(12) UK Patent Application (19) GB (11) 2 213 221 (13) A

(43) Date of A publication 09.08.1989

(21) Application No 8828305.6

(22) Date of filing 05.12.1988

(30) Priority data
(31) 3741247 (32) 05.12.1987 (33) DE

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(51) INT CL⁴
B60T 8/60

(52) UK CL (Edition J)
F2F FDB F737

(56) Documents cited
None

(58) Field of search
UK CL (Edition J) F2F FDB
INT CL⁴ B60T

(54) Method of adapting slip threshold values for a propulsion slip and/or braking slip control system to the tyres of a motor vehicle

(57) Method of, and apparatus for, adapting slip threshold values for a propulsion slip and/or braking slip control system to the existing tyres of a motor vehicle, the instantaneously effective coefficient of friction between vehicle and road being determined from the measured values of the vehicle speed and of the vehicle longitudinal acceleration inserted in a graph and the predetermined value or the predetermined function for the slip thresholds being substituted or corrected by the slip values measured at the driven wheels in the case of an operations state defined by a measurement window 21 (see Fig 3).

Fig.3

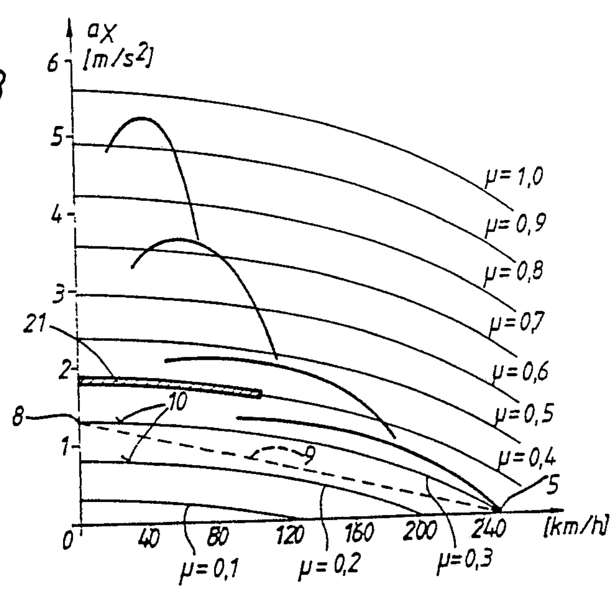

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Fig.1

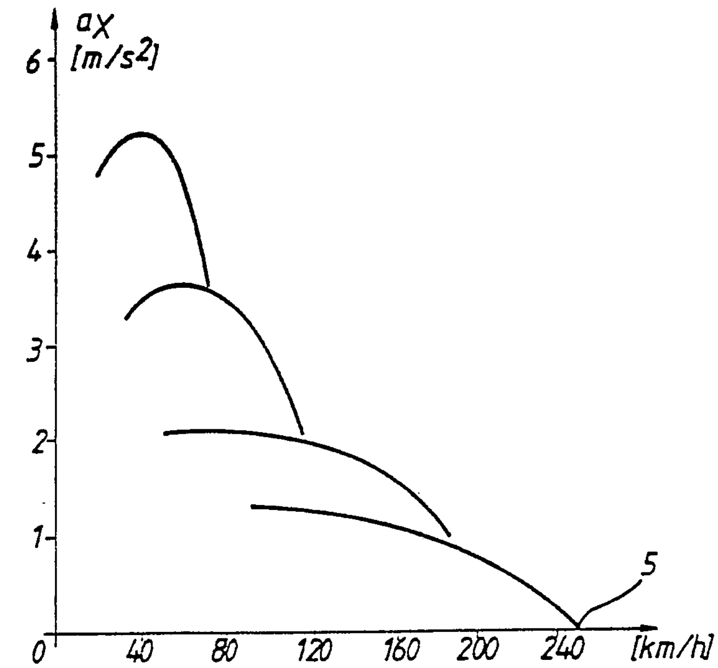
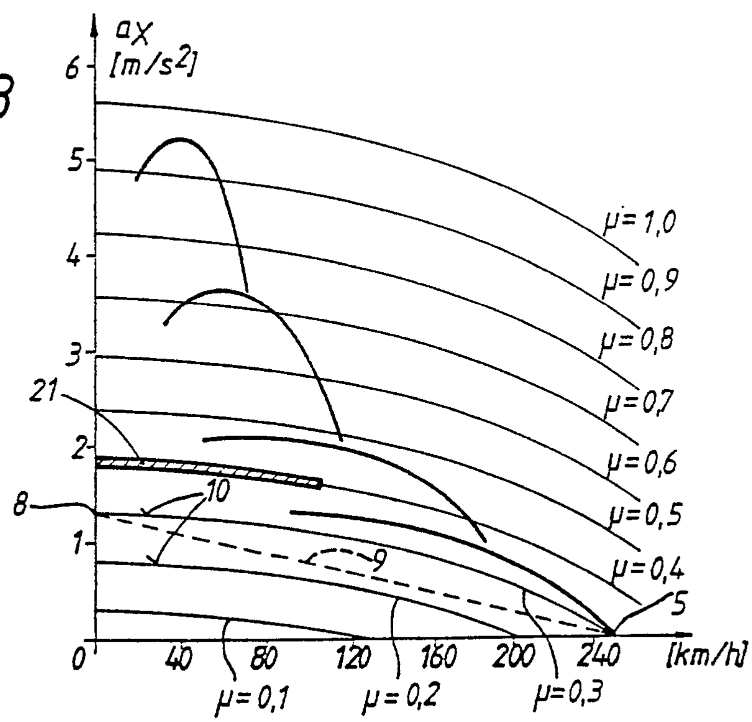
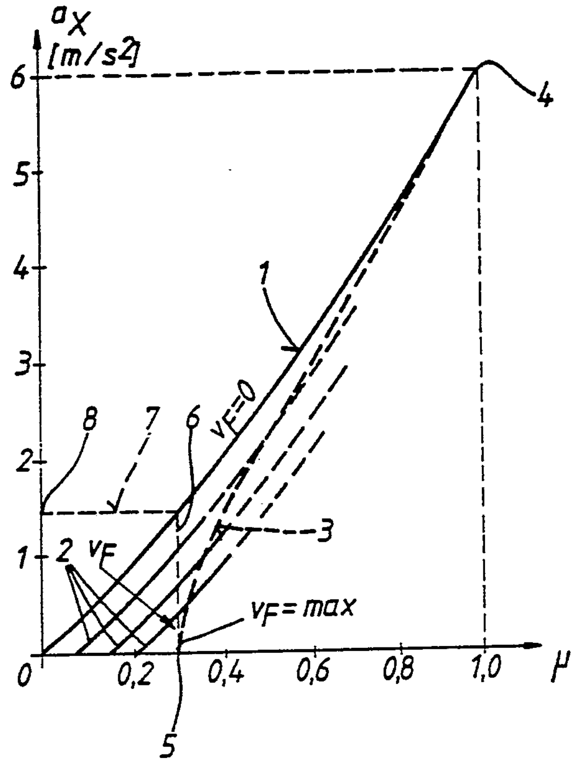

