

Rail vehicle with adjustable compensation brakes, associated braking method

The present invention relates to a railway vehicle able to travel on rails, including:

- wheels in contact on the rail;
- braking means inside the railway vehicle; and
- 5 - a mechanical compensation brake including a moving part able to come into contact with the rail to apply a braking force.

In a known manner, the braking system in the subway field employs two different kinds of braking, which are based on three different technical devices.

10 The two known braking modes are service braking, i.e., braking in a normal situation requiring a deceleration that is done gradually (for example, arrival in station, curved track, slowing of the previous train) and emergency braking, which is done in unanticipated cases over short distances.

The service braking mode is controlled by the dynamic traction/braking unit.

15 The emergency braking mode is activated by a train line. If there is no potential on this line, the tractive units inhibit their dynamic traction/braking equipment (electric) as soon as possible and safely, and apply emergency braking.

The known technical braking devices are the electrodynamic brake and the mechanical friction brake for internal braking devices, and the compensation brake, made up of an external braking device.

20 In the service braking mode, the electrodynamic brake uses the electric propulsion motor of the vehicle, by acting on a generator when it is driven by the wheels and dissipating the electrical energy produced at the output of the motor, for example a resistive load.

25 The additional presence, in the service braking mode, of the mechanical friction brake, mounted directly on the wheels, makes it possible both to offset any failure of the electrodynamic brake by substituting itself therefor and to complete the electrodynamic brake when the latter does not make it possible to provide sufficient braking by itself.

30 The adherence between the wheels and the rails can be decreased, for example due to rain or the presence of leaves on the rails, and also by the use of the mechanical friction brake itself. Thus, the braking of the mechanical friction brake is no longer correctly ensured. Furthermore, a failure of the mechanical friction brake may occur. In the aforementioned cases, the braking of the railway vehicle is not sufficient and safety must be guaranteed by elongating safety distances between the trains or lower-speed train control programs.

35 Thus, it is common to add, on the railway vehicles, in addition to the electrodynamic brake and the mechanical friction brake, an additional safety brake

independent of the wheel-rail contact, called compensation brake. The compensation brake is only activated in emergency braking mode and only in case of insufficient braking, or in case of malfunction of the mechanical friction brake.

The compensation brake allows, in a known manner, a mechanical action directly on the rails under electromagnetic command. The compensation brake is made up of magnetic pads, which ensure a high braking value of the railway vehicle.

It is also known that the compensation brake is able, in case of friction on the rails, the "clean" the rails, and thus to increase the adherence coefficient between the rails and the wheels, if the rails are wet, for example.

The current magnetic pads making up compensation brakes are used exclusively in emergency braking mode, i.e., in extreme situations, and are then used to the maximum of their braking capacity. This is why the magnetic pads performing the compensation brake function are controlled in all-or-nothing mode. Thus, the variation in deceleration between the moment preceding the activation of the magnetic pads and the activation moment thereof may be significant. This deceleration variation, also known as Jerk effect, causes an uncomfortable feeling for passengers.

The braking of the known compensation brakes is further often greater than what is necessary to ensure good passenger safety. Their operation in "all-or-nothing" mode causes abrupt braking, which must be taken into account when determining the safety distance between successive sets of wagons. This increased safety distance between two consecutive railway vehicles limits the capacity of the railway traffic on the same line.

The invention thus aims to reduce the safety distance between two successive cars on a same track, and to propose a vehicle that makes it possible to ensure greater traffic while remaining safe.

To that end, the invention relates to a railway vehicle of the aforementioned type, characterized in that it includes a compensation brake including means for regulating the braking force applied on the rail as a function of the actual deceleration of the railway vehicle, the regulating means being able to apply intermediate braking forces to the compensation brake comprised between extreme braking forces of the compensation brake.

The use of a compensation brake with a configurable force makes it possible to reduce the safety distances.

The on board compensation brake makes it possible to safely contribute additional deceleration, to the extent necessary, to the actual deceleration of the train, i.e., the intensity of which is configurable, through a solution independent of the wheel-rail contact.

This principle makes it possible to increase the braking capacities on the entire line and to compensate for the braking decreases related to losses of adherence or any braking failures on the rolling stock.

