Proceedings of 2010 ASME Rail Transportation Division Fall Technical Conference
RTD2010
October 12-13, 2010, Roanoke, Virginia, USA

RTDF2010-42009

CHARACTERISTICS OF EDDY CURRENT BRAKING

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ABSTRACT

Eddy current braking has long held the promise of frictionless braking of railroad trains. The advantages of eliminating friction brake equipment are particularly valuable to high speed rail passenger service. Tests over the last decade have identified a number of controllable challenges to implementing eddy current brakes involving the vehicle, track, and wayside equipment. High speed trains equipped with eddy current brakes are in service in Europe and under consideration worldwide. This paper illustrates the fundamental characteristics of eddy current braking, locates the technology with respect to other braking systems technologies, and highlights wayside compatibility issues involved in deploying high speed trains with eddy current braking.

INTRODUCTION

High Speed Rail (HSR) imposes challenging demands on friction and dynamic braking systems. Braking capacities are constrained by space and weight limitations on the train with consequent limitations on the rate at which the braking energy can be dissipated as heat or electrical energy. Eddy current braking systems dissipate the braking energy in the running rails and do so without any reliance on wheel/rail adhesion or wear of friction brake components. The capability of the rails to store and dissipate heat is higher than that available on the train (though not unlimited) therefore eddy current braking is a natural complement to friction and dynamic braking in high speed service.

Eddy current equipped trains have successfully operated on a few European lines for years, however, the cost of adapting the infrastructure and concerns about rail heating and electromagnetic compatibility have impeded widespread use. Trial installations are underway in Japan and South Korea. Current TSI regulations promote the consideration of ECB compatibility for new European HSR lines primarily to address lower noise limits. [1]

NOMENCLATURE

DB	Deutsche Bahn
EB	Emergency Braking
ECB	Eddy Current Brake
EIM	European Infrastructure Managers
Fa	Magnetic attractive force
FB	Eddy current braking force
FSB	Full Service Braking
HSR	High Speed Rail
ICE3	An integrated 8-car train introduced on DB in 2000
LZB	Linienzugbeeinflussung – Train control system used on DB high speed lines
ma	Mass equivalent of Fa
TSI	Technical Specification for Interoperability promulgated by the European Railway Agency

OPERATING PRINCIPLE

Eddy current brakes (ECB) employ Lenz's Law that states that an induced current is always in such a direction as to oppose the motion or change causing it. Large electromagnets carried between the wheels induce electrical currents in the running rails as shown in Fig. 1. The swirling eddy currents induced in the rail not only create an opposing magnetic field but also give rise to ohmic losses that convert the electrical energy to heat. This is a distinctly different principle than used by track brakes that employ electromagnets to clamp brake shoes to the top of the running rail and produce braking effort by the friction between the shoes and the rail head. ECBs do not make any contact with the rail, are unaffected by rail head adhesion, and are noiseless.

The drag effect produced by the eddy currents is a function of the strength of the magnetic field, the gap between the magnet and rail, properties of the rail, and the speed of the train. In practice, it has the desirable feature of being nearly constant above 50 km/h (30 mph). Varying the energizing current

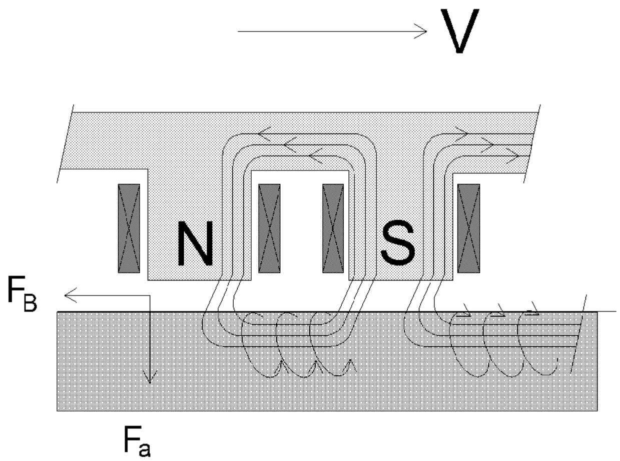

Figure 1 Braking (F_B) and attractive (F_a) forces

provides control of braking effort from zero through full service and emergency rates.

Since rails are steel, there is an additional attractive force between the magnets and rail perpendicular to the braking force. The attractive force is low at high speed and rises exponentially as speed decreases. It approximately equals the braking force in magnitude around 200 km/h (125 mph) and exceeds the braking force by a factor of three or greater below 50 km/h (30 mph). The ECB braking effort must be reduced at low speed so that the attractive force plus the train weight stays within the axle loading limit of the track structure.

