(54) Title: METHOD AND SYSTEM FOR CONTROL OF A REGENERATIVE BRAKING SYSTEM IN A VEHICLE

(57) Abstract: The method and a control unit for controlling a regenerative brake system in a vehicle for which there is a defined maximum speed \( v_{\text{max}} \) which the vehicle should not exceed are presented. According to the present invention at least one predicted speed \( v_{\text{pred}} \) for the vehicle on a section of road is determined. If the at least one predicted speed \( v_{\text{pred}} \) exceeds the maximum speed \( v_{\text{max}} \) along the section of road, the regenerative brake system is then activated before an actual speed \( v_{\text{veh}} \) of the vehicle reaches the maximum speed \( v_{\text{max}} \). The result is braking over more time and with less power than in previous known solutions, making it possible for the regenerative brake system to utilise more of the brake energy than in previous known systems.
METHOD AND SYSTEM FOR CONTROL OF A REGENERATIVE BRAKING SYSTEM IN A VEHICLE

Technical field

The present invention relates to a method for controlling a regenerative brake system according to the preamble of claim 1 and a control unit according to the preamble of claim 28.

The present invention relates also to a computer programme and a computer programme product which implement the method according to the invention.

Background

Vehicles may vary in speed when travelling on a section of road. These speed variations may for example be due to changes in torque demanded from an engine of the vehicle or to the vehicle accelerating or decelerating because of a gradient on the section of road. Vehicles, particularly heavy vehicles such as trucks, buses or any other heavy vehicles, are typically accelerated on downhill runs by their great train weight m, which conversely often decelerates them on uphill runs.

For many vehicles there is a defined maximum speed \( v_{\text{max}} \) which the vehicle should not exceed. This maximum speed \( v_{\text{max}} \) may be used to prevent the vehicle reaching too high a speed, e.g. a speed exceeding the speed limit for the section of road or exceeding a maximum permissible speed for the vehicle.

On a given section of road the maximum speed \( v_{\text{max}} \) may thus be a speed limit which the driver does not wish to exceed, e.g. to avoid risk of being accused of speeding. The driver typically brakes, e.g. by using a brake pedal, if the vehicle exceeds \( v_{\text{max}} \).
Many motor vehicles today are equipped with cruise control. One object of cruise control is to achieve a predetermined uniform speed. Cruise control is often conducted in vehicles by two interacting systems, viz. a cruise control system which demands torque from an engine system, and a downhill speed control system which prevents the vehicle from developing excessive speed, particularly on downhill runs.

The cruise control tries to adjust the engine torque in order to avoid deceleration, or avoid applying brake action, on downhill runs where the vehicle is accelerated by its own weight. A general object of the cruise control is to provide the vehicle driver with easier driving and greater comfort by making it unnecessary for him/her to apply acceleration in order to maintain a set speed \( v_{set} \) chosen by him/her. The set speed \( v_{set} \) is the speed set by the driver which he/she wishes to maintain on level roads. The cruise control then provides an engine system of the vehicle with the set speed \( v_{set} \) for control of the engine system. The set speed \( v_{set} \) is often related to a speed limit for a section of road on which the vehicle is at the time.

A traditional downhill speed control brakes the vehicle automatically when a downhill control speed \( v_{dhsc} \) is reached. The downhill control speed \( v_{dhsc} \) is often related to the cruise control's set speed \( v_{set} \) with an offset so that the downhill control speed \( v_{dhsc} \) is equal to the set speed \( v_{set} \) plus the offset speed \( v_{off} \), i.e. \( v_{dhsc} = v_{set} + v_{off} \). When a downhill speed control is used, the maximum speed \( v_{max} \) corresponds to the downhill control speed \( v_{dhsc} \), i.e. \( v_{max} = v_{dhsc} \).

The downhill speed control thus for example regulates the speed of heavy vehicles on downhill runs on which they are accelerated by their own weight. The regulation by the
downhill speed control uses auxiliary brakes, e.g. a retarder, an exhaust brake and a four-stage electromagnetic brake (Telnaa), or a hybrid system comprising an electrical device which serves as a brake when used in a generator mode of the device. Other types of brakes may also be used by the downhill speed control.

**Brief description of the invention**

On conventional vehicles, downhill speed control braking or driver-controlled braking, e.g. by using a brake pedal, usually represents a complete loss. Downhill speed control braking and driver-control braking are often related to the aforesaid maximum speed $v_{\text{max}}$.

On vehicles provided with a regenerative brake system, some of the total brake energy can be recovered. How much is recoverable depends inter alia on the magnitude of the brake energy and/or the brake energy, and on other parameters specific to the regenerative brake system.

The invention will herein be mainly described in relation to downhill speed control braking, but one skilled in the art will appreciate that similar effects and problems to those which arise in downhill speed control braking may also arise in driver-controlled braking. The principles of the present invention may be applied in substantially all driving situations which allow choice of when to apply brake action.

If the exact time when braking of the vehicle is to commence is not critical from a safety perspective, in which case its timing may be controlled by the control unit according to the present invention, the present invention may be employed. Braking on a downhill run is one example of such a situation.
The present invention may be employed on substantially all types of vehicles which have a regenerative brake system, comprising inter alia hybridised vehicles and totally electric vehicles.

A regenerative brake system may be an integral part of a vehicle's power train, as in a hybridised vehicle in which an electrical machine is run in generator mode during braking so that at least some of the brake energy is utilised.

Regenerative brake systems may comprise one or more from among a battery, a supercapacitor, a flywheel, a spring, a hydraulic pump cooperating with an accumulator, a pneumatic compressor cooperating with a pressure tank, and a device for conveying energy to a consumer on board the vehicle. These devices recover or transfer the energy which is braked away by the brake system. When the energy is conveyed to consumers on board the vehicle, loads may be caused to consume it at times when braking takes place. In favourable conditions, a properly functioning regenerative brake system may recover a substantial proportion of the brake energy.

