents with additional and/or more detailed information. Further information will be given on the relevance of the parameter for the project.

2. ECB DESIGN (ROLLING STOCK)

An ECB is located in the bogie between the wheels. The actual version of the ECB consists of 8 magnetic poles with alternating magnetic fields. In case of braking the ECB will be lowered so that only a small air gap of about 7 mm remains between rail head and ECB.

[3] gives a compact overview on relevant design and performance parameter of an ECB.

2.1 BRAKE FORCE

The relevant/necessary ECB brake force depends on the braking architecture of the vehicle, the maximum speed and other existing brake systems (chart 16 of [3] shows a typical force – speed diagram).

A vehicle with an ECB has a brake system that is independent from the friction coefficient and without wear and also independent from the wheel rail adhesion.

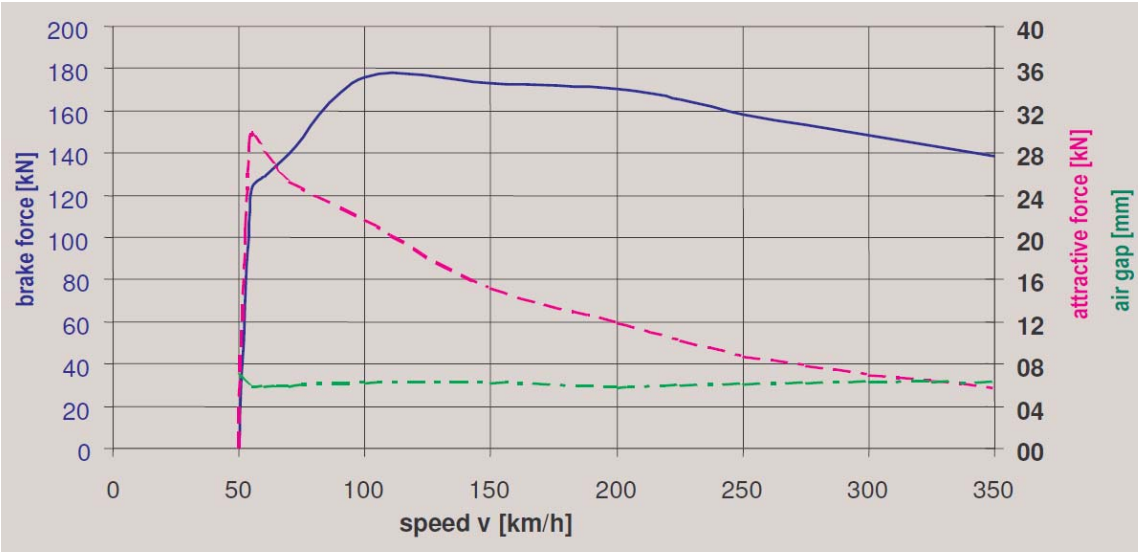

Figure 1: characteristics ICE3 (ECB type EWB154R [19])

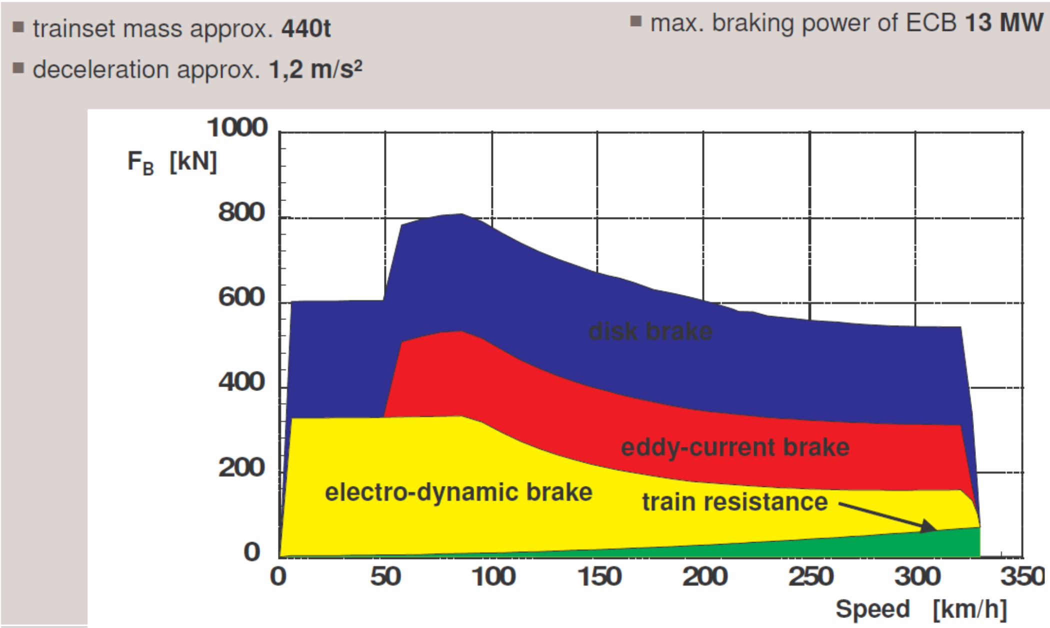

Figure 2: brake management ICE3 (ECB type EWB154R [19])

2.2 Construction, Dimensions

The conditions in the vehicles bogie affect the dimensions of the ECB as well as the minimum clearance outline, see [3].

