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GB 1444865 A　　　US 5294191 A

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B60T 13/74
ONLINE DATABASES:WPI

(54) **Electric vehicle having a hydraulic brake system**

(57)　An electric-powered vehicle includes at least one electric motor 32 which is controlled and monitored by an electronic control system 14 for driving at least one vehicle wheel 28 in a traction mode of the motor and also for selectively providing a contribution to overall braking torque when operated in a braking mode, and a driver operated hydraulic braking system operating on at least the front wheels of the vehicle and including an electronically controlled booster 10. When modulation of the overall braking torque is required (e.g. for ABS) the variation of the electric torque is arranged to stay within the "regenerative range" of operation of the electric motor, at least under predetermined operating conditions of the vehicle. When the battery 34 is fully charged, during a braking mode, the hydraulic braking torque is increased and the electric braking torque is decreased.
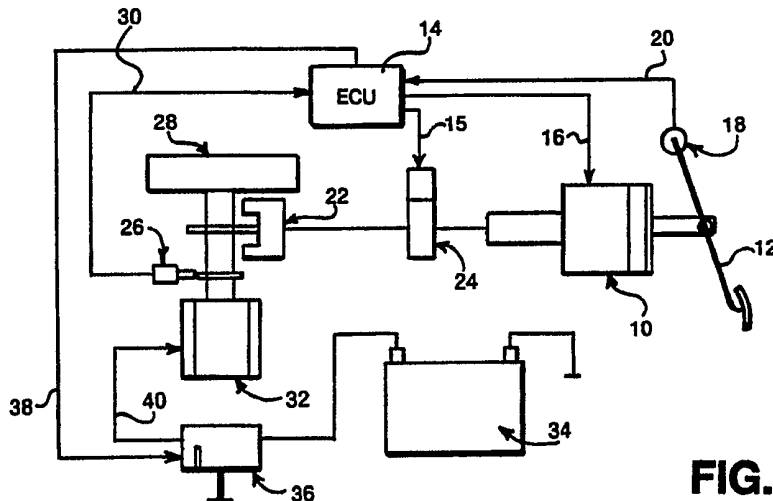