ax
[m/s2]
6
5
4
3
2
1
0
40
80
120
160
200
240
[km/h]
5

Fig.3

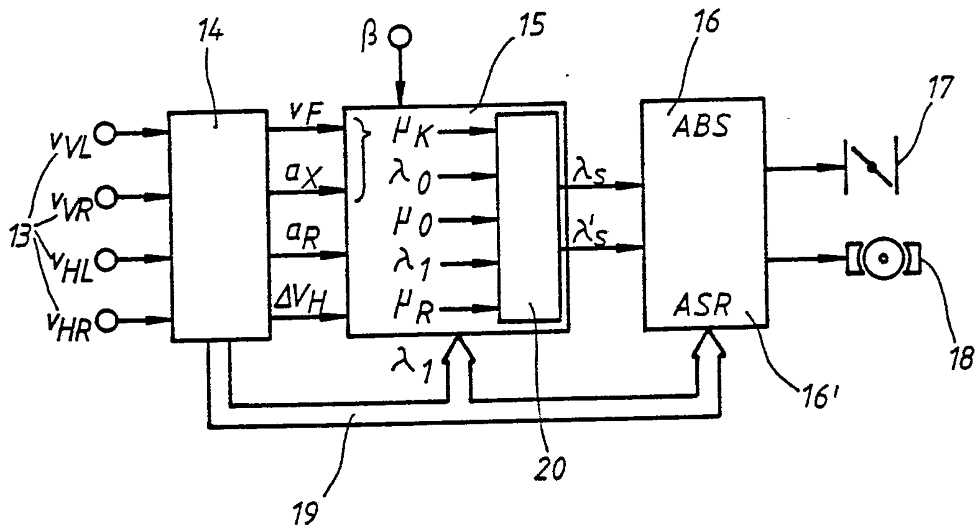

ax
[m/s2]
6
5
4
3
2
1
0
40
80
120
160
200
240
[km/h]
μ=1,0
μ=0,9
μ=0,8
μ=0,7
μ=0,6
μ=0,5
μ=0,4
21
10
8
9
5
μ=0,1
μ=0,2
μ=0,3



a_X [m/s²]
6
5
4
3
2
1
0
0,2
0,4
0,6
0,8
1,0
μ
1
2
3
4
5
6
7
8
$v_F=0$
v_F
$v_F=max$