- mechanical dimensions (lxbxh)
- number and dimension of coils
- distance to rail / air gap / air gap control / gauge
- material of significant parts
- mass mounted on the bogie / mass of additional components.

2.3 Electrical parameters

Power supply

The electrical power supply of an ECB could be realized via battery (e.g. 110 V) or via a tap on the DC voltage link of the vehicle traction unite. While the supply via battery (normally) has no or only less harmonics the supply via DC voltage link includes the harmonics generated by the switching of the current converter and/or traction converter. Higher frequent harmonics could lead to equivalent changes of the current in the coils of the ECB and the resulting magnetic field emissions. Depending on the spectral contents of the magnetic field emissions single signalling components could be influenced and/or disturbed (see the frequency working range of signalling systems of chapter 3).

Cabling

Tests and the first operation phase of the ECB have shown, that the cabling – the connection of the ECB with the power supply (e.g. DC voltage link / ECB controller) and the connection between the two ECB of one bogie - has a significant influence on the interference of certain types of axle counters (e.g. ZP 43). Parasitic cable capacities of approximately 0,5 nF in combination with the inductivity of the ECB coils could generate resonant circuits with resonance frequencies within the working frequencies of single axle counters. With the installation of additional choking coils and / or band stop filters in the connection paths, the influence could be reduced. To minimize the influence, the parasitic cable capacities should be as low as possible. Furthermore resulting resonance frequencies should not lie within the working frequencies of single axle counters (see frequency management of axle counters [4]).

Current flow in the coils

The current flow in the coils varies typically between 10 A and 95 A (DC).

Maximum temperature of the coils

As result of the very high current in the coils (see above) the temperature of the coils increases very fast and can – if a maximum temperature of over 200°C is reached – destroy the coils. This must be avoided. Therefore the current temperature is permanently calculated by a computer program. If the temperature reaches a limit value during a service brake the ECB is switched off. This variable limit value is set in the manner that there remains sufficient thermal reserve to use the ECB for the next emergency brake. The absolute limit temperature of the coils is set at 200 °C.

As this value is limited, it should be considered by the next steps of the project.

Capability of resistance concerning environmental conditions

The magnetic field emission of the ECB depends amongst others on the impedance/inductivity of the coils of the ECB (see subclause cabling above). Experiences of the ECB under daily working conditions have shown that the impedance/inductivity of the ECB changes in case of a short circuit between windings of adjacent coils or between coils and housing (earth fault, e.g. lost of isolation at very high temperature or mechanical damage) or humidity inside the housing of the ECB/coils. That's why it is important to avoid these interferences with a robust inner architecture and external housing.

3. SIGNALLING SYSTEMS

Amongst others signalling systems can be influenced by emitted magnetic field emissions from the ECB. Depending on the track side installed equipment, the influencing mechanism are different. Temporally changing magnetic fields may induce currents in cables and the electronic parts or influence directly the detection signals of magnetic field based sensors mounted on the rail (e.g. axle counters, wheel sensors). Furthermore strong magnetic fields change the magnetic situation of the rail the axle counter or wheel sensor was calibrated to and so influence the analogue signals of magnetic field based sensors, also.

Very strong magnetic fields can also lead to a permanent damage of certain components (permanent malfunction with the danger of not detecting a vehicle).

For the evaluation of the magnetic field emissions, the frequency shifts, resulting from a running field source (vehicle) have to be considered.

Measurements of the magnetic field emissions of an ECB in the track area have been carried out in 2001 on a line section of the line Minden – Bad Oeynhausen. In the frequency area from 10 Hz to 10 kHz maximum field emissions over 2 mT were detected for frequencies lower than 300 Hz (over 300 Hz the emissions reduced rapidly, main part resulting from the single ECB-poles). In the frequency area from 10 kHz to 100 kHz maximum magnetic field emissions up to 20 µT were detected.

3.1 INFLUENCED SIGNALLING SYSTEMS

3.1.1 Axle counters and wheel sensors

Magnetic fields emitted by the ECB may have two main influencing mechanisms on axle counters. Depending on the intensity and the frequency of the emitted magnetic fields (x, y, z-direction) axle counters can be influenced and disturbed within the working frequency range of the axle counter detector/wheel sensor (generation of further non existing axles/delete of existing axles). Furthermore as result of the magnetic saturation of the rail the magnetic behaviour of the rail changes and the typical characteristic wheel curve of axle counters will vary significantly.

All these effects could lead to a miscount of axles or the detection of non existing wheels and so to restrictions in the railway operation or at certain specific cases (e.g. sensors used for the control of level crossings) to safety relevant issues.

Remarks: Axle counters and wheel sensors working with permanent magnets can be damaged permanently by very high magnetic fields (demagnetised). As this are typically (older) permanent magnetic components with a reduced number of installations this effect has not to be considered in the project.