The braking compensation uses the real-time acquisition of the actual deceleration of the train and the calculation of just the necessary additional compensation force to be applied, and lastly the configurable application of the braking owing to the magnetic friction pads installed on board.

This configurable compensation brake remains primarily intended for use in the emergency braking mode, but could also be involved in the service braking mode.

According to the embodiments, the railway vehicle according to the invention comprises one or more of the following features, considered alone or according to any possible combinations:

- said railway vehicle includes:

- means for providing a reference deceleration value depending on the position of the railway vehicle on the line;

- means for measuring the actual deceleration of the railway vehicle; and the regulating means are able to calculate the braking force to be applied to the rail by the compensation brake, as a function of the deviation between the reference deceleration value and the actual deceleration value;

- the regulating means are able to vary the braking force applied to the rail by the compensation brake continuously, as a function of the actual deceleration value;

- the compensation brake includes several electromagnets, or several permanent magnets, the position of which can be remotely controlled, controlled independently to provide the braking force;

- the braking means inside the railway vehicle comprise:

- an electrodynamic brake including a drive motor of the vehicle able to operate as a generator while being driven by the wheels; and

- a mechanical friction brake able to ensure mechanical braking on the wheels of the vehicle, and means for activating the mechanical friction brake in case of insufficient braking or failure of the electrodynamic brake;

- in a service braking mode, said railway vehicle includes means for successively activating:

- the electrodynamic brake, then

- the mechanical friction brake, then

- the compensation brake under the command of the regulating means, until reaching a desired reference deceleration.

- in an emergency braking mode, said railway vehicle includes means for successively activating:

- the mechanical friction brake, then
 - the compensation brake under the command of the regulating means,
- until reaching a desired reference deceleration.

The invention also relates to a braking method of a railway vehicle traveling on rails including the following steps:

- measuring an actual deceleration of the railway vehicle by measuring means;
- commanding braking means inside the railway vehicle;
- applying a regulated braking force from a compensation brake including a moving part able to come into contact with the rail to apply the braking force, the regulation of the braking force applied by the compensation brake imposing intermediate braking forces comprised between extreme braking forces of the compensation brake as a function of an actual deceleration of the railway vehicle on the compensation brake.

The invention will be better understood upon reading the following description, provided solely as an example, and in reference to the appended drawings, in which:

- figure 1 is a schematic profile view of a railway vehicle according to one example embodiment of the invention, comprising two motor cars and several trailer cars;
- figure 2 is a schematic profile view of a motor car of a railway vehicle according to the invention;
- figures 3 and 4 are flowcharts of the method carried out by the braking control means during the service braking mode and the emergency braking mode, respectively; and
- figure 5 is a diagram of the regulator of the compensation brake.

Figure 1 shows a railway vehicle 10 traveling in a first direction S along a railroad track 12 comprising rails 14.

The railway vehicle 10 is for example a local train, a regional train or even a subway train.

The railway vehicle 10 is supplied with electricity by a general electricity source. The general electricity supply is for example done by a powerline 16 situated above the railway vehicle 10. The powerline is connected to the railway vehicle 10 by a pantograph 18.

The railway vehicle 10 includes a first motor car 20, a second motor car 22, and several intermediate or trailer cars 24 comprised between the first motor car 20 and the second motor car 22.

The first motor car 20 and the second motor car 22 are able to ensure pulling and braking of the railway vehicle 10 when the railway vehicle 10 is traveling on the line 12.

Hereinafter, the term "motor car" indifferently refers to the first motor car 20 or the second motor car 22, the first motor car 20 and the second motor car 22 having an identical structure and function.

In light of figure 2, each motor car 20, 22 for example includes two bogies 25 resting on axles bearing wheels 26 mounted on either side of the axle, the wheels 26 being in contact with the rails 14.

The motor car 20, 22 includes internal braking means 30, a compensation brake 32, visible in figures 1 and 2, and means 34 for controlling all of these braking means.

The internal braking means 30 advantageously comprise an electrodynamic brake 50 and a mechanical friction brake 52.