Previous known downhill speed controls base their function on how an actual speed $v_{act}$ of the vehicle is related to the downhill control speed $v_{dhsc}$, in such a way that brake action is applied when the downhill control speed $v_{dhsc}$ is reached. It then continues to be applied so that the downhill control speed $v_{dhsc}$ is maintained. Such braking often results in a relatively large amount of energy being braked away at high power, which is rarely optimum from a regeneration perspective. In other words, previous known downhill speed controls waste energy through it being braked away at such high power that not all of this brake energy can be utilised by the regenerative brake system, making it necessary to also
use traditional brake systems. The level of the power which can be utilised by the regenerative brake system in previous known systems is thus not optimum for regeneration.

There are two main reasons why high powers are not optimum during regeneration. One is that the regenerative brake system has a maximum capacity, which means that conventional brake systems have to be used if the brake power required is greater than this maximum capacity. Another reason is that the efficiency of the regeneration is lower at higher powers.

All in all, today's known downhill speed control systems result in non-optimum regeneration in the brake system, since they take no account of regeneration-related characteristics of the power train and/or the brake system.

It is therefore an object of the present invention to propose a control which results in a more energy-efficient regenerative brake system.

This object is achieved by the aforesaid method for controlling a regenerative brake system according to the characterising part of claim 1. It is also achieved by the aforesaid control unit according to the characterising part of claim 28, and by the aforesaid computer programme and computer programme product.

The present invention controls when, i.e. at what time/location, the regenerative brake system has to be activated to result in advantageous regeneration in the power train. The invention chooses this time/location earlier than in previous known systems, which means that the braking can take place over a longer period of time, thereby reducing the mean power of the braking, since the energy to be braked away is spread over a longer period of time. This means that the
regeneration takes place at a lower mean power, making it possible for more of the brake energy to be utilised by the regenerative brake system than in previous known systems. The control of the braking will thus be adjusted to the regenerative brake system's capacity for recovering brake energy. In other words, the regeneration is optimised on the basis of the regenerative brake system's regeneration characteristics to make possible a higher proportion of energy recovery.

Using a lower brake power, i.e. by braking over a longer time according to the invention, means that more of the braking can be conducted with the regenerative brake system than in previous known braking at higher brake power. This is advantageous, since no energy is recovered when braking with traditional brake systems. The present invention also achieves lower fuel consumption, since the energy recovered may for example be used subsequently to relieve for example the load upon the vehicle's combustion engine or to operate other consumers on board.

The present invention thus makes it possible to capture and use more of the total brake energy by means of the regenerative brake system than in previous known systems, since more of the brake power is within the regenerative brake system's maximum capacity. Even if the brake power in previous known forms of brake control is below the regenerative brake system's maximum capacity, the efficiency of the regenerative brake system may increase if the present invention is employed. A larger proportion of the brake energy is thus recovered by using the present invention, at brake powers both above and below the maximum capacity.
The time/location for activation of brake action may in favourable circumstances be chosen such that the regenerative brake system can utilise substantially all of the brake energy. This means that substantially no energy is wasted by being simply braked away, since substantially no traditional brake systems are used to lower the vehicle's speed.

A lowered average speed which arises from a lengthening of the braking period according to the invention also has the affect of reducing the air resistance to the vehicle. This means that less energy is braked away by the air resistance, making it possible for more energy to be braked away by the regenerative brake system. Thus more of the braking may be conducted by the regenerative brake system in situations where it is possible to recover the energy. The present invention thus makes it possible for some of the energy previously braked by the air resistance to be recovered by the regenerative brake system.

**Brief list of drawings**

The invention is explained in more detail below with reference to the attached drawings, in which the same reference notations are used for similar items,

Figure 1 is a flowchart of the method according to the present invention,

Figure 2 illustrates an example of a driving situation,

Figure 3 illustrates an example of a driving situation,

Figure 4 illustrates an example of a driving situation, and

Figure 5 depicts a control unit.

**Description of preferred embodiments**
Figure 1 is a flowchart of the method according to the present invention. A first step 101 of the method determines at least one predicted speed \( v_{pred} \) which the vehicle is predicted to follow along a section of road. The at least one predicted speed \( v_{pred} \) is thus here determined for a period of time which the vehicle will spend on the section of road. The section of road is that immediately ahead of the vehicle and may for example have here a length \( L \) of 1000 metres or any suitable length. The at least one predicted speed \( v_{pred} \) may here be determined in various ways and on the basis of various parameters, as described in more detail below.

There is a defined maximum speed \( v_{max} \) which the vehicle should not exceed. A second step 102 of the method according to the present invention activates a regenerative brake system of the vehicle if the at least one predicted speed \( v_{pred} \) exceeds the maximum speed \( v_{max} \) along the section of road, and the activation of the regenerative brake system takes place according to the invention before an actual speed \( v_{act} \) of the vehicle reaches the maximum speed \( v_{max} \). A third step 103 of the method recovers brake energy in the regenerative brake system when brake action is applied.

The second method step 102 therefore analyses whether the at least one predicted speed \( v_{pred} \) determined in the first step will exceed the maximum speed \( v_{max} \) along the section of road. If such is the case, the actual speed \( v_{act} \) at which the vehicle is travelling and the maximum speed \( v_{max} \) are compared to determine when the vehicle's actual speed \( v_{act} \) will reach \( v_{max} \). The regenerative brake system is then activated before \( v_{act} \) reaches \( v_{max} \).

In previous known systems, only the actual speed \( v_{act} \) was compared with the maximum speed \( v_{max} \), and the braking was
activated when \( v_{\text{act}} \) exceeded \( v_{\text{max}} \). The present invention instead identifies first whether braking will be appropriate on the basis of the predicted speed \( v_{\text{pred}} \). It then uses this knowledge to activate the regenerative brake system earlier than in previous known systems, i.e. to choose an activation location \( P_{\text{regen}} \) which is reached before \( v_{\text{act}} \) reaches \( v_{\text{max}} \). This results in braking over a longer period of time and a consequently lower brake power during the braking, making it possible for more of the brake energy to be utilised by the regenerative brake system than in previous known systems.

