

The present invention relates to a method and to a device for braking vehicles by automatically controlling the braking torque applied to a wheel. It applies especially to the braking systems of vehicles and particularly of their wheels. More generally, the invention relates to the braking of all vehicles where the braking has to be carried out under conditions of great safety.

Patents and Patent Applications US-A-3,508,795, DE-A-2,204,092 and EP-A-2,252,595 show examples of control or monitoring of braking.

The currently known devices for monitoring braking mainly use, as basic parameter, the measurement of the speed of rotation of the wheels. With the aid of this parameter and of the characteristic braking equation, they monitor the variations in acceleration or deceleration of the wheel. Moreover, other devices, by virtue of the implementation of automatic speed control, monitor the speed of the braked zone which, compared with the reference speed of the vehicle, determines the maintaining of the braked wheel at a fixed value of slip, the slip being the difference between the speed of the vehicle and the speed of rotation of the wheel multiplied by its radius.

In the previous two cases, the performance of the device is directly related to the number of measurement signals per wheel revolution delivered by the sensor mounted on the wheel to be monitored. Depending on these applications, this number can vary from 50 to 200 per wheel revolution, which requires sophisticated sensors which are expensive and not reliable enough. These methods exhibit other drawbacks; in particular, the detection of the deceleration in the speed of the wheel is difficult to achieve when the curves representing the adherence as a function of slip have a slight maximum or are flat like those encountered in the case where the ground is wet for example. In fact, these methods do not optimize the stopping distance but prevent the wheels from locking. The braking efficiency of the systems produced according to these methods is approximately 60%

to 70%, this efficiency which demonstrates the braking effectiveness is defined by the ratio between the actual braking distance obtained and the theoretical braking distance calculated for a maximum value of a given adherence curve. Finally, these methods have the major drawback that they do not give good braking safety to the vehicles. Indeed, the detections or regulations are carried out on the speed of rotation of the wheels without taking account of the braking torques exerted on these wheels. Now, for identical speed reference values, the braking torques exerted on the wheels are generally different, which creates braking imbalance likely to bring about, in particular, a loss in control of the path of the vehicles.

With the purpose of avoiding these accidents, there are methods in which the control of braking is carried out using two systems, on the one hand a regulating loop and, on the other hand, a computer. The governing loop rapidly corrects the system in the presence of disturbances, while the computer, on the basis of information regarding the speed of the braked wheel and the braking torque, calculates the adherence curve between the tyre and the track, determines the maximum of this curve and formulates a signal which, altering the reference value of the speed governor, brings the system to this maximum. While the speed governor quickly compares the discrepancies relative to the reference value of slip, the computer carries out pregoverning, taking account of tendencies or slow drifts and altering the reference value of the governor in order to bring the operation of the system close to the maximum of the adherence curve and keep it there. Nevertheless, these methods assume linear relationships between, on the one hand, the pressure exerted on the brake and the control current delivered by the governor and, on the other hand, between the braking torque exerted on the wheel and the pressure exerted on the brake. Now, in actual fact, such linear relationships do not exist, these in fact being only very approximately linear. In order to get around

this last drawback, solutions propose direct automatic control of the braking torque exerted on each of the wheels of the vehicle. These solutions, which theoretically are satisfactory, are, however, very difficult to implement owing particularly to the need for very sophisticated and very expensive sensors for sensing torque and speed, to make them effective.

The object of the invention is to overcome the aforementioned drawbacks, in particular to simplify the implementation of automatic control of the braking torque.

To this end, the subject of the invention is a method for braking vehicles by automatically controlling the braking torque applied to the wheel, the adherence of the wheel on a braking track being defined by an operating point which can vary along an adherence curve as a function of the slip of the wheel, characterized in that the parameter by means of which the braking torque is automatically controlled is the sign of the variation in slope of the adherence curve at the aforementioned operating point, the braking torque increasing when the sign of the variation in slope at the operating point on the adherence curve is negative and the braking torque decreasing when the sign of the variation in slope at the operating point of the adherence curve is positive.

The subject of the invention is also a device for implementing the aforementioned method.