The trailers do not have an electrodynamic brake 50, but each include a mechanical friction brake 52 and a compensating brake 32.

The electrodynamic brake 50 is a motor brake. It includes a motor 54 driving the vehicle, which is connected, on the one hand, electrically to the catenary 16, and on the other hand, mechanically to the wheels 26. In case of braking, and as is known in itself, the motor is able to produce electrical current under the effect of the driving of the wheels and return this current to the catenary 16 or to a charge (not shown), and thus to brake the railway vehicle 10. A control unit 55 of the electrodynamic brake 50 is installed on the power circuit of the motor to define the circulation direction of the electric current. It is controlled by the control means 34 of the brake.

The mechanical friction brake 52 includes friction sleepers able to be applied directly on the wheels 26 or on discs secured to the wheels, under the control of an actuator 56. The mechanical friction brake 52 is able to be activated during the service braking mode or the emergency braking mode.

Both so-called service and emergency braking modes are present on the vehicle and managed by the braking control means 34.

In the service braking mode, the electrodynamic brake 50 is used as a priority.

In this service braking mode, the mechanical friction brake 52 is able to receive a braking order from the braking control means 34, in the event the deceleration of the railway vehicle 10 caused by the electrodynamic brake 50 is below a desired deceleration value.

In the service braking mode, the mechanical friction brake 52 is stressed at high speeds, automatically under the command of the control means 34 to offset the lack of

power of the electrodynamic brake (motor brake) 50 via the method known in itself called conjugation of the electrodynamic and mechanical brakes.

In the emergency braking mode, the mechanical friction brake 52 alone is activated, to the exclusion of the electrodynamic brake 50.

The compensation brake 32 is a mechanical brake with electromagnetic control able to apply friction directly on the rails 14, which is why it is considered a braking means outside the vehicle. The compensation brake 32 is used in the emergency braking mode and/or service braking mode in addition to the mechanical friction braking 52 or electrodynamic braking 50, respectively.

The compensation brake 32 includes a base 58 secured relative to the bogies 25 of each car of the railway vehicle, and a pad 60 that is movable relative to the base under the control of a set of electromagnets 62 mounted mechanically in parallel between the base 58 and the pad 60.

The pad 60 is movable vertically relative to the base between a raised position, in which the pad 60 is separated from the rail 14, and a lowered position, in which the pad 60 is applied on the upper surface of the rail 14. In figure 2, the moving pad 60 is shown in the lowered position.

The electromagnets 62 are each individually connected to a control unit 64 for their individual power supply.

The control unit 64 is able to selectively power only a determined number of electromagnets as a function of a braking setpoint received from the braking control means 34.

The friction force exerted by the pad 60 on the rail is a function of the number of powered electromagnets 62.

Alternatively, the electromagnets are replaced by one or several actuators with permanent magnets, the force of which applied between the base 58 and the pad 60 can be controlled by the control unit 64 as a function of the setpoint received from the control means 34.

The control means 34 include an automatic train control (ATC) system 74, able to provide a reference deceleration value γ_{ref} , means 76 for measuring the actual deceleration γ_{mes} of the railway vehicle 10, and a unit 78 for computing a braking setpoint for the internal braking means 30 and the compensation brake 32.

In particular, the computing unit 78 is able to regulate the braking force of the compensation brake 32 to apply, to the compensation brake, intermediate braking forces comprised between extreme braking forces, i.e., zero and maximal, of the compensation brake. Advantageously, the compensation brake 32 and the regulation are adapted so

that the compensation brake can apply all of the force values continuously between the extreme braking forces.

As is known in itself, the automatic control system 74 is able to provide a reference deceleration value γ_{ref} that in particular depends on the position of the train on the track, the positions of other trains, the general condition of the train, etc. For example, the reference deceleration value γ_{ref} is equal to 2 m.s^{-2} .

Advantageously, the reference deceleration value γ_{ref} is updated at regular time intervals by the automatic control system 74. Updating the reference deceleration value γ_{ref} thus makes it possible to adapt the braking as a function of the position of the railway vehicle 10 on the line 12. For example, the reference deceleration value γ_{ref} can be lower in the ascending grades than the descending grades to impart an “iso-feeling” of the apparent deceleration of the train by the passengers.