The prior art method and the method according to the present invention are illustrated schematically in the non-limitative example in Figure 2. A vehicle here embarks upon a downhill run at a first location \( P1 \). In prior art solutions the actual speed \( v_{\text{act, regular}} \) would be increased on the downhill run by the vehicle's train weight \( M \) until it reached the defined maximum speed \( v_{\text{max}} \) at a second location \( P2 \). Only when the actual speed \( v_{\text{act, regular}} \) reached the defined maximum speed \( v_{\text{max}} \) did previous solutions activate the braking. The actual speed \( v_{\text{act, regular}} \) then remained at the level of \( v_{\text{max}} \) until the downhill run ended at a third location \( P3 \) and the vehicle began to lose speed. The vehicle was finally back at the original speed at a fourth location \( P4 \). Prior art thus braked the vehicle between the second location \( P2 \) and the third location \( P3 \).

The present invention determines the at least one predicted speed \( v_{\text{pred}} \) for the section of road ahead of the vehicle. It then analyses the predicted speed \( v_{\text{pred}} \) to see whether it will exceed maximum speed \( v_{\text{max}} \) if no braking takes place. In this example \( v_{\text{pred}} \) would exceed \( v_{\text{max}} \) at the second location \( P2 \) if no braking was effected. According to the invention the braking will therefore be activated at an activation location \( P_{\text{regen}} \) which is before the second location \( P2 \) at which the actual
speed $v_{act}$ according to the invention would have reached the maximum speed $v_{max}$ if no braking was effected. The invention applies brake action until the third location $P_3$ is reached. At a merging location $P_{common}$ situated after the second location $P_2$, the actual speed $v_{act}$ according to the invention coincides with the previous known actual speed $v_{act_{-regular}}$.

As may be seen in Figure 2, the actual speed $v_{act}$ according to the present invention is below the actual speed $v_{act_{-regular}}$ according to previous known solutions from the activation location $P_{reg\_en}$ to the merging location $P_{common}$, which means that the average actual speed $v_{act}$ according to the present invention is lower than the actual speed $v_{act_{-regular}}$ according to previous known solutions. The present invention applies brake action from the activation location $P_{reg\_en}$ to the third location $P_3$, thereby lengthening the braking time by the space between the activation location $P_{reg\_en}$ and the second location $P_2$ as compared with prior art. This means that the braking takes place over a longer distance/time and at lower brake power than in previous known solutions.

The brake power may thus be regulated to a level which is more favourable for regeneration with the regenerative brake system, making it possible for more of the brake energy to be utilised by the regenerative brake system than in previous known systems.

Here and throughout this specification the invention is described in terms of locations such as $P_1$, $P_2$, $P_3$, $P_4$, $P_{reg\_en}$ and $P_{common}$, but one skilled in the art will appreciate that these locations correspond to respective points in time.

The magnitude of the maximum speed $v_{max}$ may be determined in various different ways. If the vehicle is equipped with a cruise control whereby the driver sets for example a desired
set speed $v_{\text{set}}$, the maximum speed $v_{\text{max}}$ may have a magnitude related to the set speed $v_{\text{set}}$. In one embodiment of the invention the maximum speed $v_{\text{max}}$ may exceed the set speed $v_{\text{set}}$ by X percent, i.e. $v_{\text{max}} = v_{\text{set}} \cdot (1 + \frac{X}{100})$. Since the driver often chooses the set speed with respect to a speed limit for the section of road, the maximum speed $v_{\text{max}}$ will often here be also indirectly related to a speed limit for the section of road.

In one embodiment of the invention the maximum speed $v_{\text{max}}$ is related to a downhill control speed $v_{\text{dhsc}}$ of a downhill speed control on board the vehicle. The maximum speed may here be set equal to the downhill control speed $v_{\text{dhsc}}$, i.e. $v_{\text{max}} = v_{\text{dhsc}}$. This embodiment thus provides a connection to the downhill speed control and its use on downhill runs.

The magnitude of the maximum speed $v_{\text{max}}$ may also be related to how the driver behaves when driving the vehicle. If for example he/she often begins to brake at a certain driver-dependent speed $v_{\text{brake\_driver}}$ on downhill runs, the system will learn to set the maximum speed $v_{\text{max}}$ at this value, i.e. $v_{\text{max}} = v_{\text{brake\_driver}}$. The system is thus here adjusted to the driver's behaviour, and if for example he/she begins to brake at a lower speed on downhill runs than previously, the value of the driver-dependent speed $v_{\text{brake\_driver}}$ will decrease.

In one embodiment the magnitude of the maximum speed $v_{\text{max}}$ is related to the nature of the section of road and/or the traffic on it. The magnitude of $v_{\text{max}}$ is therefore decided by one or more characteristics of the section of road, e.g. a speed limit or a road curvature. The characteristics may also comprise the presence or absence of one or more speed cameras and the traffic situation on the section of road, e.g. whether there is any queuing or not.
When the maximum speed $v_{\text{max}}$ is related to surrounding traffic on the section of road, radar may be used to determine a speed of, and/or a distance from, a vehicle in front. The maximum speed $v_{\text{max}}$ may then be determined in such a way that there will be no risk of running into, or coming too close to, the vehicle in front. Radar is used inter alia by adaptive cruise controls (ACC), which mean that radar information is available on board vehicles equipped with such adaptive cruise controls. The extra complexity will therefore be modest in this embodiment.

In one embodiment of the invention the magnitude of the maximum speed $v_{\text{max}}$ may vary along said section of road. In other words, $v_{\text{max}}$ is dynamic. Its magnitude may for example here be a function of time or locations on the section of road. It may then for example take the form of a vector with possibly different values pertaining to different times/locations.