Tests at different development states have shown that the influence on axle counters was more significant / critical for:

- a power supply via DC voltage link (in comparison with a former battery supply)

- smaller axle to axle distances at the bogie

- ECB with a higher number of magnetic poles (e.g. increase from 6 to 8)

For axle counters, working on base of magnetic transmitters and receivers (e.g. ZP 30 or ZP 43), the intensity of the magnetic coupling between ECB and axle counter increases with the frequency.

In 1999 and 2000 several tests were realized with different ECB-optimized types of axle counters (e.g. ZP30 with Sk 30 H - WB, ZP 43 M/E - WB; worst case mounting/operation conditions) and with modified ECB (e.g. with additional choking coils and optimized earthing concept) at the high speed line Fulda – Würzburg. The test runs have shown that the distance to the limit levels was very low (e.g ZP 30) but no axle counter was influenced by the active ECB in way that additional counts occur or that the axle counters reached a disturbance state.

Consideration in the project ECUC: By the test and the authorisation of the ICE 3 train (equipped with ECB) the influence and disturbance of axle counters and wheel sensors by the ECB was a very important topic. The influence of axle counters, working within the single areas of the frequency management of the TSI CCS interface document should be considered.

3.1.2 Speed detection (GPE)

The GPE (speed ckecking facility) uses the output signals of trackside installed balises (Indusi, 500 Hz, 1000 Hz, 2000 Hz) for the determination of the actual running speed of a vehicle. Tests realized in 1999 at the high speed line Fulda-Würzburg have shown, that the ECB induces some sporadically disturbances (peaks). Based on the specific requirements of the GPE-system (e.g. minimum time between single pulses, number of relevant pulses within certain time windows, ..) the GPE system was not disturbed in an unacceptable way [2]. However for the operation of the ICE 3 the switchboxes of the GPE have been modified / replaced [1].

Consideration in the project ECUC: The magnetic field emissions of the ECB in the frequency range of the balises (see above) should be considered in the tests of ECUC project. This includes the specific behaviour of a running vehicle, equipped with an ECB, too (frequency shift in dependency of the running speed).

3.2 Non influenced signalling systems

Note: In this context “non influenced” means that it has been proven that the operation of the ECB does not have any disturbing or damaging interferences or that the signal / noise ratio is sufficient enough to avoid disturbing interferences.

3.2.1 Hot box detectors

Hot box detection systems work in combination with axle counters or wheel sensors of a special type. As some of the used wheel sensors could be influenced by the ECB (see chapter 3.1) this some of these wheel sensors and axle counters have to be modified or replaced to ECB-compatible ones [1]. Further modifications on the hot box detectors itself (e.g. temperature detectors) were not necessary (same situation for DB and SNCF).

SNCF experienced also during tests disturbances on hot box detectors: the poles of ECB (when ECB are applied) were seen as additional axles by the axle detector function of hot box detectors. The solution selected on the “LGV EST” line consisted in inhibiting the axle detector function when a magnetic field generated by the ECB is present, thus avoiding the disturbance of DBC.

Consideration in the project ECUC: No further specific consideration necessary.

3.2.2 Loops for level crossing

In 1999 DB has carried out tests on a section of the high speed line Fulda-Würzburg for the examination of the influence / disturbance of level crossing loops (inducting loops) by ECB. No significant interferences / disturbances had been detected [1].

Consideration in the project ECUC: No further specific consideration necessary.

3.2.3 Cables

Measurements have been carried out by DB for the determination of the influence of the ECB on signal cables (stranded/twisted wires, mounted at the rail foot and in a distance of app. 1 m to the rail, test of normal and earth fault situations, worst case situations) and connected components in 1999 on a line section of the high speed line Fulda-Würzburg. The results show that there was only a insignificant influence up to a frequency of 25 kHz and also above 25 kHz the influence was very low [2].

Consideration in the project ECUC: No further specific consideration necessary.

3.2.4 PZB (Punktförmige ZugBeeinflussung)

The PZB (intermittent automatic train-running control using "Indusi" (inductive train control)) uses for the line side installation same parts (balises, working frequencies 500 Hz, 1000 Hz 2000 Hz) as the GPE-system as described above.

Consideration in the project ECUC: No further specific consideration necessary.

3.2.5 LZB (LinienZugBeeinflussung)

In 1999 on a section of the high speed line Fulda-Würzburg test have been executed to check the compatibility of the ECB (ICE 3) with the LZB-system (continuous automatic train-running control). The evaluation was made on base of the error rate measurement [2]. As there were no disturbances of the LZB-telegram detected, no further activities / modifications of the infrastructure side equipment were necessary [1].

Consideration in the project ECUC: No further specific consideration necessary.

3.2.6 TVM (Transmission Voie-Machine)

Examinations on the influence of TVM by the ECB have shown that influences may occur but these influences do no lead to any disturbances.

The continuous transmission of information is based on the circulation of the signalling current through the rail with an emitter common to the track circuit and the continuous transmission.