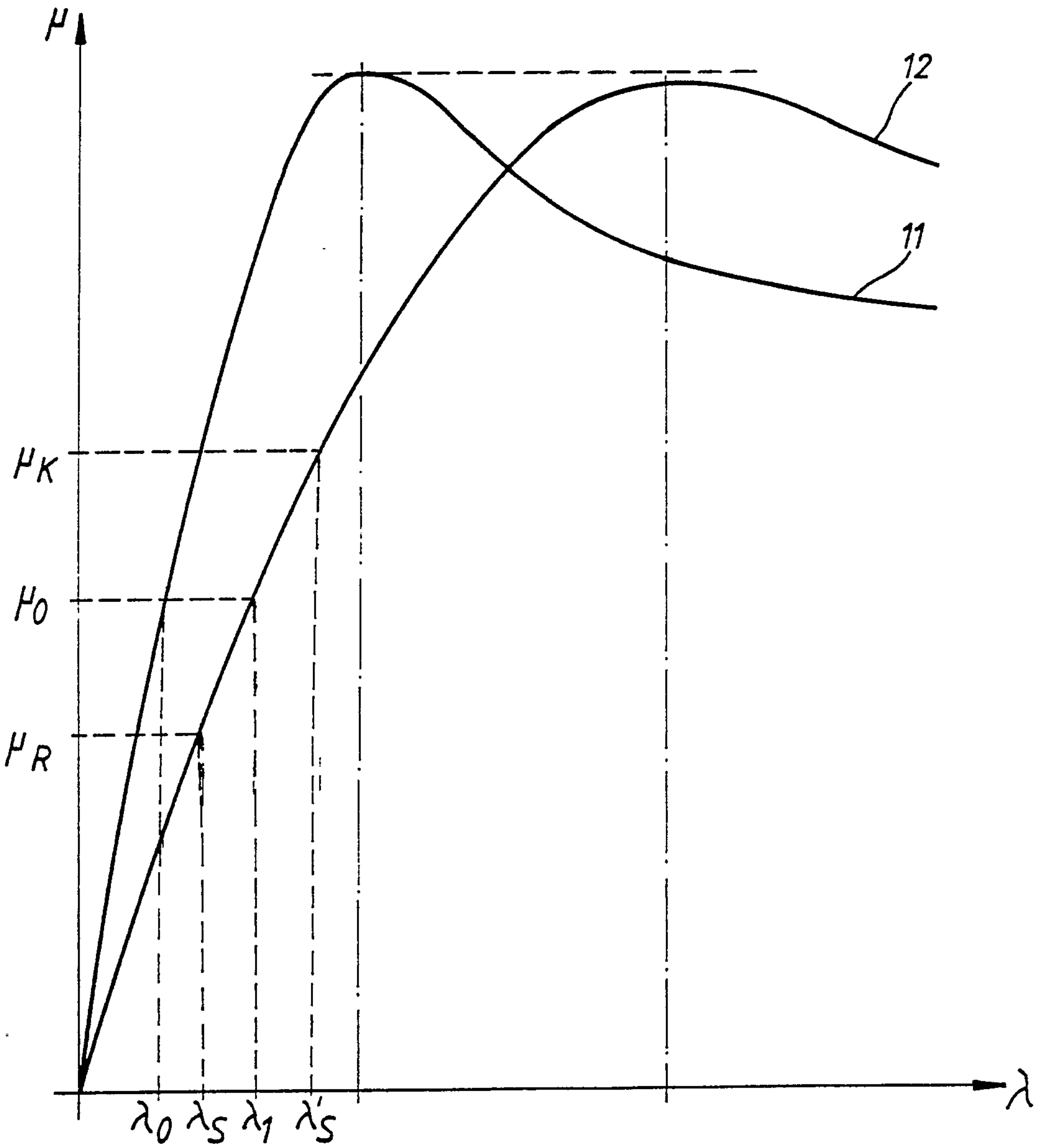
Fig. 2

Fig.5



14
15
16
17
18
19
20
16'
13
v_{VL}
v_{VR}
v_{HL}
v_{HR}
v_F
a_X
a_R
ΔV_H
β
μ_K
λ_0
μ_0
λ_1
μ_R
λ_1
λ_s
λ'_s
ABS
ASR

Fig. 4



Method of adapting slip threshold values for a propulsion slip and/or braking slip control system to the tyres of a motor vehicle

The invention relates to a method of adapting slip threshold values for a propulsion slip and/or braking slip control system to the tyres of a motor vehicle. The invention also relates to an apparatus for performing this method.

A device for determining slip threshold values for a propulsion slip control system is known from German Offenlegungsschrift OS 3,545,652. In this device a mean slip threshold is substituted by a lower value when the vehicle travels in a curve faster than a predetermined speed, the vehicle longitudinal acceleration is within a specific range and a propulsion slip control occurs. Conversely, the mean slip threshold is substituted by a higher value when the vehicle is likewise travelling in a curve and the vehicle longitudinal acceleration is above the range previously mentioned. An adaptation of the slip threshold to the stability required for travelling a curve is therefore detectable in a sense when travelling curves; the coefficient of friction, that is to say the grip of the vehicle relative to the nature of the road then being travelled is not taken into consideration here, so that a changeover to a lower slip threshold value occurs on a dry gripping road for example, although this would not actually be necessary.

A variation of slip threshold values has a hitherto been known only in the case of propulsion slip control systems to adapt to specific driving states and/or to improve traction and/or stability. No attention has been paid hitherto to different equipment of the vehicle as regards the tyres, although vehicles with both propulsion slip and braking slip control systems react very differently to one and the same road, according to whether they are equipped with summer or winter tyres, or with new or worn tyres.