In one embodiment of the present invention the predicted speed $v_{\text{pred}}$ is determined on the basis of knowledge of the section of road. This knowledge may be based on one or more from among positioning information, e.g. GPS (global positioning system) information, map information, topography information, weather reports, information communicated between vehicles and information communicated by radio, and may comprise knowledge of prevailing topography, road curvature, traffic situation, roadworks, traffic density and road surface states. It may comprise a speed limit for the section of road ahead and a traffic sign pertaining to the road. Many vehicles today are provided with systems, e.g. navigation systems and cruise control systems, which use such information. This embodiment may therefore be implemented with little additional complexity in vehicles where the information is already available.
Figure 3 depicts a non-limitative example of using knowledge of the section of road in the same driving situation as in Figure 2. The actual speed $v_{act_{-regular}}$ and the braking in prior art are as described above as in relation to Figure 2.

In one embodiment of the present invention, where there is knowledge of the section of road, the determination of the at least one predicted speed $v_{pred}$ takes this knowledge into account. The predicted speed $v_{pred}$ largely corresponds in the diagrams to the curve of the actual speed $v_{act_{-regular}}$ in prior art. As the control unit which conducts the determination of $v_{pred}$ then has very good knowledge of the nature of the section of road ahead, a very exact determination of $v_{pred}$ may be made. This very exact predicted speed $v_{pred}$ may serve as a basis for determining the braking in such a way that the energy recovery for the regeneration in the regenerative brake system is maximised while at the same time the vehicle maintains a suitable actual speed $v_{act}$ at the end of the downhill run. The braking may also be commenced earlier, since the control unit can with great certainty predict that $v_{act}$ will exceed $v_{max}$ if no braking takes place.

This is illustrated in the example in Figure 3, in which the at least one predicted speed $v_{pred}$ for the section of road ahead of the vehicle is determined and analysed to see whether it will exceed the maximum speed $v_{max}$ if no braking takes place.

As mentioned above, the predicted speed $v_{pred}$ corresponds here largely to the curve of the actual speed $v_{act_{-regular}}$ according to prior art. As the control unit knows that predicted speed $v_{pred}$ is reliable, it can already apply brake action at the beginning of the downhill run, i.e. at the first location PI. The activation location $P_{reg_{en}}$ thus here coincides with the first location PI, i.e. $P_{reg_{en}} = P1$, which is before the second location P2 at which the actual speed $v_{act}$ according to the
invention would have reached the maximum speed \( v_{\text{max}} \) if no braking was effected. The second location \( P_2 \) is in fact also where previous known solutions would have begun to apply brake action. In this embodiment, brake action may therefore be applied immediately when the vehicle begins to accelerate on the downhill run, since on the basis of knowledge of the section of road this acceleration can easily be predicted to reach \( v_{\text{max}} \).

The invention applies brake action until the third location \( P_3 \) is reached. In this example the third location \( P_3 \) coincides with the merging location \( P_{\text{cor}} \), i.e. \( P_{\text{common}} = P_3 \), which is where the actual speed \( v_{\text{act}} \) according to the invention and the previous known actual speed \( v_{\text{act-regular}} \) again coincide.

As may be seen in Figure 3, the actual speed \( v_{\text{act}} \) according to the present invention is below the actual speed \( v_{\text{act-regular}} \) according to previous known solutions for a relatively long time, from the activation location \( P_{\text{regen}} \) to the merging location \( P_{\text{common}} \). The average actual speed \( v_{\text{act}} \) according to the present invention will thus be below the average actual speed \( v_{\text{act-regular}} \) according to previous known solutions over the same period beginning at the first location \( P_1 \) and ending at the third location \( P_3 \).

The present invention applies brake action from the activation location \( P_{\text{regen}} \) to the third location \( P_3 \), thereby lengthening the braking distance/time by the space between the first time location \( P_1 \) and the second location \( P_2 \) as compared with prior art. This means that the braking takes place over a longer period of time and at a consequently lower brake power, making it possible for more of the brake energy to be utilised than in previous known solutions. The braking may also be controlled with great precision so that the maximum speed \( v_{\text{max}} \).
is reached at precisely the end of the downhill run, in order to maximise the vehicle's fuel saving.

One embodiment of the present invention determines a speed profile $v_{\text{prof}}$ which extends from an actual speed $v_{\text{act}}$, e.g. the actual speed $v_{\text{act}}$ at the first location $P_1$, to the maximum speed $v_{\text{max}}$, e.g. at the third location $P_3$. In the example in Figure 3 the speed profile $v_{\text{prof}}$ might then correspond to the broken line for the actual speed $v_{\text{act}}$ according to the present invention between the first position $P_1$ and the third position $P_3$. Thus the appropriate speed profile $v_{\text{prof}}$ may here first be determined in order to serve as a basis for activation of the regenerative brake system. The appropriate shape of the speed profile $v_{\text{prof}}$ may depend on which parameter is to be optimised, e.g. fuel saving, regeneration, acceptability to drivers, acceptability to other road users and/or driver comfort.

In one embodiment the speed profile $v_{\text{prof}}$ is determined such that the resulting brake power is within a favourable range for the regenerative brake system's regeneration. For example, a certain brake system may here have a maximum regeneration capacity corresponding to a first brake power limit value, in which case the speed profile $v_{\text{prof}}$ in this embodiment is determined such that the resulting brake power is below this limit value.

There are strategic cruise controls, e.g. look-ahead cruise controls (LACCs), which use knowledge of road sections ahead, i.e. knowledge of the nature of the road ahead, to determine the configuration of a reference speed $v_{\text{ref}}$ which in such cruise controls is supplied to an engine system of the vehicle for control of a torque demand from the engine. In strategic cruise controls the reference speed $v_{\text{ref}}$ is allowed, within a certain range, to differ from the set speed $v_{\text{set}}$ chosen by the
driver, in order to achieve a more fuel-saving way of driving based on the knowledge.

LACCs may use the various forms of knowledge in a variety of different ways. Knowledge of for example a speed limit on the road ahead may be used to effect fuel-efficient lowerings of speed before a coming lower speed limit. Similarly, knowledge of for example a roundabout or intersection ahead may also be used as a basis for fuel-efficient braking before reaching them.