The main advantages of the invention is that it allows a maximum braking effectiveness of the order of 95% to be obtained, that it makes it possible to use speed sensors which are simple and inexpensive to produce, and finally that it improves the safety of vehicles by allowing the braking torque on each wheel to be controlled and allowing braking to be distributed as need be.

Other features and advantages of the invention will become clear with the aid of the description which follows with relation to the appended drawings which represent:

- Figure 1, a curve representing the adherence as a function of the slip of a wheel;
- Figure 2, part of the adherence curve of Figure 1
- 5       - Figure 3, an adherence curve without a maximum;
- Figure 4, one possible embodiment block diagram for the implementation of the method according to the invention;
- Figure 5, a detailed part of the block diagram
- 10       of Figure 4.

Figure 1 shows a curve representing the adherence of a wheel on a braking track as a function of the slip of this wheel. This adherence is a function, at a given instant, of the surface condition of the wheel and of the track. In Figure 1, the values marked along the ordinate axis  $F \times R$  correspond to the multiplication of the aerodynamic drag  $F$  by the radius of the wheel  $R$ , while the values marked along the abscissa axis  $g$  correspond to the slip of the wheel relative to the ground, the slip  $g$  being defined by the ratio

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$$\frac{V - v_{\text{wheel}}}{V}$$

where  $V$  is the value of the speed of the vehicle relative to the ground and  $v_{\text{wheel}}$  the product of the angular velocity  $\omega$  of the wheel times its radius  $R$ , i.e.  $v_{\text{wheel}} = R\omega$ . The adherence curve of Figure 1 comprises a part 1 where the function is an increasing function and a part 2 where the function is a decreasing function. It passes through a maximum value  $M$ . All adherence curves have this shape and are, depending on the conditions, flattened to a greater or lesser extent, that is to say have a more or less pronounced maximum value  $M$ . The two zones corresponding to the parts 1 and 2 are separated by a line 3 comprising the point  $M$ . The adherence is generally defined by the ratio  $\frac{F}{F_v}$  where  $F$  is the drag defined hereinabove for Figure 1 and  $F_v$  is the lift. Nevertheless, in the cases of application of the invention, as this lift is constant, it has not been taken into account

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in the definition of adherence. The product  $FR$  defined hereinabove has been substituted for the ratio  $\frac{F}{F_v}$  for defining adherence, this product is a number resulting from the characteristic braking equation:

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$$F - ff = \frac{I}{R} \frac{d\omega}{dt} = (1) \quad [sic]$$

where  $F$  is the drag,  $ff$  is the braking force,  $I$  is the moment of inertia of the wheel ( $I$  is constant) and  $\frac{d\omega}{dt}$  is the derivative of the angular velocity of the wheel with respect to time, by multiplying the characteristic  
10 equation (1) by the radius of the wheel, we get:

$$FR - C = I \frac{d\omega}{dt} (2)$$

where  $C$  is the braking torque applied to the wheel. Subsequently, adherence will be defined by the product  $FR$ .

In the absence of braking, the slip  $g$  is theoretically nil; nevertheless, in actual fact, parasitic  
15 braking means that there is always a slight amount of slip and the operating point on an adherence curve is situated, for example, at a point  $A$  which is not situated at the origin as Figure 1 indicates. As soon as the  
20 braking device is activated, the operating point shifts in the direction of increasing slip, passes through the maximum point  $M$  and travels along the part 2 of the adherence curve, passing through the point  $B$  for example at the risk of continuing towards excessive and dangerous  
25 slipping, this being all the more dangerous for one and the same vehicle if the slip, and consequently the adherence, might be different from one wheel to another.

In fact, to ensure maximum braking effectiveness, it is necessary for the operating point of the adherence  
30 curve 1,2 to be situated at the point  $M$ , that is to say where the adherence is at a maximum.