WAYSIDE COMPATIBILITY

The fact that ECB utilizes the rail as an integral part of the braking system imposes new demands on the design of the track and wayside systems related to safety and structural stability. Application to existing lines may be cost prohibitive or not technically feasible. Incorporating compatibility requirements into new lines raises capital costs. Wayside maintenance costs are increased in both cases. [2]

Major compatibility issues include:

- Rail heating
- Track uplift
- Physical clearance with guarded points and other track components
- Augmentation of axle loading
- Magnetic compatibility with wayside equipment such as point machines, hot wheel detectors and covers for equipment enclosures
- Electromagnetic compatibility with signaling and train detection systems

The dissipation of braking energy in the rail creates longitudinal forces due to thermal expansion. Repeated stopping of trains at a signal, for example, may raise rail temperature to a point at which track buckling becomes a consideration. Train frequency and headway are factors in the consideration of the suitability of a line for ECB compatibility. The train driver must manually disable ECB on lines not certified for its use.

Emery [3] suggests that use of ECB only for emergency braking can mitigate or eliminate the rail heating issue. This is possible if dynamic and friction braking alone can achieve the required full service braking rate at high speed.

Track uplift is a factor at low speeds due to the magnetic attractive force. Currently DB certifies ECB use only on slab track because of its ability to resist the additional track stresses from uplift and rail heating.

The attractive force augments axle loading as an apparent additional mass equal to the force divided by standard gravity:

$$m_a = \frac{F_a}{g}$$

The ECB control must limit the exciting current at low speeds so that the mass equivalent plus the ordinary carriage weight complies with axle loading requirements.

Careful survey of the line is required to ensure physical clearance between the ECB truck-mounted components and all track structures. There are reports that in some cases it was necessary to replace wayside equipment box covers with non-magnetic materials to avoid being torn off by the attractive force. [4]

Voltages and currents induced by the passage of ECB magnetic field can disrupt the function of the signal system and wayside axle counters. This is a significant operational safety issue that requires the highest level of verification. Schykowski [1] reports that remnant magnet flux in inactive ECBs interfered with axle counters on the Cologne – Frankfort line during its certification testing.

PRACTICAL APPLICATION

Figure 2 shows the Knorr Bremse model EWB145R eddy current brake installed on an ICE3 truck. The unit consists of two electromagnet assemblies, a frame, torque bars, pneumatic lifters, and height adjusters. Weight of the truck-mounted unit is 860kg (1,900 lb). Associated cabling and control units add to the total system weight.

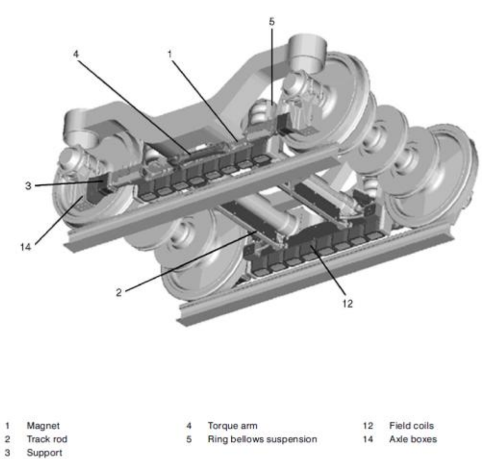

Figure 2 ECB installation on ICE3 truck (courtesy Knorr Bremse)

Each ECB unit provides up to 19 kN (4,270 lbf) for full service brake and 21 kN (4,720 lbf) for emergency braking. There are eight units deployed on cars 2, 4, 5, and 7 of an 8-car trainset. ECB-equipped trucks are fitted with three axle-mounted brake disks per wheelset. The trucks on cars 1, 3, 6, and 8 are motored and have two axle-mounted disks per wheelset. The two ECB units on each car are connected in series and powered by regenerated energy from the traction motors in other cars. [5] Peak energizing power is 86 kW per truckset. [6]

Figure 3 shows the braking and attractive forces versus speed for a single unit with constant excitation for emergency braking.