An LACC does for example allow the reference speed $v_{ref}$ to be raised before a steep uphill run to above the set speed $v_{set}$, since the vehicle may be assumed to lose speed uphill because of its high train weight relative to engine performance. LACCs similarly allow the reference speed $v_{ref}$ to drop to below the set speed $v_{set}$ before a steep downhill run, since the vehicle may be assumed to be accelerated downhill by its high train weight. The concept here is that greater fuel economy is achieved by making use of the vehicle's acceleration caused by its own weight downhill than by first accelerating before the downhill run and then braking downhill. LACCs may thus reduce fuel consumption with hardly any effect upon journey time.

Figure 4 illustrates a non-limitative example of how an embodiment of the present invention may interact with an LACC. The actual speed $v_{acc_{regu}}$ and the braking in prior art are as described in relation to Figures 2 and 3 above. One skilled in the art will appreciate that the invention may be employed not only in the downhill situation depicted in Figure 4 but also in the context of other speed changes initiated by LACCs.

In one embodiment of the present invention, where there is knowledge of the section of road and there is interaction with
an LACC the determination of the predicted speed $v_{\text{pred}}$ takes into account the knowledge which the LACC possesses. As mentioned above, in certain situations the LACC lowers the reference speed $v_{r,e}$ to below the set speed $v_{\text{set}}$, e.g. before a downhill run, since this reduces the need for conventional braking and is efficient in terms of fuel economy.

If the LACC indicate that it intends to reduce the actual speed $v_{\text{act}}$, e.g. before a downhill run, brake action may, as depicted in Figure 4, be applied already at an activation location $P_{r,\text{gen}}$ before the downhill run begins at the first location $P_1$. Regeneration may thus be conducted by the regenerative brake system when the lowering of the actual speed $v_{\text{act}}$ takes place before the downhill run, resulting in a further lengthening of braking time. Compared with previous known solutions, this embodiment of the invention here increases the braking time and the braking distance by the space from the activation location $P_{r,\text{gen}}$ to the second location $P_2$ where the previous known solutions would have begun to brake.

The regeneration may then proceed for the braking during substantially the whole downhill run until the actual speed $v_{\text{act}}$ according to the present invention reaches the maximum speed $v_{\text{max}}$ and also coincides with the actual speed $v_{\text{act,regular}}$ according to previous known solutions at the third location $P_3$ at the end of the downhill run, where $P_3 = P_{\text{common}}$.

As may be seen in Figure 4, the actual speed $v_{\text{act}}$ according to the present invention is below the actual speed $v_{\text{act,regular}}$ according to previous known solutions for a long time, from the first location $P_1$ to the merging location $P_{\text{common}}$. This results in the average actual speed $v_{\text{act}}$, and also the brake power, according to the present invention being below the
average actual speed $v_{act-regu}$ according to previous known solutions over the same period. Regeneration may also be conducted from the actual speed $v_{act}$ according to LACC being allowed to be below the set speed $v_{set}$ at the activation location $P_{regen}$, which occurs before the downhill run begins at the first location $P_1$.

The braking in this embodiment therefore takes place over a longer distance and time and results in a lower brake power, making it possible for the regenerative brake system to utilise a larger proportion of the brake energy than in previous known solutions.

In one embodiment of the present invention it is assumed when determining the predicted speed $v_{pred}$ that the gradient along the section of road is substantially the same as where the vehicle is at the time when the determination takes place. In this embodiment there is no need for the vehicle to have access to map information, positioning information and/or topography information, since the road gradient where the vehicle is at the time may be determined in other ways, e.g. on the basis of an accelerometer or a force equation. The gradient where the vehicle is may also be available on board, since it is used by other systems, e.g. systems for gear choice or the like. This embodiment therefore often involves the vehicle in a limited amount of complexity.

In one embodiment of the present invention the determination of the predicted speed $v_{pred}$ is based on the actual speed $v_{act}$ and an actual acceleration $a_{act}$ of the vehicle. This is followed by analysing how close the vehicle's actual speed $v_{act}$ is to the maximum speed $v_{max}$ and how quickly the vehicle is approaching it.
The activation location $P_{\text{regen}}$ is then also determined on the basis of a difference between the vehicle's actual speed $v_{\text{act}}$ and maximum speed $v_{\text{max}}$ and on the basis of an actual acceleration $a_{\text{act}}$ of the vehicle. It may for example be deemed appropriate to apply brake action if $v_{\text{act}}$ is relatively close to, and also quickly approaching, $v_{\text{max}}$.

In one embodiment of the present invention the determination of the at least one predicted speed $v_{\text{pred}}$ is based on an assumption that the fuel supply to the engine is throttled for the whole or parts of the section of road. The predicted speed $v_{\text{pred}}$ is here based on an engine brake simulation whereby the engine torque is based on a dragging of the engine, i.e. on a drag torque curve for the engine.

In one embodiment of the present invention the determination of the at least one predicted speed $v_{\text{pred}}$ is based on an assumption that the vehicle freewheels for the whole or part of the section of road. The simulation of the predicted speed $v_{\text{pred}}$ is here based on a freewheeling simulation whereby the vehicle rolls freely with open clutch and/or in neutral gear.

When the vehicle is freewheeling no power is transmitted from the engine to the tractive wheels.

In cruise control driving the power train torque, i.e. the vehicle's propulsive torque, is regulated by a vehicle speed regulator which receives speed set-point values from the cruise control logic. In traditional cruise controls the set speed $v_{\text{set}}$ serves as such a set-point value. In cruise controls where the reference speed $v_{\text{ref}}$ is allowed to deviate from the set speed $v_{\text{set}}$, as in LACCs, the reference speed $v_{\text{ref}}$ serves as this set-point value.

In one embodiment of the present invention the determination of the at least one predicted speed $v_{\text{pred}}$ is based on a cruise
control simulation which is conducted on board the vehicle on the basis of a vehicle speed set-point value. In cases where the vehicle travels with the cruise control operating, the speed set-point value in the simulation may then be based on the cruise control's set speed $v_{set}$.