The automatic control system 74 is also able to send an activation instruction for the emergency braking mode. This instruction, denoted EB Request, is able to cause rapid braking of the train. This activation instruction for the emergency braking mode simultaneously includes a deactivation instruction for the service braking mode.

The measuring means 76 are able to measure an actual instantaneous deceleration γ_{mes} of the railway vehicle 10 when the railway vehicle 10 is traveling on the line 12, independently of the incline of the track 14. The measuring means 76 for example comprise an accelerometer or a gyroscope.

Advantageously, the measurement of the actual deceleration γ_{mes} of the railway vehicle 10 is able to be repeated at a regular time interval, for example equal to 100 ms.

The computing unit 78 is connected to the automatic control system 74 and the deceleration measuring means 76 to receive the reference deceleration value γ_{ref} and optionally the emergency braking instruction EB Request, as well as the measurement of the actual deceleration γ_{mes} of the railway vehicle 10.

The computing unit 78 is able to compare the measured actual deceleration γ_{mes} of the railway vehicle 10 measured by the measuring means 76 and the reference deceleration value γ_{ref} .

In the service braking mode, illustrated in figure 3, the computing unit 78 is able to activate, first the electrodynamic brake 50, then the mechanical friction brake 52, in the case where the actual deceleration γ_{mes} is lower than the reference deceleration value γ_{ref} , due to insufficient braking, and lastly the compensation brake 32 if the reference deceleration value is still not reached.

To that end, the computing unit 78 is also able to determine a deceleration threshold of the railway vehicle 10 measured by the measuring means 76, below which

the activation of the compensation brake 32 is necessary in addition to the mechanical friction brake 52.

The emergency braking mode is activated by the computing unit 78 upon receiving an instruction EB Request from the automatic control system 74.

5 During this emergency braking, and as illustrated in figure 4, the mechanical friction brake 52 is first engaged and, if the measured deceleration γ_{mes} is below a desired deceleration γ_{ref} , the compensation brake 32 is activated in addition with a braking force determined by the computing unit 78 to reach the desired deceleration γ_{ref} .

10 In both modes, the control unit 64 is able to receive a setpoint signal for the compensation brake sent by the computing unit 78, and to command the compensation brake 32 with a braking force corresponding to the setpoint to modify the braking force induced by the compensation brake 32, and thus to modify the actual deceleration value γ_{mes} of the railway vehicle 10 so that it reaches the desired value γ_{ref} .

15 The details of the braking method of the railway vehicle according to the invention implemented under the control of the unit 78 in the service braking mode will now be described in light of figure 3.

In the service braking mode, the electrodynamic brake 50 is favored.

20 When the service braking mode is activated in step 302 for the application of a delay in force, a calculation of the force for the electrodynamic brake 50 is first done, as is known in itself, in step 304. This braking force is applied to the electrodynamic brake 50 in step 306.

A test is done in step 308 to determine whether the measured actual deceleration γ_{mes} is greater than or equal to the reference deceleration γ_{ref} provided by the system.

25 If this is the case, a new force for the electrodynamic brake is calculated in step 304 and the braking force is applied in step 306.

If this is not the case, it is determined, during a test done in step 310, whether the maximum capacity of the electrodynamic brake has been used. If this is not the case, a new force for the electrodynamic brake is calculated in step 304 and the braking force is applied in step 304.

30 This force is increased until the actual deceleration γ_{mes} is greater than or equal to the reference deceleration γ_{ref} or until the maximum capacity of the electrodynamic brake 50 is reached.

If, in step 310, this maximum capacity of the electrodynamic brake 50 is reached, the mechanical friction brake 52 is then activated.

To that end, the computing unit 78 determines the necessary force for the mechanical friction brake in step 312 to reach the desired deceleration γ_{ref} . The setpoint thus calculated is applied in step 314.