FIG. 8

GB 2 282 651 A
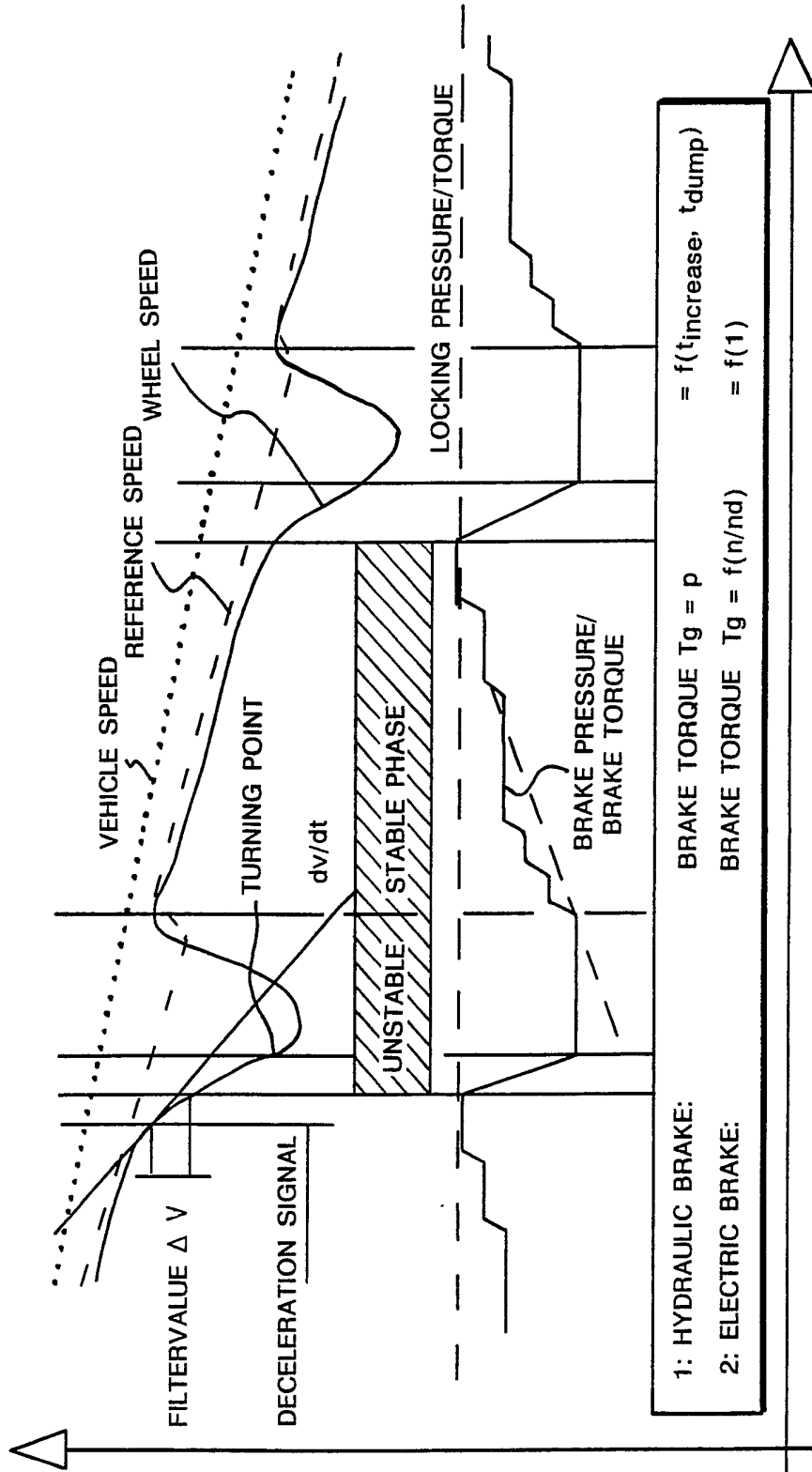
ABS Control Cycle