Consideration in the project ECUC: No further specific consideration necessary.

3.3 SIGNALLING SYSTEMS WHICH CAN POSSIBLY BE INFLUENCED

3.3.1 KVB (Contrôle de vitesse par balise)

No (specific) tests have been carried out to check the influence of the ECB on the line side KVB equipment. So it is still open, if any significant disturbances will be produced by ECB.

Concerning the working frequencies of the KVB balises:

The KVB balises are powered up by a magnetic field of frequency 27.115 MHz modulated at 50 kHz provided by the rolling stock. The signals returned by the balise are under a frequency of 4.5 MHz.

Concerning the mounting position of the KVB balises:

KVB balises are installed horizontally in the axis of the track, with the main axis the Eurobalise is identical to the axis of the track with a lateral tolerance of +/- 20mm. Usually the height between the top of the rail and the reference superior face of the balise is between 70 and 165mm.

Consideration in the project ECUC: This system will not be checked in this project because disturbing interferences at this range of frequency are not previewed.

3.3.2 Euro balise

Tests and examinations carried out in 2000 on a line section of the high speed line Fulda-Würzburg by Siemens (accompanied by DB) have shown, that euro balises will still work proper / reliable also after the influence by an active ECB [2].

Up to now the influence of ECB on euro balises has not been tested in France (open).

Concerning the working frequencies of the Euro balises:

The on-board antenna provides power to the balises by generating a magnetic field. The magnetic field shall be produced at a frequency of 27.095 MHz with a tolerance of ±5 kHz. For the uplink transmission, the balise shall generate a magnetic field that shall be picked up by the on-board antenna unit. The magnetic field produces two frequencies: 3.951 MHz and 4.516 MHz used for FSK.

Concerning the mounting position of the Euro balises:

Euro balises are installed horizontally in the axis of the track, with the main axis the Euro balise identical to the axis of the track with specific tolerances on each axis and angle (see SUBSET-036 - FFFIS for Euro balise for further information)

Consideration in the project ECUC: Up to know, the tests carried out show eurobalises has not been disturbed by the emission of ECB. Moreover, at the moment, there is not any standard which defines the compatibility between ECB and eurobalises. Nevertheless, the measurement of this signal by means of an on-board system or a non-standard antenna will be studied in the tests of WP5

3.3.3 Track circuits

Measurements carried out on DB network for the FTGS 917 track circuits (remote-fed audio-frequency track circuit) have shown that the use of ECB does not produce disturbing interferences in the working area (9.5 kHz – 16.5 kHz) of the track circuits [2]). For the operation of the ICE 3 train, equipped with ECB, no further activities are necessary concerning track circuits from infrastructure side [1].

Examinations in France have shown that track circuits generally can be influenced and disturbed by ECB. The ECB was compatible with the track circuits on the “LGV Est”-line (UM 71). The frequencies used for the track circuit UM71 are 1700Hz, 2000Hz, 2300Hz and 2600Hz. These frequencies are used one after the other and are the limits of the track sections. As the results have only been obtained for specific track circuits (UM71), the results can not be extended to other types of track circuits.

Consideration in the project ECUC: The measurements of WP5 to check the compatibility between ECB and track circuits will be based on the EN50238-2, where the measurement of feeding current of the train is defined. This current will be processed after the measurements and possibly (if estimated relevant by the project) added in the model focusing on specific features to check the compatibility of ECB equipped trains.

3.4 ECB COMPATIBILITY LIST

To avoid incompatibilities of the ECB with components of signalling systems mounted or used on the track and to avoid safety or reliability relevant problems an "ECB compatibility list" [1] has been established in Germany after initial compatibility problems with the ECB of ICE3 and signalling systems. This list describes procedures which have to be done trackside concerning signalling systems before the infrastructure manager and the national safety authority gives permission to use the ECB. Depending to the type of axle counter or wheels sensor several actions are necessary to prevent damage or malfunction of signalling systems. For this purpose four categories have been defined:

0 = no changes necessary

1 = only little chances necessary on trackside components (e.g. replace of electronic components trackside or of the complete axle counter sensor or wheel sensor).

2 = usually a complete axle counter detector or wheel sensor has to be replaced into a type that is compatible with ECB; so far necessary some electronic parts within the interlocking also have to be replaced.

3 = massive changes on trackside components and/or within the interlocking are necessary.

4. INTERACTION WITH THE INFRASTRUCTURE

This section describes the thermo-mechanical and the mechanical effects of ECB in the infrastructure.

4.1 RAIL TEMPERATURE

The temperature of the rail head increases when a switched on ECB passes over it.

The acceptable rail temperature is addicted to infrastructural matters. E.g. on slab track a higher rail temperature can be permitted compared to a track consisting of sleepers and ballast. So the threshold cannot be set in general.

If an active ECB with maximum brake force passes over the rail the rail temperature increases up to 5.6 K. Depending on the brake forces the temperature increase could be smaller. For a typical service brake application an increase of 2.5 K is normal. These values come from tests with ICE 3.

SNCF has also experiences regarding temperature increase.