The set-point value may also be based on the vehicle's current actual speed $v_{act}$ or an estimation of a driver's desired actual speed $v_{act}$. This embodiment achieves an accurate estimate of the at least one predicted speed $v_{pred}$ even when cruise control driving is not employed, i.e. during accelerator pedal driving.

In one embodiment of the invention the activation location $P_{regen}$ is determined to a location where the vehicle accelerates and where it is found that the predicted speed $v_{pred}$ will exceed the maximum speed $v_{max}$. An example of such an activation location $P_{regen}$ is depicted in Figure 2, in which the vehicle is on a downhill run and is accelerated by its train weight, while at the same time it may be found that $v_{pred}$ will exceed $v_{max}$.

In one embodiment of the present invention the activation location $P_{regen}$, i.e. the location where the regenerative brake system is activated, is determined to the location where the vehicle has a power surplus and where it is found that $v_{pred}$ will exceed $v_{max}$. A vehicle is assumed here and throughout this specification to have a power surplus if it accelerates without fuel supply to the engine. An example of such an activation location $P_{regen}$ is depicted in Figure 2, where the vehicle is on a downhill run and is accelerated by its train weight.

In one embodiment of the invention the activation location $P_{regen}$ is determined to a location from which it is calculated
that the maximum speed $v_{\text{max}}$ may be reached along the section of road by using a brake energy which may be provided with the regenerative brake system. An example of such an activation location $P_{e, \text{gen}}$ is depicted in Figure 3, where it may be found at the first location PI that the speed profile $v_{\text{prof}}$ can be achieved by braking with the regenerative brake system so that $v_{\text{max}}$ is reached along the section of road, e.g. at the third location $P_3$.

In one embodiment of the present invention the activation of the regenerative brake system is based on an adaptive algorithm which analyses how much brake energy needs to be braked away, which brake energy changes dynamically while the vehicle is in motion, inter alia due to its speed and to road gradient. This dynamically variable brake energy then serves as a basis for calculating adaptively the brake action to be applied in order to brake away this brake energy.

The adaptive algorithm may here be based on at least one prediction of a braking process $v_{\text{pred}_{ \text{brake}}}$ of the vehicle. A braking process $v_{\text{pred}_{ \text{brake}}}$ denotes here how the actual speed $v_{\text{act}}$ will be altered by the appropriate brake action determined.

In one embodiment the braking process $v_{\text{pred}_{ \text{brake}}}$ is determined on the basis of the current brake action, i.e. the brake action applied at the time when the prediction of $v_{\text{pred}_{ \text{brake}}}$ is made. In another embodiment the prediction of $v_{\text{pred}_{ \text{brake}}}$ changes dynamically during the braking. In another embodiment $v_{\text{pred}_{ \text{brake}}}$ is determined on the basis of a brake action which is pre-calculated on the basis of an appropriate brake action to be applied, its appropriateness being assessed on the basis of a brake energy which needs to be braked away.

If the prediction of the braking process $v_{\text{pred}_{ \text{brake}}}$, i.e. the prediction of how the actual speed $v_{\text{act}}$ of said vehicle will be
altered by the appropriate brake action determined, will reach the maximum speed $v_{\text{max}}$, the brake action, i.e. the brake torque/brake power, is increased. If conversely the prediction of $v_{\text{pred.brake}}$ shows that $v_{\text{act}}$ will not reach $v_{\text{max}}$, the brake action, i.e. the brake torque/brake power, is decreased.

The increase and/or decrease in brake action may here be determined on the basis of how close to the maximum speed $v_{\text{max}}$ the prediction of the braking process $v_{\text{pred.brake}}$ comes. The result is a regulation which just reaches $v_{\text{max}}$ at the end of the downhill run.

These embodiments of the invention thus achieve during the braking a control of the brake system which results in a dynamic and more advantageous regeneration with the regenerative brake system, since the brake power can be regulated to a level which is more favourable for regeneration.

One skilled in the art will appreciate that a method for controlling a regenerative brake system according to the present invention may also be implemented in a computer programme which, when executed in a computer, causes the computer to conduct the method. The programme usually takes the form of a computer programme product 503 (depicted in Figure 5) stored on a digital storage medium and is contained in a computer-readable medium of the computer programme product. Said computer-readable medium comprises a suitable memory, e.g. ROM (read-only memory), PROM (programmable read-only memory), EPROM (erasable PROM), flash memory, EEPROM (electrically erasable PROM), a hard disc unit, etc.

Figure 5 depicts schematically a control unit 500 comprising a calculation unit 501 which may take the form of substantially any suitable kind of processor or microcomputer, e.g. a
circuit for digital signal processing (digital signal processor, DSP), or a circuit with a predetermined specific function (application specific integrated circuit, ASIC). The calculation unit is connected to a memory unit 502 which is situated in the control unit 500 and which provides the calculation unit with, for example, the stored programme code and/or the stored data which the calculation unit needs to enable it to perform calculations. The calculation unit is also adapted to storing partial or final results of calculations in the memory unit 502.

The control unit 500 is further provided with respective devices 511, 512, 513, 514 for receiving and sending input and output signals. These input and output signals may comprise waveforms, pulses or other attributes which the input signal receiving devices 511, 513 can detect as information and which can be converted to signals processable by the calculation unit 501. These signals are then conveyed to the calculation unit. The output signal sending devices 512, 514 are arranged to convert signals received from the calculation unit in order, e.g. by modulating them, to create output signals which can be conveyed to other parts of the vehicle.

Each of the connections to the respective devices for receiving and sending input and output signals may take the form of one or more from among a cable, a data bus, e.g. a CAN (controller area network) bus, a MOST (media oriented systems transport) bus or some other bus configuration, or a wireless connection.