for Hydraulic
and Electric Brake System
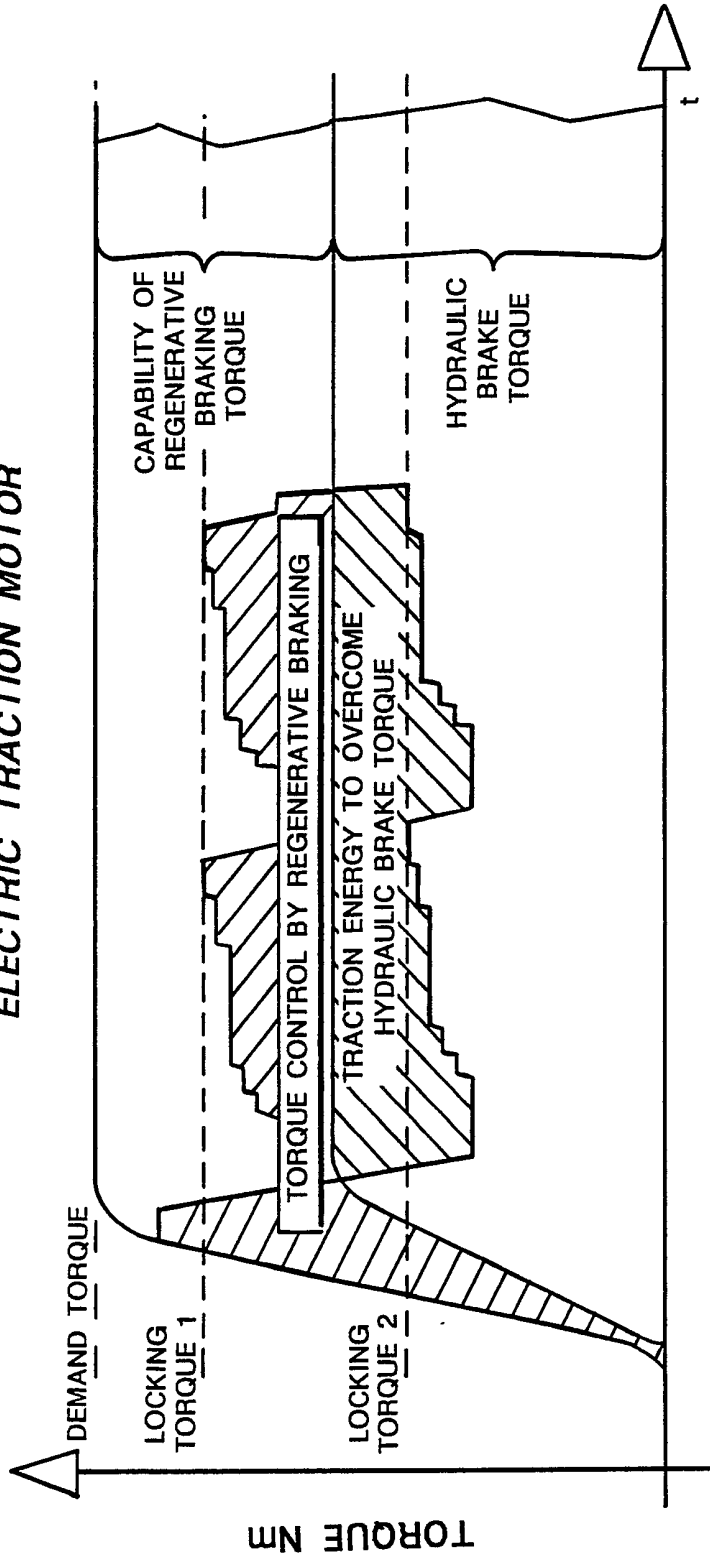