Constant slip values which had to be coordinated with the least favourable case - smooth ice - are used predominantly in known control systems. However, these slip thresholds are too low for a higher coefficient of friction, so that only slight accelerations are then possible and the propulsion slip control system is switched on with unnecessary frequency. Different sets of tyres and the vehicle reactions which they modify are not taken into consideration.

The present invention seeks to disclose a method which can predetermine slip thresholds better associated with the existing tyres of a motor vehicle, and therefore to create optimum control conditions in both propulsion slip and braking slip control systems. The invention also seeks to disclose an apparatus for performing this method.

According to the invention there is provided a method of adapting slip threshold values for a propulsion slip and/or a braking slip control system to the existing tyres of a motor vehicle, wherein a curve, specific to the respective type of vehicle, of the attainable vehicle acceleration (a_x) from vehicle standstill ($V_F=0$), as determined from the speeds of the non driven wheels, is determined as a function of the coefficient of friction (μ), this curve being extended, taking into consideration the resistances to motion which are a function of the vehicle speed (V_F), into a graph of the coefficient of friction (μ) as a function of the vehicle speed (V_F) and of the vehicle acceleration (a_x), and a measurement window associated with a specific coefficient of friction (μ_0) is established in this graph, and wherein a basic slip threshold value (λ_0) to be associated with the specific coefficient of friction (μ_0) is then substituted by the slip value (λ_1) occurring at the driven wheels, when the motor vehicle attains a driving state defined by the measurement window and simultaneously

a) the vehicle is travelling straight ahead ($\beta=0$),

b) the driven wheels have no speed differential (ΔV_H),
c) the acceleration (a_R) of the driven wheels corresponds to the vehicle acceleration (a_x), and
d) no propulsion slip or braking slip control occurs,
the respective slip threshold value (λ_s) applied in each case corresponding to, or being associated with, the corrected slip value (λ_1) associated with the specific coefficient of friction (μ_0).