Putting all information together you get as a typical average maximum temperature increase of 0.036 K/kN (depending – amongst others - on the type and the material of rail). This law has been obtained during tests on ICE3 train, and cannot necessarily be applied to other type of implementations of ECB. This temperature increase can be considered as an additional source of constraints, taking into account the other already existing: natural heating of the rail, interaction with engineering structure… Operational rules have to be defined in consequence to avoid the increase of temperature.

If the rail temperature is limited due to infrastructural reasons it is necessary to provide a system that observes the temperature and allows or prohibits braking with ECB according to the current temperature.

The increase of the temperature and the resulting forces in the track should be considered within the project.

See also [16], [17] and [18].

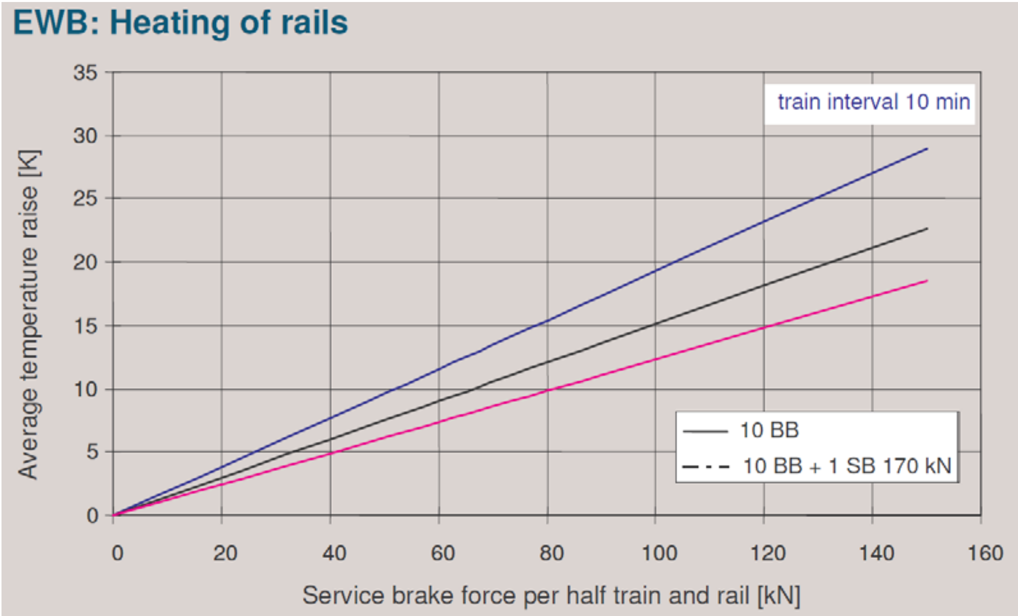

Figure 3: temperature of the rail depending to brake force (ECB type EWB154R of ICE3 [19])

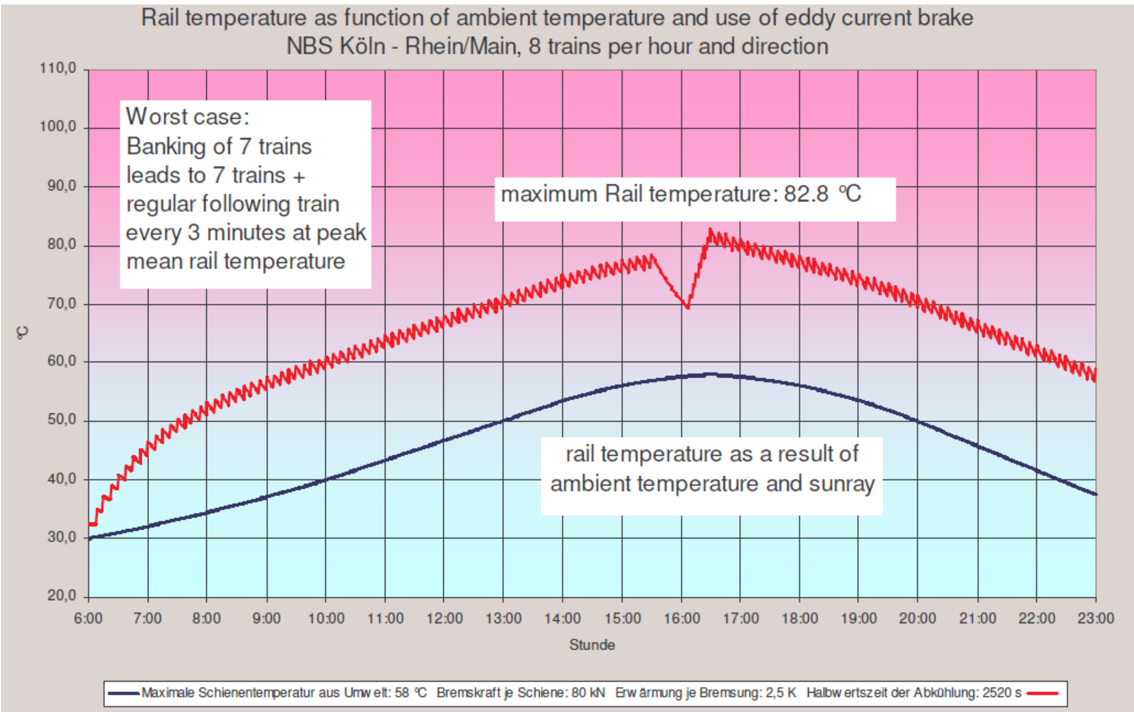

Figure 4: temperature as a function of ambient temperature and use of ECB (ECB type EWB154R of ICE3 [19])

4.2 Mechanical Stress

It is necessary to limit the forces to avoid resistant deformations to track and switches, see [7].