FIG. 1

FIG.2

ABS CONTROL WITH ELECTRIC
TRACTION MOTOR

IN COMBINATION WITH

ELECTRONICALLY CONTROLLED BOOSTER

FIG.3

GEARBOX

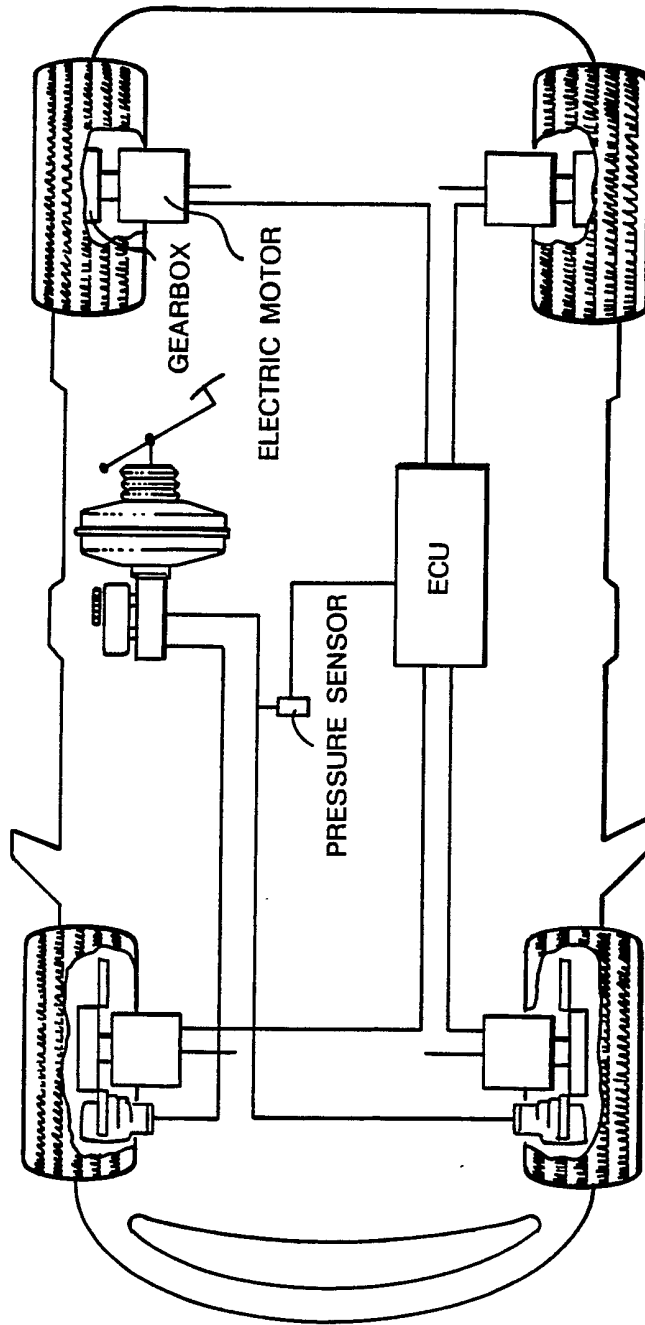ELECTRIC MOTOR

PRESSURE SENSOR

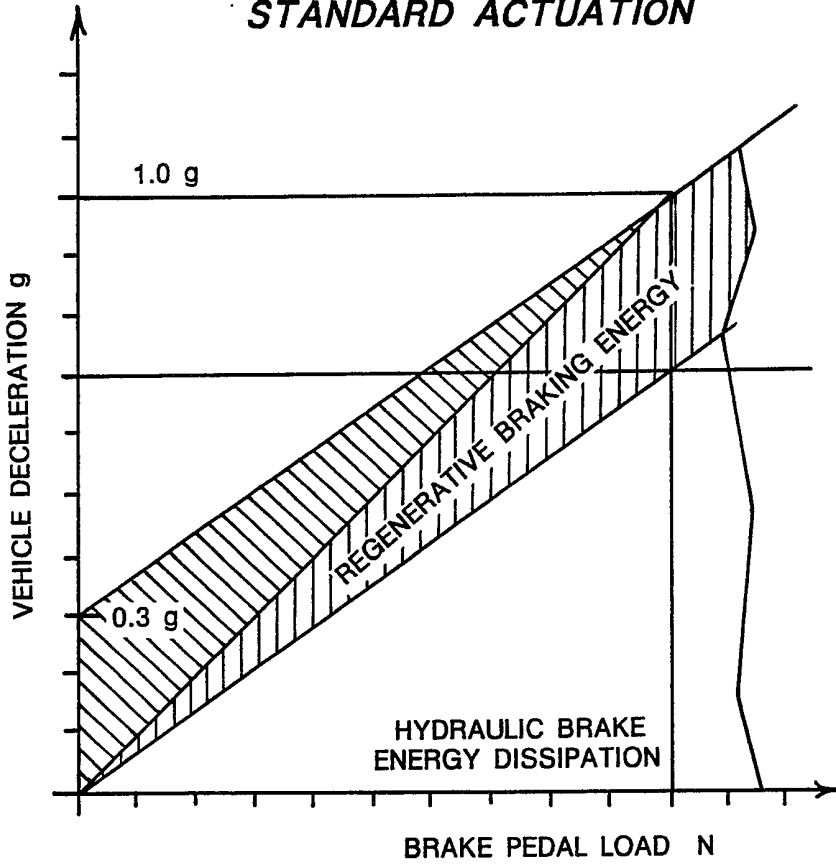ECU
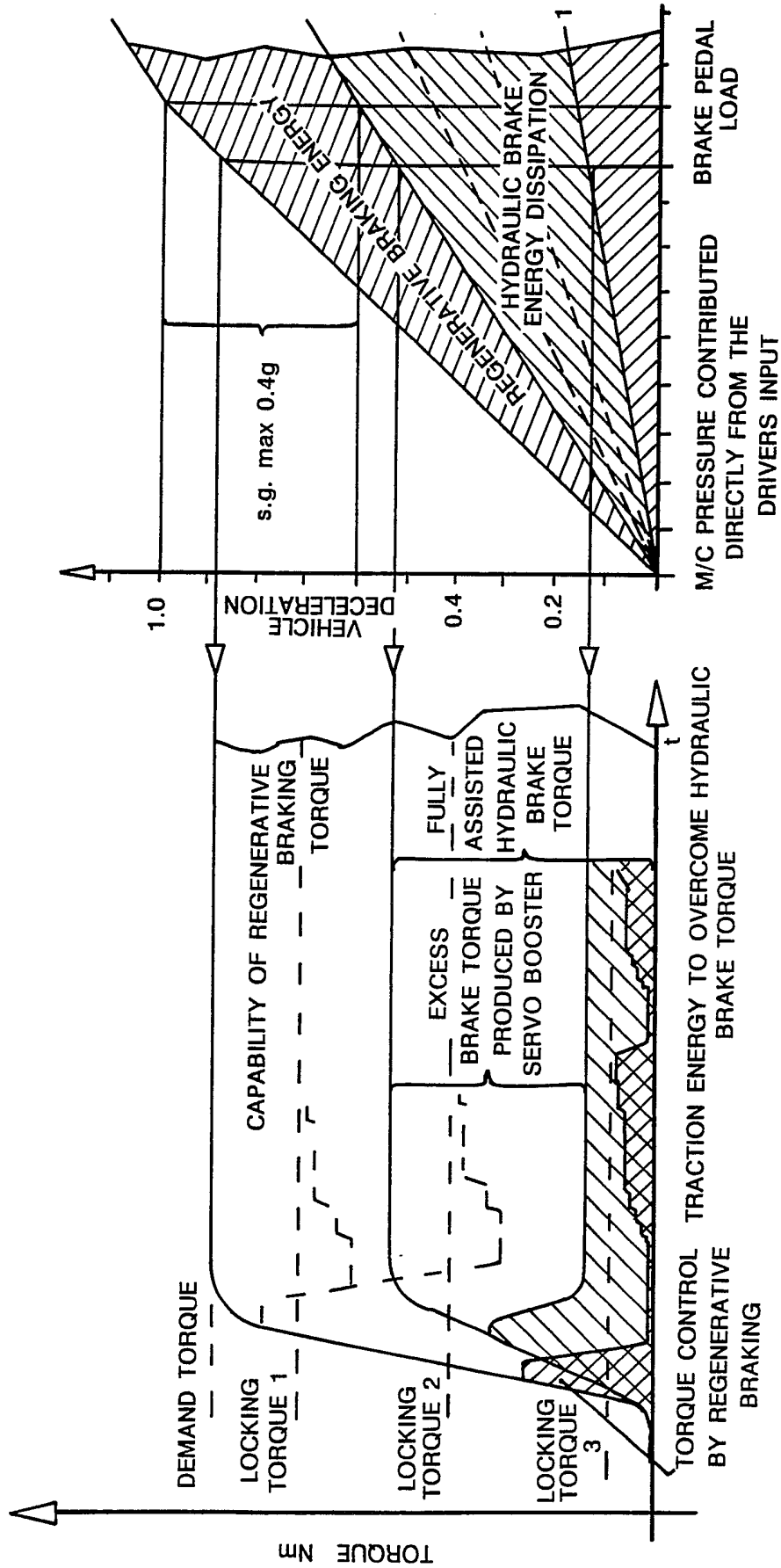
FIG.4