It is possible by this method to adapt the slip thresholds automatically to the respective tyres during travel and thus to create optimum control conditions.

Further particulars of the invention may be learned from the following description of a method according to the invention and of an embodiment of an apparatus for performing this method.

In the drawing:

Fig. 1 shows a road performance graph,

Fig. 2 shows a graph of the attainable vehicle longitudinal acceleration as a function from the coefficient of friction,

Fig. 3 shows a road performance/coefficient of friction graph prepared from the two graphs according to Fig. 1 and Fig. 2,

Fig. 4 shows a graph with different coefficient of friction/slip curves and

Fig. 5 shows a diagrammatic embodiment of an apparatus for performing the method accordant to the invention.

Fig. 1 shows a road performance graph known per se, for a specific type of a motor vehicle which can be determined empirically by experiments or calculated by using a physical model of a stable rigid two-wheeler, from known vehicle quantities with certain simplifications. From this road performance graph it is possible to see what vehicle longitudinal acceleration - plotted on the ordinate - is attainable in the individual gears at a specific vehicle speed - plotted on the abscissa - with the engine at full load.

The vehicle longitudinal acceleration from vehicle standstill which is attainable as a function of the coefficient of friction between vehicle and road can also be calculated for the specific type of vehicle by means of the same physical model of stable rigid two-wheeler. The result of this calculation is the curve 1 shown in Fig. 2. Because it is only valid for the vehicle speed $V_F = 0$ km/h, it passes through the origin of the system of coordinates. Resistances to motion do not occur here. If the resistances to motion (rolling resistance, air resistance etc) are taken into consideration in the circulation, then the lines 2 marked in Fig. 2 are obtained, which are shown here only for a few discrete speeds up to the maximum vehicle speed $V_{F\ max}$. The increase in the speed is indicated by an arrow. This family of curves is bounded by a dash-line curve 3 which is obtained from the road performance graph in FIg. 1 and indicates the maximum vehicle longitudinal acceleration which is attainable at the respective vehicle speed. From this it is clear that the maximum acceleration is only obtainable from vehicle standstill for an optimum coefficient of friction (Point 4), and that no further acceleration is possible at vehicle maximum speed V_{Fmax} (Point 5). However, this graph also shows the minimum coefficient of friction which is necessary to attain a specific vehicle speed. This value can be read off on the abscissa, where the curve 2 associated with the required vehicle speed intersects or touches it. The two graphs according to Fig. 1 and Fig. 2 can now be combined to form a road performance/coefficient of friction graph as shown in Fig. 3.

Two different points with the same coefficient of friction will be found in each case in Fig. 2, namely for a specific constance vehicle speed and for vehicle standstill, for example. As an instance:

At the Point 5, at vehicle maximum speed, the minimum coefficient of friction is approximately $\mu = 0.3$. For this coefficient of friction a maximum vehicle longitudinal acceleration from vehicle stand-still of approximately $a_x = 1.4\ m/s^2$. (lines 6,7 and Point 8) is attainable. If these two points are transferred into the road performance graph (in Fig. 1) and joined together, Fig. 3, points 5 and 8 and dash-line 9, then this line 9 gives approximately a curve of constant coefficient of friction or constant grip, and the graph becomes a road performance/coefficient of friction graph. The curves of constant grip are only straight lines when simplified, in the practical case they are curved lines 10. They can be determined for the entire graph and are shown in Fig. 3. Thus, a definite coefficient of friction μ is associated with each point of this graph, the coordinates of which are composed of a specific value of the vehicle speed V_F and a specific value of the vehicle longitudinal acceleration a_x.