4.3 Mechanical contact

Any mechanical contact of the ECB with the rail or other objects may damage the ECB. The following Figure 5 and Figure 6 show examples for damages caused by contact with the rail or contact with unknown objects. So it is very important to insure by maintenance means a correct adjustment of the air gap. Due to the wear of the wheels every 150,000 km the air gap is readjusted to a specified value of 5 – 7 mm [8].

Contact of the coils with unknown objects (e.g. ballast) can not be avoided completely. Therefore protective plates have been added to the underside of the ECB coil former to protect the coils (see Figure 7).

Under normal conditions no contact between ECB and rail should occur. Contact with unknown objects can not completely be avoided.

Figure 5: damage to ECB from collision due to insufficiently large air gap [8]

Figure 6: damage to ECB from collision with unknown objects [8]

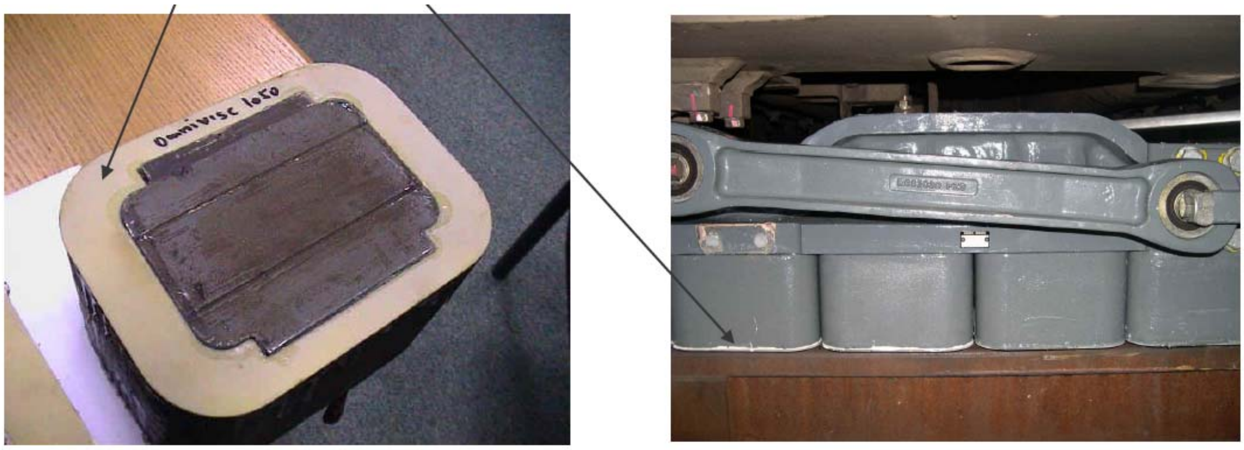

Figure 7: protective plates around the coil former of the ECB [8]

4.4 SUCTION OF METAL PARTS, COVERS

Resulting from stray fields of the ECB it could be possible that loose metal parts near the rail are attracted by an active ECB. Before and during the first month of ICE 3 operation all ferromagnetic equipment near the track was fixed and the correct position (below top of the rail) was checked.

Especially the housings that cover the motors of switches are sometimes critical and have to be fixed properly