During the test in step 316, it is determined whether the measured actual deceleration γ_{mes} is greater than or equal to the reference deceleration γ_{ref} . If so, the setpoint applied to the mechanical friction brake is maintained in step 314. If $\gamma_{mes} < \gamma_{ref}$, it is determined in step 318 whether the mechanical friction brake 52 has reached its maximum capacity. If this is not the case, a new calculation of the braking force for the mechanical friction brake 52 is done in step 312. If the maximum capacity of the mechanical friction brake 52 is reached, the compensation brake 32 is activated in step 320 and following.

To apply the compensation brake, in step 320, a calculation of the force to be provided by the compensation brake 32 is done. The braking setpoint is determined by the computing unit 78 as a function of stored abacuses providing the braking force to be applied by the compensation brake 32 as a function of the desired deceleration γ_{ref} , the braking force applied by the electrodynamic brake 50 and characteristics of the track.

In step 322, the setpoint is applied to the compensation brake 32, which then exerts, directly on the rail via the pads 60, from each of the bogies of the railway vehicle, the braking force according to the force calculated in step 320.

In step 324, identical to step 316, the measured actual deceleration γ_{mes} is compared to the reference deceleration γ_{ref} provided by the system 74.

If $\gamma_{mes} \geq \gamma_{ref}$, the force to be applied by the compensation brake 32 is recalculated in step 320 for the purpose of commanding the compensation brake such that γ_{ref} converges toward γ_{ref} ; otherwise, steps 302 and following are carried out again.

It will thus be understood that in the service braking mode, the electrodynamic brake 50 is first used, then, in case of additional braking need, the mechanical friction brake 52 is applied, with a setpoint corresponding to just the setpoint necessary to obtain the desired deceleration. In case of additional braking need, the braking not being able to be exerted by the electrodynamic brake 50 and the mechanical friction brake 52, the compensation brake 32 is applied.

In case of insufficient service braking, while all three types of brakes (electrodynamic, mechanical, then compensation) are applied maximally, the emergency braking mode is activated.

The braking method of the railway vehicle 10 according to the invention implemented under the control of the unit 78 in the emergency braking mode will now be described in light of figure 4.

The emergency braking mode of the railway vehicle 10 is activated, in step 400, by reception of a command EB Request by the computing unit 78 from the system 74, for example following the detection of an obstacle in front of the railway vehicle 10.

5 The mechanical friction brake 52 is activated in step 402 by the computing unit 78 by command of the actuators 56.

The braking force applied in this case by the mechanical friction brake 52 is maximal.

In step 404, the measured actual deceleration γ_{mes} is compared to the reference deceleration γ_{ref} provided by the system 74.

10 If $\gamma_{mes} \geq \gamma_{ref}$, the command of the compensation brake 32 is not activated.

Conversely, if $\gamma_{mes} < \gamma_{ref}$, then the braking force for the command of the compensation brake 32 is calculated in step 406 to reach the reference deceleration γ_{ref} , then this setpoint is applied in step 408.

15 After applying the setpoint via the compensation brake, the test of step 410 is carried out to determine whether $\gamma_{mes} > \gamma_{ref}$.

If it is, steps 402 and following are carried out again.

If $\gamma_{mes} < \gamma_{ref}$, then the calculation of the braking force to be added is carried out again in step 406 to partially reduce the effect of the compensation brake 32 so that the measured deceleration γ_{mes} converges toward the reference deceleration γ_{ref} .

20 The regulator, which slaves the braking force to the deceleration implemented by the computing unit 78 to control the compensation brake 32, is illustrated in figure 5. It ensures a continuous variation of the braking force.

The control setpoint U of the compensation brake is calculated by the computing unit 78 and simultaneously sent to the control unit 64.

25 From the reference deceleration value γ_{ref} of the railway vehicle 10 and the measurement of the actual deceleration γ_{mes} of the railway vehicle 10, the computing unit 78 uses a subtractor to calculate a difference Δ between the reference deceleration value γ_{ref} of the railway vehicle 10 and the measurement of the actual deceleration γ_{mes} of the railway vehicle 10, such that $\Delta = \gamma_{ref} - \gamma_{mes}$.

30 If the difference Δ is zero or negative, the correction provided by the corrector is not applied to the compensation brake.