Fig. 4 shows a graph known per se, having two coefficient of friction/slip curves, curve 11 being obtained with a summer tyre and curve 12 with a winter tyre on one and the same road. Different slip thresholds λ_0 and λ_1 are therefore obtained for a specific coefficient of friction μ_0. For example, if the slip threshold for a propulsion slip control system is λ_0, and if this is optimally coordinated with the summer tyres associated with the curve 11, then it is easy to see that in the case of a tyre change to a winter tyre corresponding to the curve 12, the control system now starts to control with a slip threshold λ_0 at a considerably lower coefficient of friction than λ_0, and therefore ceases to operate optimally, because this tyre exhibits a considerably greater slip for the same coefficient of friction μ_0.

For this reason, a narrow measurement window 21 is defined in the road performance/coefficient of friction graph according to Fig.3 and according to the scales indicated on the graph it is determined by $\mu = 0.4$ and a road speed range V_F <100km/h.

Now when the motor vehicle is at an operating point contained in this measurement window 21, $V_F = 50$ km/h and

$a_x = 1.8\ m/s^2$ for example, which corresponds to an instantaneously effective coefficient of friction of $\mu = 0.4$, then if the motor vehicle is in a driving state defined later it is possible to measure the slip which occurs at the driven wheels at this operational point. For example, if the predetermined slip threshold value equals λ_0, and if a slip value λ_1 is measured at the driven wheels with the tyres currently in use at this operational point, then the measured slip value λ_1 is adopted, so that a new threshold value λ_1 which is associated with the coefficient of friction μ_0 is now established in the coefficient of friction/slip graph.

This slip threshold coordination should be performed only in a "normal" driving state in which no dynamic road parameter variations occur, that is to say when travelling straight ahead (steering angle $\beta = 0$), while the driven wheels exhibit no speed differential Δv_H due to different coefficients of friction (homogeneous road), while the acceleration of the driven wheels corresponds to the vehicle acceleration a_x (no propulsion torque excess) and while no propulsion slip or braking slip control action is occurring.

With the new slip value λ_1 thus determined, which is associated with the coefficient of friction μ_0, it is now possible for an anti-locking system in which a slip threshold value λ_s associated with a coefficient of friction of $\mu_R = 0.15$ is applied for example, to find this easily from a predetermined function $\lambda = f(u)$. If this function is linear, for example, then

$$\lambda_s = \lambda_1 . \mu_R / \mu_0$$

This value is approximately constant so long as the tyre characteristics remain the same. If the tyres become worn or are substituted by others, then the slip threshold λ_s also varies.

In a propulsion slip control system other slip thresholds are generally valid, which can also be adapted to the road instantaneously travelled periodically at intervals in the millisecond range by the said method, by determining an instantaneous coefficient of friction $_K$ from the graph (10) according to the input quantities of vehicle speed V_F and vehicle longitudinal acceleration a_x, and calculating a slip threshold value λ'_s associated with the latter according to a predetermined function $\lambda = f(\mu)$, likewise linear for example, from

$$\lambda_s = \lambda_1 . \mu_K / \mu_0$$

Braking slip and/or propulsion slip control systems operate with these slip threshold values λ_s and/or λ'_s according to their programmes in a manner known per se.

A diagrammatic embodiment of an apparatus for performing the method according to the invention is illustrated in Fig. 5. 13 designates speed sensors of the four vehicle wheels which output signals associated with the wheel speeds and/or wheel circumferential speeds V_{VL}, V_{VR}, V_{HL}, V_{HR} of the left and right front and rear wheels to an electronic circuit 14 which calculates from them the vehicle speed V_F, the vehicle longitudinal acceleration a_x as well as speed differential, ΔV_H, acceleration Q_R and the slip values λ_R, λ_L of the driven wheels.

Reference 15 designates a stored graph to which the vehicle speed V_F and the vehicle longitudinal acceleration a_x are fed as input quantities, and which outputs a coefficient of friction μ_K associated with these input quantities.

If the conditions

a)steering angle $\beta = 0$,

b)no speed differential Δv_H of the driven wheels,

c)acceleration a_r corresponds to vehicle acceleration a_x and

d)no PSC or BSC control action

are fulfilled, and an operation state established by a measurement window defined in the graph (10) is attained, then slip λ_1 measured instantaneously at the driven wheels is detected and replaces the permanently predetermined slip value λ_0 which is stored together with the above defined quantities μ_0 and μ_π.