In the case of control of the braking of one wheel by automatically controlling the braking torque exerted on it, it is possible to know the adherence  
35 defined by the product  $FR$ , in fact, from the

relationship (2):

$$FR = C + I \frac{d\omega}{dt} \quad (3).$$

Thus, measurements of the braking torque  $C$  and of the variation in angular velocity of the wheel  $\frac{d\omega}{dt}$  give the value of  $FR$ . Likewise, measurements of the speed of the vehicle and the speed of the wheel give the value of the slip  $g$ . In fact, at any instant, with the aid of means for measuring the braking torque  $C$  applied to the wheel, means for measuring the speed of the vehicle and the angular velocity of the wheel and calculating means, it is possible to define the adherence of the wheel and therefore to define a function point [sic]  $P$  on the adherence curve of Figure 1. During braking, the object of automatically controlling the braking torque must be, for each wheel, to keep the operating point on the adherence curve at the point  $M$  corresponding to the maximum value of adherence. To do this it is necessary to define a relationship, simple if possible, between the position of the operating point on the adherence curve and the value of the braking torque applied to the wheel, this is what is achieved by the method according to the invention. In fact, mere calculation of the operating point  $P$  defined by its coordinates  $FR$  and  $g$  does not allow it to be situated with respect to the point  $M$ , because in practice the adherence curve is never known a priori. A fortiori, the point  $M$  of maximum adherence is not known. It is therefore necessary at least to use the first derivative of  $FR$  with respect to  $g$ . In the part 1 of the adherence curve, the first derivative of  $FR$  with respect to  $g$ ,  $\frac{dFR}{dg}$ , is positive, while in the part 2, this derivative is negative. At the point  $M$  of maximum adherence, this derivative is positive to the left and negative to the right, there is no zero derivative at this point, which is demonstrated by a peak at this point as the adherence curve of Figure 1 shows and as is the general case for all adherence curves encountered in real life. The sign of this first derivative  $\frac{dFR}{dg}$  indicates the position of the operating point  $P$  with respect to the point  $M$ . Nevertheless, in the part 2 of the adherence

curve in particular, where the first derivative is negative, the sign of this first derivative  $\frac{dFR}{dg}$  in particular gives no information on the change in the operating point P towards increasing slip g or decreasing slip g. For all adherence curves encountered in real life, the second derivative of FR with respect to g,  $\frac{d^2FR}{dg^2}$  [sic] is strictly positive over the whole of the part 2 to the right of the point M of maximum adherence, and in contrast is strictly negative over the whole of the part 1 to the left of the point M. This is not validated in the case where the adherence curve is flat and does not have a maximum. In this case, the derivatives  $\frac{dFR}{dg}$  and  $\frac{d^2FR}{dg^2}$  [sic] are zero. Flat adherence curves are encountered, for example, in the case of tyres on steel in the rain. The value of the second derivative  $\frac{d^2FR}{dg^2}$  [sic] which is strictly positive indicates that the relative value of the slope of the curve is an increasing function of the slip g, whereas the slope is a decreasing function of the slip if  $\frac{d^2FR}{dg^2}$  [sic] is strictly negative.

Figure 2 shows the part 2 of the adherence curve of Figure 1 close to the point M of maximum adherence. In order to automatically control the braking at the point M as a function of the braking torque exerted on the wheel, it is necessary to be able to define a relationship between the change in the operating point P and this torque. The method according to the invention in fact uses the sign of the variation in slope at the operating point P to determine whether the point P is moving towards the point M or towards high slippage, and it is this information which will be used to slave the braking to the point of maximum adherence M by acting on the braking torque exerted on each of the wheels.

According to the method according to the invention, from the relationship (3), the measurements of the braking torque applied to the wheel and the measurements of the speeds of the vehicle and of the wheel, a computer successively defines the coordinates of positions of the operating point on the adherence curve, for example the coordinates (g1, F1R), (g, FR) and (g2, F2R) respectively

of points P1, P and P2, then for these three successive points it calculates  $\frac{FR - F_1R}{g - g_1} = \Delta_1$  and  $\frac{F_2R - FR}{g_2 - g} = \Delta_2$

and calculates  $\frac{\Delta_2 - \Delta_1}{g_2 - g_1} = S(4)$  only the sign of which is used.

5 Figure 2 illustrates the method according to the invention. The points P1, P and P2 represent three successive positions of the operating point on the adherence curve.  $\Delta_1$  and  $\Delta_2$  calculated before are the values of the slopes, in relative values, of the segments also identified by  $\Delta_1$  and  $\Delta_2$  in Figure 2 and respectively  
10 segments between P1 and P on the one hand, and P and P2, on the other hand.