If the difference Δ is positive, a corrector C(s), implemented by the computing unit 78, determines the setpoint U having to be applied by the compensation brake 32 from its transfer function, denoted C(s). Advantageously, the setpoint U is calculated for each
35 compensation brake of the vehicle, taking into account the weight P of the only vehicle on which the compensation brake is mounted.

This setpoint U is applied to the unit 64 of the compensation brake 32, the transfer function of which is denoted $H(s)$. This results in a deceleration of the train Braking, this force being measured by the measuring means 76.

5 It will be understood that the compensation brake being commanded with a continuously variable setpoint, the value of which is comprised between the two extreme braking forces of the compensation brake and depending in a non-Boolean manner on the actual deceleration of the vehicle, the train can follow the desired reference deceleration very closely.

10 Thus, the abrupt braking caused by the current compensation brakes operating in all-or-nothing mode is avoided, which makes it possible to reduce the maximum distance separating two vehicles on the line, the upstream train no longer fearing abrupt braking of the train situated downstream.

12
CLAIMS

1.- A railway vehicle (10) able to travel on rails (14), including:

- wheels (26) in contact on the rail (14);
- braking means (30) inside the railway vehicle (10); and
- a mechanical compensation brake (32) including a moving part (60) able to come into contact with the rail (14) to apply a braking force;

characterized in that the compensation brake (32) includes means (78) for regulating the braking force applied on the rail (14) as a function of the actual deceleration (γ_{mes}) of the railway vehicle (10), the regulating means (78) being able to apply intermediate braking forces to the compensation brake (32) comprised between extreme braking forces of the compensation brake (32).

2.- The railway vehicle (10) according to claim 1, including:

- means for providing a reference deceleration value (γ_{ref}) depending on the position of the railway vehicle (10) on the line (12);
- means (76) for measuring the actual deceleration (γ_{mes}) of the railway vehicle (10);

characterized in that the regulating means (78) are able to calculate the braking force to be applied to the rail by the compensation brake (32), as a function of the deviation between the reference deceleration value (γ_{ref}) and the actual deceleration value (γ_{mes}).

3.- The railway vehicle (10) according to claim 1 or 2, characterized in that the regulating means (78) are able to vary the braking force applied to the rail by the compensation brake (32) continuously, as a function of the actual deceleration value (γ_{mes}).

4.- The railway vehicle (10) according to any one of the preceding claims, characterized in that the compensation brake (32) includes several electromagnets (62), or several permanent magnets, the position of which can be remotely controlled, controlled independently to provide the braking force.

5.- The railway vehicle (10) according to any one of the preceding claims, characterized in that the internal braking means (30) of the vehicle comprise:

- an electrodynamic brake (50) including a drive motor (54) of the vehicle able to operate as a generator while being driven by the wheels (26); and

- a mechanical friction brake (52) able to ensure mechanical braking on the wheels (26) of the vehicle, and means for activating the mechanical friction brake (52) in case of insufficient braking or failure of the electrodynamic brake (50).

6.- The railway vehicle (10) according to claim 5, characterized in that in a service braking mode, it includes means (78) for successively activating:

- the electrodynamic brake (50), then
- the mechanical friction brake (52), then
- the compensation brake (32) under the command of the regulating means (78), until reaching a desired reference deceleration (γ_{ref}).

7.- The railway vehicle (10) according to claim 5 or 6, characterized in that in an emergency braking mode, it includes means (78) for successively activating:

- the mechanical friction brake (52), then
- the compensation brake (32) under the command of the regulating means (78), until reaching a desired reference deceleration (γ_{ref}).

8.- A braking method of a railway vehicle (10) traveling on rails (14) including the following steps:

- measuring an actual deceleration (γ_{mes}) of the railway vehicle (10) by measuring means (76);

- commanding braking means (30) inside the railway vehicle;

- applying a regulated braking force from a compensation brake (32) including a moving part (60) able to come into contact with the rail (14) to apply the braking force, the regulation (78) of the braking force applied by the compensation brake imposing intermediate braking forces comprised between extreme braking forces of the compensation brake (32) as a function of an actual deceleration (γ_{mes}) of the railway vehicle (10) on the compensation brake (32).