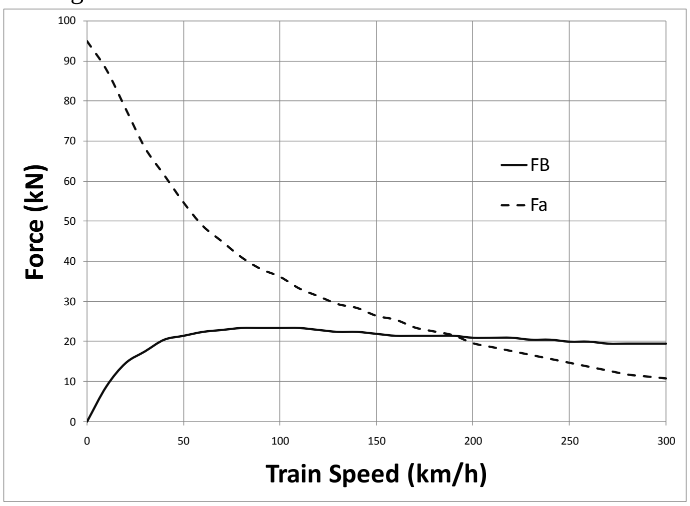

Figure 3 ECB truckset forces with EB energization

The fully loaded ICE3 has an average axle load of 13.8 t. European high speed regulations limit axle load to 17 t, therefore, Fa maximum is 63 kN per truck. This occurs at about 45 km/h. In practice, the onboard control system deenergizes the ECB system below 50 km/h.

ICE 3 combined braking systems exceed the deceleration requirements of Linienzugbeeinflussung (LZB) train control as shown in Fig. 4.

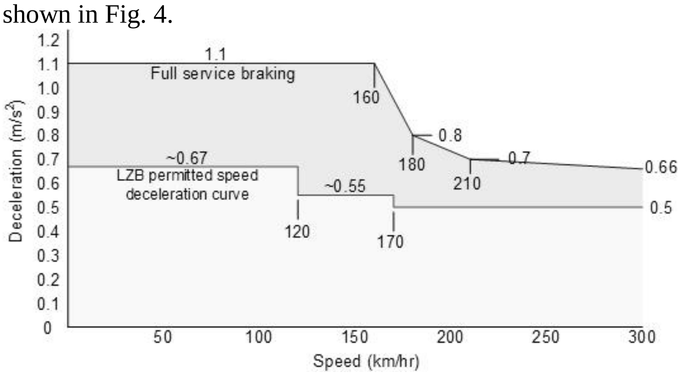

Figure 4 ICE 3 braking rates [7]

Figure 5 shows a representative brake blending curve, however, due to the complexity of the onboard vehicle control system and the number of variables taken into account this curve cannot be considered typical or definitive. The figure shows that ECB provides half the braking effort from 330 km/h to 200 km/h at which speed dynamic braking dominates until it fades at low speed.

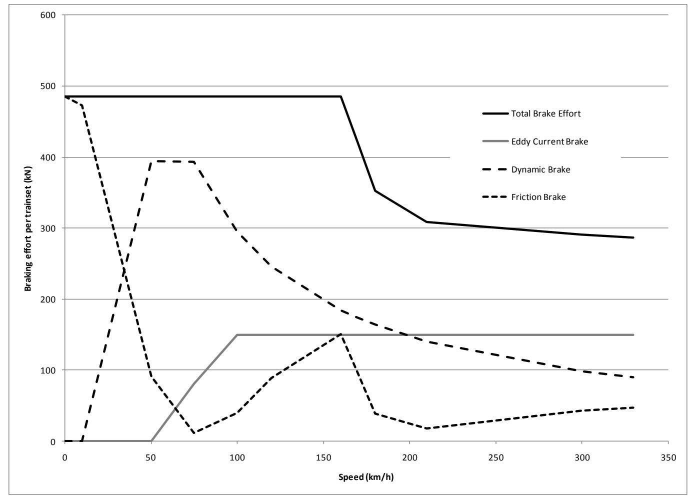

Figure 5 Representative brake blending curve

When not active, pneumatic lifters hold the ECB in a high position to maximize clearance to track components. Upon activation, air is vented from the lifters and the ECB drops to its low position 7 mm above the rail head. Air pressure is linearly ramped up between 200 km/h to 100 km/h to maintain the air gap by countering deflection in the ECB support. The pressure is constant below 100 km/h until the ECB is deactivated at low speed.

Knorr recommends checking the air gap adjustment every 20,000 km and when wheelsets are turned or replaced.

Rail temperature rise depends on brake entry speed, braking effort, and train headway. Ten trains making FSB applications at a signal, for example, on ten minute headways followed by one train making an EB raises rail temperature by 31°K. [6] This temperature rise adds to the ambient temperature and rail heating caused by solar radiation.

Temperature of the ECB magnet windings are monitored by the onboard control system to prevent winding temperature from exceeding 200°C.

ACKNOWLEDGMENTS

The author gratefully acknowledges the assistance of Andrew Long, Manager System Engineering & Design, Knorr Brake, Westminster, Maryland in providing product documentation.

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