The ratio  $S = \frac{\Delta_2 - \Delta_1}{g_2 - g_1}$  expresses the variation in slope on the adherence curve when the positions of the operating point pass from P1 to P then from P to P2. Now,  
15 this part is an increasing function of the slip g.

Thus, if  $S = \frac{\Delta_2 - \Delta_1}{g_2 - g_1}$  is positive, that signifies that the operating point is moving towards increasing slip in the direction of the arrow 4 and is moving away  
20 from the maximum M; this is the case where P1 precedes P which precedes P2. In this case it can be seen from Figure 2 that the slope  $\Delta_2$  is less than the slope  $\Delta_1$  in terms of absolute value, and therefore greater in terms of relative value because these slopes are negative. In  
25 contrast, if the operating point is moving towards decreasing slip, that is to say in the direction of the arrow 5 towards the point of maximum adherence M, the case in which P2 precedes P which precedes P1, then the ratio  $\frac{\Delta_1 - \Delta_2}{g_1 - g_2}$  defined by the computer will be negative.

30 The same method can be applied to the part 1 of the curve to the left of the point of maximum adherence M with the same conclusions since the first and second derivatives have opposite signs with respect to those of the part 2, S in fact being the sign of the variation in  
35 slope of the adherence curve at the operating point P. Thus, if the ratio S is positive, the operating point is moving away from the point M, and if S is negative, then it is moving towards it. In fact, the braking method

according to the invention slaves the operating point P to the point of maximum adherence by automatically controlling the braking torque the parameter of which is the sign of the ratio S defined previously, S in fact  
5 being the sign of the variation in slope of the adherence curve at the operating point P. Finally, in order to control the braking of one wheel by automatically controlling its braking torque, the method according to the invention makes use of the fact that the second derivative  $\frac{d^2FR}{dg_1}$  is strictly negative over the part 1 of the  
10 adherence curve to the left of its maximum and strictly positive over the part 2 to the right of this maximum whereas the first derivative is positive to the right and negative to the left of its maximum.

15 The method according to the invention which uses only the sign of the ratio S makes it possible to tolerate errors in the accuracy of the measurement of the speeds of the vehicle and of the wheel, and makes it possible to simplify the speed detectors mounted on the  
20 wheels, for example just a few measurement signals per wheel revolution are necessary.

In the case where the adherence curve does not have a maximum, such as the curve 6 in Figure 3 for example, a limit value 7 termed maximum slip value is  
25 stored in memory in the circuits of the computer for example so as to prevent the operating point on the adherence curve from tending towards high slip g.

Figure 4 shows the block diagram of one possible embodiment for the implementation of the method according  
30 to the invention. This figure shows a device applied to one wheel, but it is however possible to split the calculation means between all the wheels of a vehicle. The device of Figure 4 comprises control and regulating means 41, whose output controls an electric actuator 42  
35 which activates the brake 43 via, for example, a hydraulic member. The brake 43 exerts a braking torque on the wheel 44. A torque sensor 45 placed on the brake 43 delivers to the control and regulating unit the measurement of the braking torque exerted on the

wheel 44. A speed sensor 46 placed on the wheel delivers the measurement of the speed of the wheel 44 to the control and regulating unit 41. The latter moreover takes account of the braking torque reference value 47 given by  
5 the driver of the vehicle and the speed of the vehicle 48 delivered by a sensor external to the device of Figure 4, this sensor may, for example, be a radar, a laser beam, or a tachometer.

Figure 5 details a possible embodiment of the  
10 control and regulating means 41. An interface module 51 converts the information transmitted by the sensor 46 for sensing the angular velocity of the wheel, the sensor 45 for sensing the braking torque exerted on the wheel, the sensor 48 for sensing the speed of the vehicle and also  
15 the braking torque reference value 47 which are [sic] transmitted by the driver into digitized values which can be taken into account by a digital computer 52. This computer 52 may for example contain at least one standard arithmetic calculation unit associated with a floating  
20 operator and with working memory. In order to digitize the transmitted information, the interface module 51 uses clock signals 53 and analog-digital converters if the signals are of the analog type or counters if they are of the periodic or alternating type. The signal coming from  
25 the sensor 46 for sensing the angular velocity of the wheel may, for example, be processed according to two methods, through measurements of frequencies in the high speed range, and through measurements of periods in the medium and low speed range. On the basis of the  
30 parameters coming from the interface module 51 and of a sampling frequency defined, for example, by the clock 53, the computer defines the values of the adherence FR and of the slip g which relate to the wheel, then, on the basis of the adherence and slip values previously stored  
35 in memory 54 for example, it defines the sign of the ratio S calculated according to the relationship (4).