One aspect of the invention proposes a system comprising a control unit adapted to controlling a regenerative brake system in a vehicle. The control unit comprises a prediction unit adapted to determining at least one predicted speed $v_{pred}$.
for the vehicle on a section of road. This determination may be conducted in various different ways in the embodiments described above of the method, to which end the prediction unit is adapted to being able to make the predictions according to the respective embodiment.

The control unit comprises also an activation unit adapted to activating the regenerative brake system before an actual speed $v_{act}$ of the vehicle reaches the maximum speed $v_{max}$ if the at least one predicted speed $v_{pred}$ exceeds $v_{max}$ along the section of road.

The control unit, and consequently the system, according to the present invention have the same advantages as indicated above for the methods according to the invention.

One skilled in the art will appreciate that the aforesaid computer may take the form of the calculation unit 501 and that the aforesaid memory may take the form of the memory unit 502.

One skilled in the art will also appreciate that the above system may be modified according to the various embodiments of the method according to the invention. The invention relates also to a motor vehicle 1, e.g. a truck or a bus, provided with at least one control unit for controlling a regenerative brake system according to the invention.

The present invention is not restricted to the invention's embodiments described above but relates to and comprises all embodiments within the protective scope of the attached independent claims.
Claims

1. A method for controlling a regenerative brake system in a vehicle for which there is a defined maximum speed $v_{\text{max}}$ which said vehicle should not exceed, characterised in that a control unit performs the steps of
   - determining at least one predicted speed $v_{\text{pred}}$ for said vehicle on a section of road, and
   - if said at least one predicted speed $v_{\text{pred}}$ exceeds said maximum speed $v_{\text{max}}$ along said section of road, activating said regenerative brake system before an actual speed $v_{\text{act}}$ of said vehicle reaches said maximum speed $v_{\text{max}}$, the regeneration being optimised on the basis of the regenerative brake system's regeneration characteristics.

2. A method according to claim 1, in which said section of road comprises a downhill run on which said vehicle is accelerated by a train weight $M$ of the vehicle.

3. A method according to either of claims 1 and 2, in which said maximum speed $v_{\text{max}}$ corresponds to a downhill control speed $v_{\text{dhsc}}$, i.e. $v_{\text{max}} = v_{\text{dhsc}}$, at which a system for downhill speed control brakes the vehicle.

4. A method according to either of claims 1 and 2, in which said maximum speed $v_{\text{max}}$ is related to a set speed $v_{\text{set}}$ of a cruise control.

5. A method according to either of claims 1 and 2, in which said maximum speed $v_{\text{max}}$ is related to a driver behaviour.

6. A method according to either of claims 1 and 2, in which said maximum speed $v_{\text{max}}$ is related to surrounding traffic on said section of road.
7. A method according to either of claims 1 and 2, in which said maximum speed $v_{\text{max}}$ is related to a characteristic of said section of road.

8. A method according to claim 7, in which said characteristic comprises at least one out of
- a speed limit for said section of road,
- a curvature of said section of road,
- the presence of at least one speed camera on said section of road, and
- a traffic situation within said section of road.

9. A method according to any one of claims 1-8, in which said maximum speed $v_{\text{max}}$ may change dynamically along said section of road.

10. A method according to any one of claims 1-9, in which said section of road is that nearest ahead of said vehicle.

11. A method according to any one of claims 1-10, in which knowledge of said section of road is used in said determination of said at least one predicted speed $v_{\text{pred}}$.

12. A method according to claim 11, in which said knowledge is based on at least one out of
- positioning information,
- map information, and
- topography information.

13. A method according to any one of claims 1-10, in which a road gradient affecting said vehicle at the time when said determination of said at least one predicted speed $v_{\text{pred}}$ is made is used in said determination of said at least one predicted speed $v_{\text{pred}}$. 
14. A method according to any one of claims 1-10, in which said determination of said at least one predicted speed $v_{pred}$ is based on an actual speed $v_{act}$ of said vehicle and an actual acceleration $a_{act}$ of said vehicle.

15. A method according to any one of claims 1-14, in which said at least one predicted speed $v_{pred}$ is determined on the basis of an assumption that a fuel supply to an engine of said vehicle is throttled on at least part of said section of road.

16. A method according to any one of claims 1-15, in which said at least one predicted speed $v_{pred}$ is determined on the basis of an assumption that said vehicle freewheels along at least part of said section of road.

17. A method according to any one of claims 1-15, in which said at least one predicted speed $v_{pred}$ is determined on the basis of a cruise control simulation.

18. A method according to any one of claims 1-17, in which said activation of said regenerative brake system takes place at one of the following locations:
- an activation location $P_{regen}$ at which it is found that said at least one predicted speed $v_{pred}$ will exceed said maximum speed $v_{max}$ and at which said vehicle accelerates,
- an activation location $P_{regen}$ at which it is found that said at least one predicted speed $v_{pred}$ will exceed said maximum speed $v_{max}$ and at which said vehicle has a power surplus such that said vehicle accelerates without an engine of said vehicle being supplied with fuel, and
- an activation location $P_{regen}$ from which it is calculated that said maximum speed $v_{max}$ may be reached along said section of road by means of a brake energy which can be achieved with said regenerative brake system.
19. A method according to any one of claims 1-18, in which said activation of said regenerative brake system takes place on the basis of a speed profile $v_{\text{prof}}$ which extends from an actual speed $v_{\text{act}}$ of said vehicle to said maximum speed $v_{\text{max}}$.

20. A method according to any one of claims 1-18, in which the activation of said regenerative brake system takes place on the basis of an adaptive algorithm which adaptively calculates an appropriate brake action to be applied on the basis of a brake energy which needs to be braked away.

21. A method according to claim 20, in which said adaptive algorithm comprises a prediction for said vehicle of a braking process $v_{\text{pred\_brake}}$ which depends on said appropriate brake action.

22. A method according to claim 21, in which said appropriate brake action increases if said prediction of said braking process $v_{\text{pred\_brake}}$ reaches said maximum speed $v_{\text{max}}$.

23. A method according to claim 21, in which said appropriate brake action decreases if said prediction of said braking process $v_{\text{pred\_brake}}$ is continually below said maximum speed $v_{\text{max}}$.