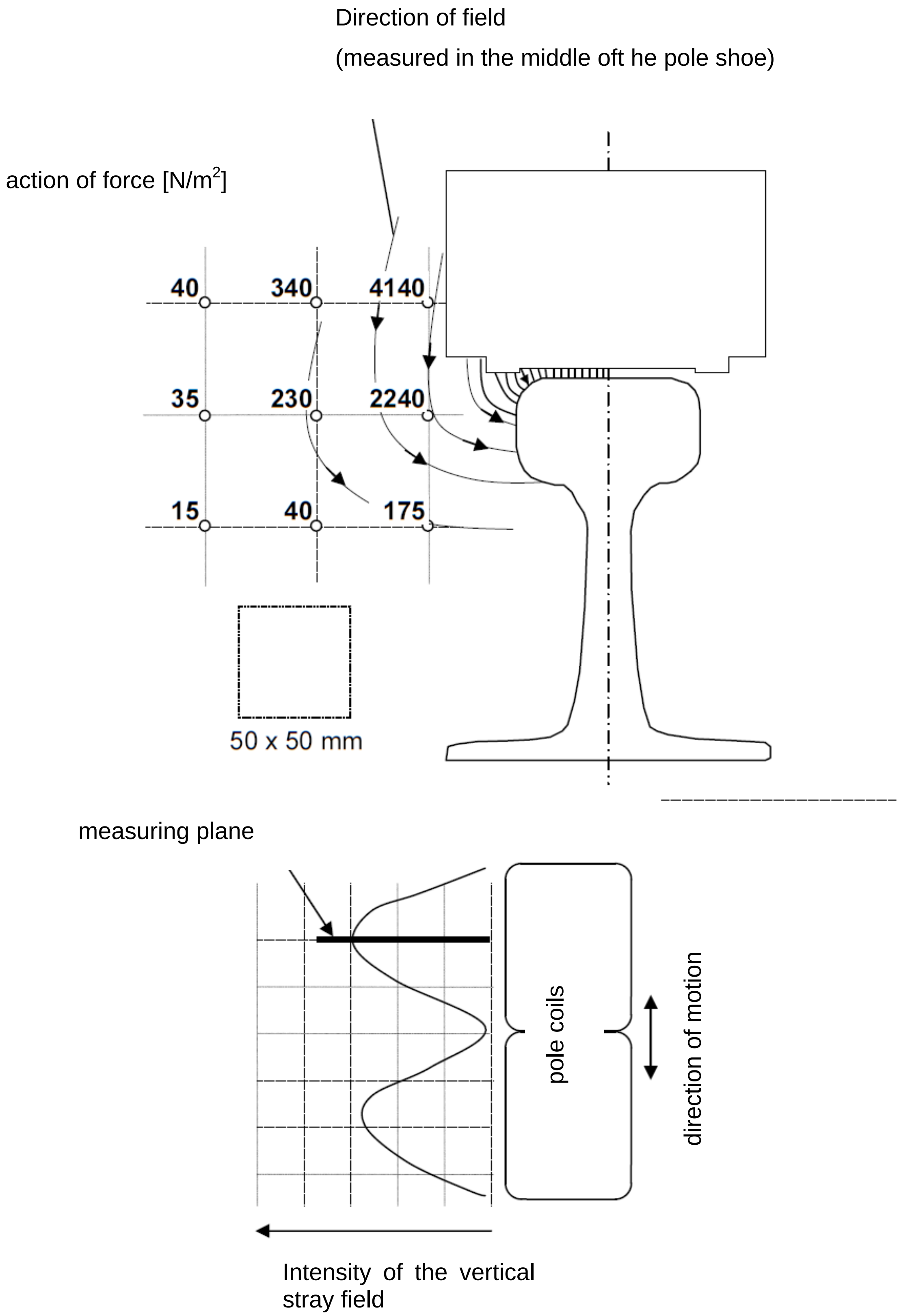

Figure 8: ECB Type EBW 154 R – Forces of the ECB under normal operating conditions to magnetisable objects referred to their surface

The given forces [N/m^2] and the shown field profile are valid for the area of the middle of the pole shoe (local maximum).

5. ECB ACTUAL OPERATING CONDITIONS

ECB are actually installed in all train sets of Deutsche Bahn class 403, 406 and coming class 407 (all known as ICE 3).

5.1 ECB CONFIGURATION

The trailer bogies are equipped with an ECB. So one ICE 3 trainset has four cars with ECBs in total.

In [3] detailed information can be found.

5.1.1 Minimum speed

Under a speed of 50km/h the attractive force outranges the brake force. As a consequence the ECB is switched off.

5.1.2 Brake cycle

Maximum temperature of the coils

As result of the very high current in the coils the temperature of the coils increases very fast and could – if a maximum temperature of over 200°C was reached – destroy the coils. This has to be avoided. Therefore the current temperature is permanently calculated by a computer program. If the temperature comes up to a limit value during a service brake the ECB is switched off. This variable limit value is set in the manner that it is enough thermal reserve to use the ECB for the next emergency brake. The absolute limit temperature of the coils is set at 200 °C.

As this value is limited, it should be considered by the next steps of the project.