The reference value of the braking torque 47 encoded by the interface module 51 informs the computer 52 that the vehicle is in a braking phase, as

soon as this reference value appears, the circuits of the computer reset themselves for example and begin calculation. An interface 55 coupled at the output of the computer 52 provides a correction signal combined with  
5 the reference value of the braking torque 57 via an adder 56. This correction signal is a function of the sign of the ratio  $S$  transmitted by the computer 52 to the interface 55. Thus, if the sign delivered by the computer 52 is positive for example, that signifies that  
10 the operating point is moving away from the maximum on the adherence curve, the interface 55 delivers a correcting signal to the reference value of the braking torque 47 so as to decrease the braking torque exerted on the wheel. If the sign is negative for example, that  
15 signifies that the operating point is moving towards the adherence maximum, the correction signal delivered by the interface 55 does not modify the reference value of the braking torque 47 so as to allow the operating point to move on the adherence curve towards the point of maximum  
20 adherence. The control signal coming from the adder 56 acts on a power amplifier 57 whose output signal directly controls the electric actuator 42. This signal may, for example, be of the variable duty cycle type so that the more this increases, the more the brake torque exerted on  
25 the wheel increases. In this case, the duty cycle is controlled by the output signal from the adder 56. The calculation means of the device shown in Figures 4 and 5, namely the computer 52, the memory 54 and the clock 53 may, for example, be split between several braking  
30 devices for wheels of one and the same vehicle.



CLAIMS

1. Method for braking vehicles by automatically controlling the braking torque applied to a wheel, the adherence of the wheel on a braking track being defined  
5 by an operating point (P) which can vary along an adherence curve (1, 2) as a function of the slip (g) of the wheel, characterized in that the parameter by means of which the braking torque is automatically controlled is the sign of the variation in slope ( $\Delta 1$ ,  $\Delta 2$ ) of the  
10 adherence curve (1, 2) at the aforementioned operating point (P), the braking torque increasing when the sign of the variation in slope ( $\Delta 1$ ,  $\Delta 2$ ) at the operating point (P) on the adherence curve (1, 2) is negative and the braking torque decreasing when the sign of the variation  
15 in slope ( $\Delta 1$ ,  $\Delta 2$ ) at the operating point (P) of the adherence curve (1, 2) is positive.
2. Method according to Claim 1, characterized in that the braking torque is automatically controlled so that the operating point (P) is coincident with the point  
20 (M) of maximum adherence of the adherence curve (1, 2).
3. Device for implementing the method according to either one of the preceding claims, comprising at least command and regulating means (41) coupled to an electric activator (42) coupled to a brake (43), a sensor (45) for  
25 sensing braking torque, and a sensor (46) for sensing angular velocity of the wheel, the outputs of which sensors are connected to inputs of the command and regulating means (41), characterized in that the command and regulating means include means for determining the  
30 sign of the variation in slope of the adherence curve at an operating point (P) which can vary along this curve.
4. Device for implementing the method according to any one of the preceding claims, characterized in that it comprises at least command and regulating means (41)  
35 which are coupled to an electric activator (42) coupled to a brake (43), a sensor (45) for sensing the braking torque and the braking torque applied to the wheel (46) [sic], a computer (52) coupled to the output of the



- interface module (51), a memory (54) coupled to the computer (52), a clock (53) commanding the computer (52) and the interface module (51), an interface (55) coupled to the output of the computer (52), an adder (56), the
- 5 inputs of which are connected to the output of the interface (55) and to the reference value for the braking torque (47), a power amplifier (57) coupled to the output of the adder (56), the output of the power amplifier (57) being intended to command the electric actuator (42).
- 10 5. Device according to Claims 3 and 4, characterized in that the calculation means (52, 53, 54) may be split between several braking devices for wheels of one and the same vehicle.