In an arithmetic circuit 20 a slip threshold value $_s$

for the braking slip control system 16 and/or a fixed or variable slip threshold value λ_s for the propulsion slip control system 16' is determined according to the formulate give above and fed to the control systems 16 or 16' together with the other required quantities (slip of driven wheels, accelerations etc, as known per se) which are passed to the control systems by lines 19, which according to their programmes influence the propulsion, indicated by a throttle flap 17, or the brakes 18 of the driven and non driven wheels in a known manner.

CLAIMS:

1. A method of adapting slip threshold values for a propulsion slip and/or a braking slip control system to the existing tyres of a motor vehicle, wherein a curve, specific to the respective type of vehicle, of the attainable vehicle acceleration (a_x) from vehicle standstill ($V_F=0$), as determined from the speeds of the non driven wheels, is determined as a function of the coefficient of friction (μ), this curve being extended, taking into consideration the resistances to motion which are a function of the vehicle speed (V_F), into a graph of the coefficient of friction (μ) as a function of the vehicle speed (V_F) and of the vehicle acceleration (a_x), and a measurement window associated with a specific coefficient of friction (μ_o) is established in this graph, and wherein a basic slip threshold value (λ_o) to be associated with the specific coefficient of friction (μ_o) is then substituted by the slip value (λ_1) occurring at the driven wheels, when the motor vehicle attains a driving state defined by the measurement window and simultaneously

a) the vehicle is travelling straight ahead ($\beta=0$),

b) the driven wheels have no speed differential (ΔV_H),

c) the acceleration (a_R) of the driven wheels corresponds to the vehicle acceleration (a_x), and

d) no propulsion slip or braking slip control occurs,

the respective slip threshold value (λ_s) applied in each case corresponding to, or being associated with, the corrected slip value (λ_1) associated with the specific coefficient of friction (μ_o).

2. A method according to claim 1, wherein the slip threshold value (λ_s) is determined by the ratio ($\lambda_s = \lambda_1 . u_R/u_o$), where the coefficient of friction μ_R is the coefficient of friction for which the control system is designed.

3. A method according to claim 1, wherein the slip threshold value (λ'_s) is determined continuously by the ratio $\lambda'_s = \lambda_1 . \mu_K / \mu_o$, the value μ_K being determined continuously from the graph.

4. Apparatus for performing the method according to claim 1 for a propulsion slip and/or braking slip control system of a motor vehicle, having sensors which determine the circumferential speeds of the vehicle wheels, having a device which determines the required operation parameters from the signals of these sensors, and having a slip comparator which reacts to a predeterminable threshold value for each non driven and/or driven vehicle wheel, wherein a device is provided to which the quantities of vehicle speed (V_F) and vehicle longitudinal acceleration (a_x) are input periodically and which outputs a coefficient of friction (μ_K) associated with these quantities and stored in a graph and which substitutes a predetermined slip value (λ_o) by the slip value λ_1) measured at the driven wheels when the motor vehicle is in an operational state defined by a measurement window associated with the coefficient of friction within the graph, and the conditions:

a)motor vehicle travelling straight ahead,

b)no speed differential of the driven wheels,

c)acceleration of driven wheels equal to vehicle acceleration and

d)no propulsion slip or braking slip control operation

are simultaneously fulfilled, and wherein an arithmetic circuit which is provided within the said device converts the predetermined slip value (λ_o) by means of predetermined coefficients of friction and of a predetermined function ($\lambda = f(\mu)$) to corresponding slip threshold values (λ_s; λ'_s) and feeds them as slip threshold values to a braking slip control system and/or to a propulsion slip control system, by which they are further processed into control signals for the propulsion and/or the brakes.

5. Apparatus for performing the method according to claim 1 for a propulsion slip and/or braking slip control system of a motor vehicle, substantially as described herein with reference to and as illustrated in the accompanying drawings.

6. A method of adapting slip threshold values for a propulsion slip and/or a braking slip control system to the existing tyres of a motor vehicle, substantially as described herein with reference to and as illustrated in the accompanying drawings.

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