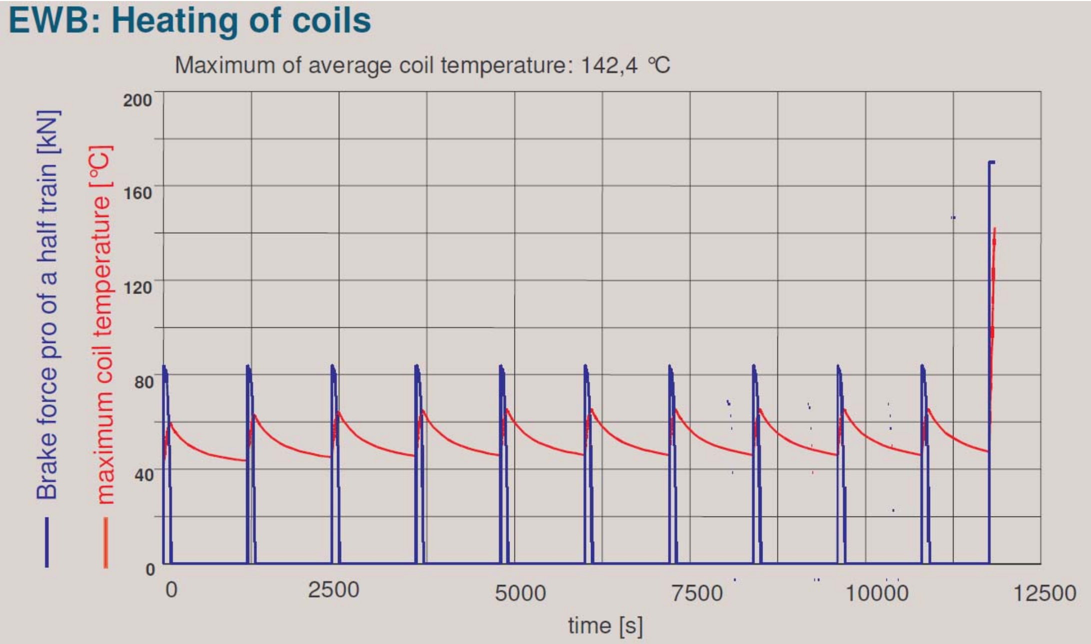

Figure 9: temperature of ECB coils depending to brake cycles for ECB type EWB154R of ICE3 [19]

5.2 INFRASTRUCTURE

Today it is allowed to use the ECB of an ICE 3 on slab track for service and emergency braking. The permission is given via LZB-CEII, later via ETCS.

On tracks with heavy or lightweight ballast the use of ECB is restricted. It is necessary to check every type of track relating to effects of temperature increase.

If there is and use of non magnetic parts in the track, especially at switches, it must be checked if the ECB can deal with this conditions. Until now no issues has arisen.

The ECB is used on UIC 60 and S54 track with an inclination of rail of 1/40 and 1/20.

5.3 OPERATIONAL CONDITIONS

5.3.1 Germany (DB)

Three categories of lines defined. ECB is

- permitted for service and emergency braking,
- permitted only for emergency braking (disturbances are accepted and are not safety relevant),
- completely forbidden (signalling components can be destroyed --> safety relevant issue).

5.3.2 France (SNCF)

For the emergency braking, if all the conditions are respected, ECB can be used from the maximum speed of the rolling stock to 50 km/h on classical lines and high speed lines of the French Railway Network (RFN), with the exception of lines specified in the trackside register.

For service braking, ECB cannot be applied on classical lines of the French Railway Network (RFN). If all the conditions are respected, ECB can be used from the maximum speed of the rolling stock to 50 km/h on high speed lines, depending also on the authorization given by the trackside register.

5.4 TEST METHODS

5.4.1 Type test (manufacturer)

Amongst others each magnet of the ECB leaving the manufacturer Knorr Bremse has to be checked concerning its interaction with the axle counter ZP43E on a special test bench. This axle counter has been chosen as a representative for all other ECB-compatible types. These measurements are performed by the manufacturer Knorr Bremse for each ECB-Magnet. It provides so called "fingerprints" individual for each ECB-magnet. Only magnets whose fingerprint curves are within a defined range are considered to be compatible with signalling systems. This range has been established by the use of an ECB on an ICE-3 whose ECB has been proven for compatibility with axle counters and wheel sensors. See also [5].

5.4.2 France (SNCF)

It has to be checked, that antennas and sensors (e.g. for automatic train control systems) mounted on the vehicle will be not disturbed by the ECB [21].

Hot box detectors, axle counter and wheel sensor shall not be interfered [20].

In any case the operation of the ECB shall not create transversal currents in both rails in order to avoid malfunction of track circuits [21].

5.4.3 Germany (DB) – axle counters and wheel sensors

According to [6]:

"The scope of inspection, the detailed test program and the criteria for evaluation shall be defined by the manufacturer (vehicle and axle counter detector / wheel sensor), operator and national safety authority (Eisenbahn-Bundesamt)".

In case of the German high speed trains ICE3 and Velaro D for example several test runs were performed during the last years.

5.5 MAINTENANCE

Before each train run a functional check of the complete brake system of the train and so inclusive the ECB is mandatory and performed almost automatically triggered by the train driver. An intensive check is mandatory during maintenance inspection in the workshop. Every 24 hours a brake test has to be done. During this test the ECB is checked mechanically and electrically.

During every braking the ECB is observed by a diagnosis system. If any failure is detected the affected ECB is switched off automatically and the driver gets information about less brake performance.

During regular maintenance work the ECB is checked visually. If necessary the air gap is adjusted.

Small mechanical defects (e.g. if ECB was hit by an object) can be repaired during regular maintenance work.

6. ENVIRONMENTAL INFLUENCE

6.1 HUMIDITY

Especially in winter the ICE 3 has to fight with problems concerning short-circuits to ground. These short circuits lead to a switched off ECB. For more information refer to [9], [10], [11], [12], [13], [14] and [15]. The cause for these short circuits is humidity in series inductor boxes caused by poor quality workmanship on cable inlet [8].

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