24. A method according to any one of claims 21-23, in which said predicted braking process $v_{\text{pred\_brake}}$ is based on any one out of
- a current brake action,
- a brake action which varies during braking, and
- a pre-calculated brake action based on an appropriate brake action to be applied, an assessment of whether said brake action is appropriate being based on a brake energy which needs to be braked away.
25. A method according to any one of claims 1-24, in which said regenerative brake system comprises at least one out of
- a battery,
- a supercapacitor,
- a flywheel,
- a spring,
- a hydraulic pump cooperating with an accumulator,
- a pneumatic compressor cooperating with a pressure tank, and
- a device for conveying energy to consumers on board said vehicle.

26. A computer programme which comprises programme code and which when said programme code is executed in a computer causes said computer to conduct the method according to any one of claims 1-25.

27. A computer programme product comprising a computer-readable medium and a computer programme according to claim 26, which programme is contained in said medium.

28. A control unit adapted to controlling a regenerative brake system in a vehicle for which there is a defined maximum speed $v_{\text{max}}$ which said vehicle should not exceed, characterised by
- a prediction unit adapted to determining at least one predicted speed $v_{\text{pred}}$ for said vehicle on a section of road, and
- an activation unit adapted, if said at least one predicted speed $v_{\text{pred}}$ exceeds said maximum speed $v_{\text{max}}$ along said section of road, to activating said regenerative brake system before an actual speed $v_{\text{act}}$ of said vehicle reaches said maximum speed $v_{\text{max}}$, the regeneration being optimised on the basis of the regenerative brake system's regeneration characteristics.
[101]
Determine $v_{\text{pred}}$ for a section of road

[102]
If $v_{\text{pred}} > v_{\text{max}}$
activate regenerative brake system before
$v_{\text{act}}$ reaches $v_{\text{max}}$

[103]
Recover energy during application of brake action

Fig. 1
Fig. 5
INTERNATIONAL SEARCH REPORT

International application No. PCT/SE2013/050738

A. CLASSIFICATION OF SUBJECT MATTER

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: B60K, B60T, B60W, G01P, G07C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE, DK, FI, NO classes as above

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category*</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>WO 20101 28898 A1 (VOLVO LASTVAGNAR AB ET AL), 11 November 2010 (201 0-1 1-11); page 2, line 13 - line 26; page 6, line 5 - line 12; page 6, line 14 - line 30; page 7, line 1 - line 4; page 7, line 13 - line 30; figures 2;3; claims 1-5 --</td>
<td>1-28</td>
</tr>
<tr>
<td>A</td>
<td>WO 201 1003663 A1 (BOSCH GMBH ROBERT ET AL), 13 January 2011 (201 1-01-13); page 2, line 12 - line 23; page 3, line 11 - line 19; page 7, line 13 - line 31; figure 1; claims 1-4 --</td>
<td>1-28</td>
</tr>
<tr>
<td>A</td>
<td>US 20080300762 A1 (CROMBEZ DALE SCOTT), 4 December 2008 (2008-1-2-04); abstract; figures 1-3 --</td>
<td>1-28</td>
</tr>
</tbody>
</table>

Additional documents are listed in the continuation of Box C.

Date of the actual completion of the international search

31.10.2013

Date of mailing of the international search report

31.10.2013

Name and mailing address of the ISA/SE

Patent- och registreringsverket

Box 5055

S-102 42 STOCKHOLM

Facsimile No. +46 8 666 02 86

Authorized officer

Tomas Lund

Telephone No. +46 8 782 25 00

Form PCT/ISA/210 (second sheet) (July 2009)
### DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category*</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>US 6364434 B1 (SWAY-TIN MIN ET AL), 2 April 2002 (2002-04-02); abstract; figure 2; claims 1, 2</td>
<td>1-28</td>
</tr>
<tr>
<td>A</td>
<td>DE 102009033953 A1 (GM GLOBAL TECH OPERATIONS INC), 11 February 2010 (2010-02-11); abstract; figure 3</td>
<td>1-28</td>
</tr>
<tr>
<td>A</td>
<td>DE 4420116 A1 (ZAHNRADFABRIK FRIEDRICHSFEN), 14 December 1995 (1995-12-14); abstract</td>
<td>1-28</td>
</tr>
</tbody>
</table>

Form PCT/ISA/210 (continuation of second sheet) (July 2009)
Continuation of: second sheet

International Patent Classification (IPC)

B60W 30/14 (2006.01)
B60K 31/00 (2006.01)
B60W 10/196 (2012.01)
B60W 30/18 (2012.01)
B60T 7/72 (2006.01)
<table>
<thead>
<tr>
<th>Country</th>
<th>Application Number</th>
<th>Filing Date</th>
<th>Publication Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>WO</td>
<td>201 0128898 A1</td>
<td>11/1/2010</td>
<td>18/04/2012</td>
</tr>
<tr>
<td>CN</td>
<td>102421 652 A1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EP</td>
<td>2427358 A1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>JP</td>
<td>201 2526250 A1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RU</td>
<td>201 1149718 A1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>US</td>
<td>201 20065852 A1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WO</td>
<td>201 1003663 A1</td>
<td>13/01/2011</td>
<td>20/01/2011</td>
</tr>
<tr>
<td>DE</td>
<td>102009027553 A1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>US</td>
<td>20080300762 A1</td>
<td>04/12/2008</td>
<td>7894967 B2</td>
</tr>
<tr>
<td>US</td>
<td>6364434 B1</td>
<td>02/04/2002</td>
<td>NONE</td>
</tr>
<tr>
<td>DE</td>
<td>102009033953 A1</td>
<td>11/02/2010</td>
<td>NONE</td>
</tr>
<tr>
<td>DE</td>
<td>44201 16 A1</td>
<td>14/12/1995</td>
<td>9533631 A1</td>
</tr>
</tbody>
</table>

Form PCT/ISA/210 (patent family annex) (July 2009)