STANDARD ACTUATION
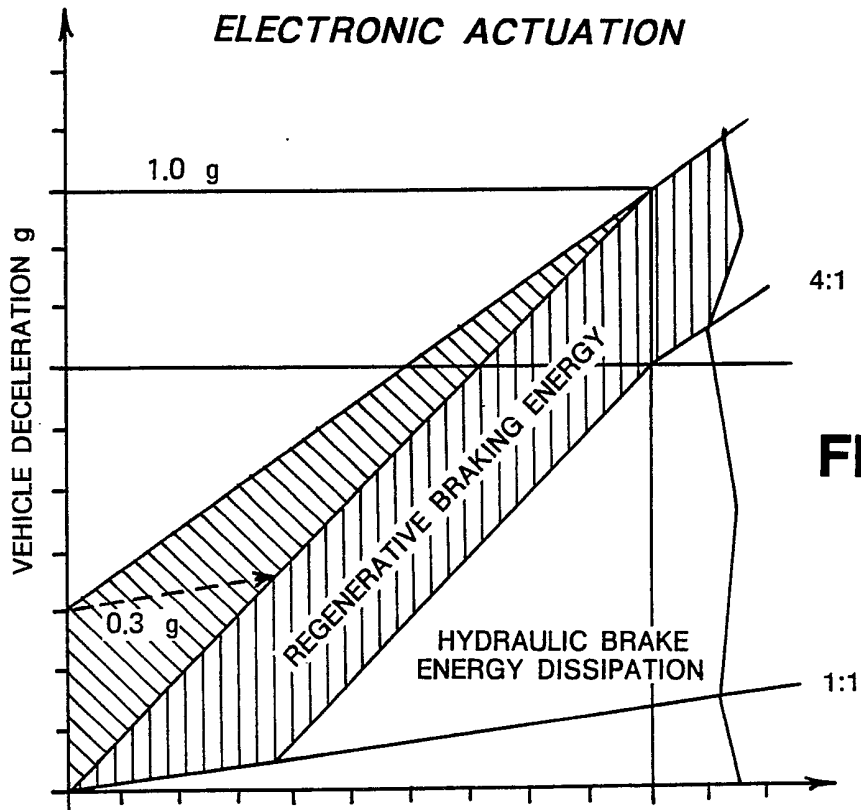

FIG. 5a

ELECTRONIC ACTUATION

FIG. 5b

SEQUENTIAL APPLICATION OF
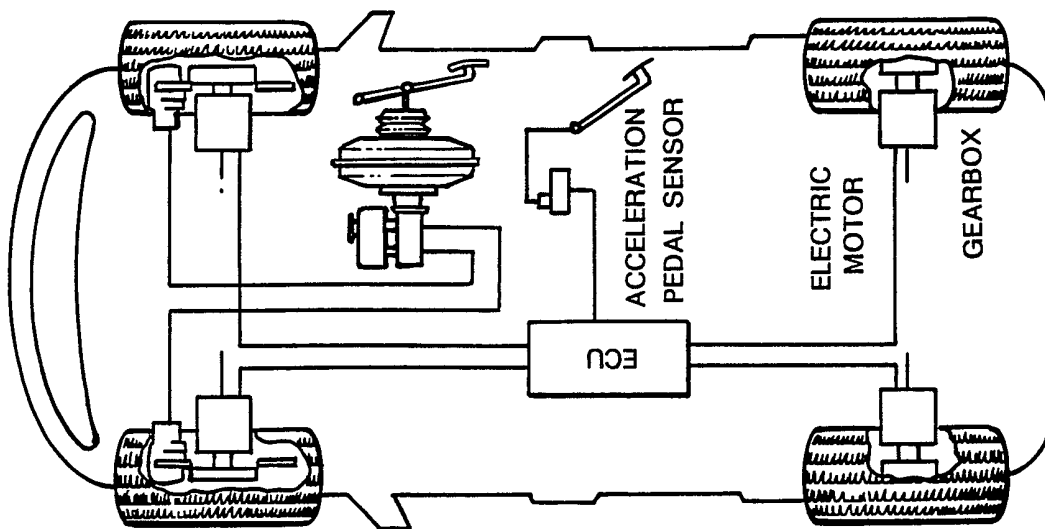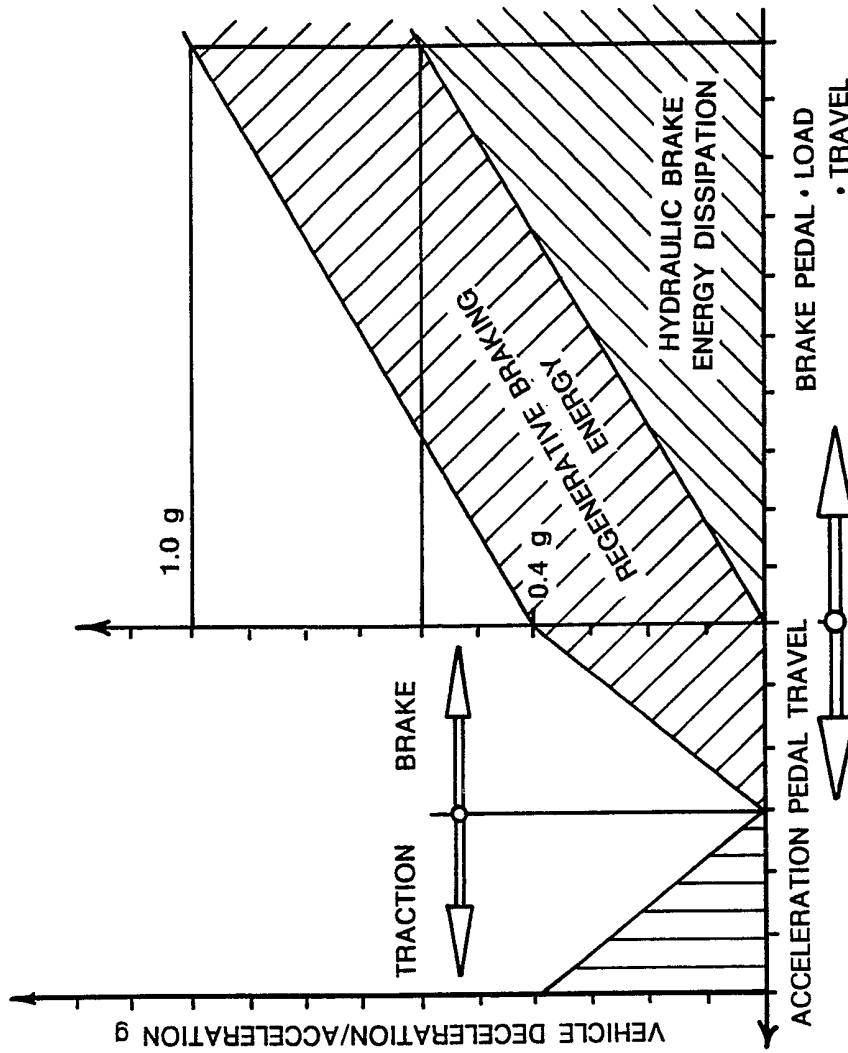REGENERATIVE AND HYDRAULIC
BRAKE SYSTEMS

FIG. 6

INTERACTION BETWEEN ELECTRIC TRACTION
MOTOR AND ELECTRONICALLY CONTROLLED
BOOSTER

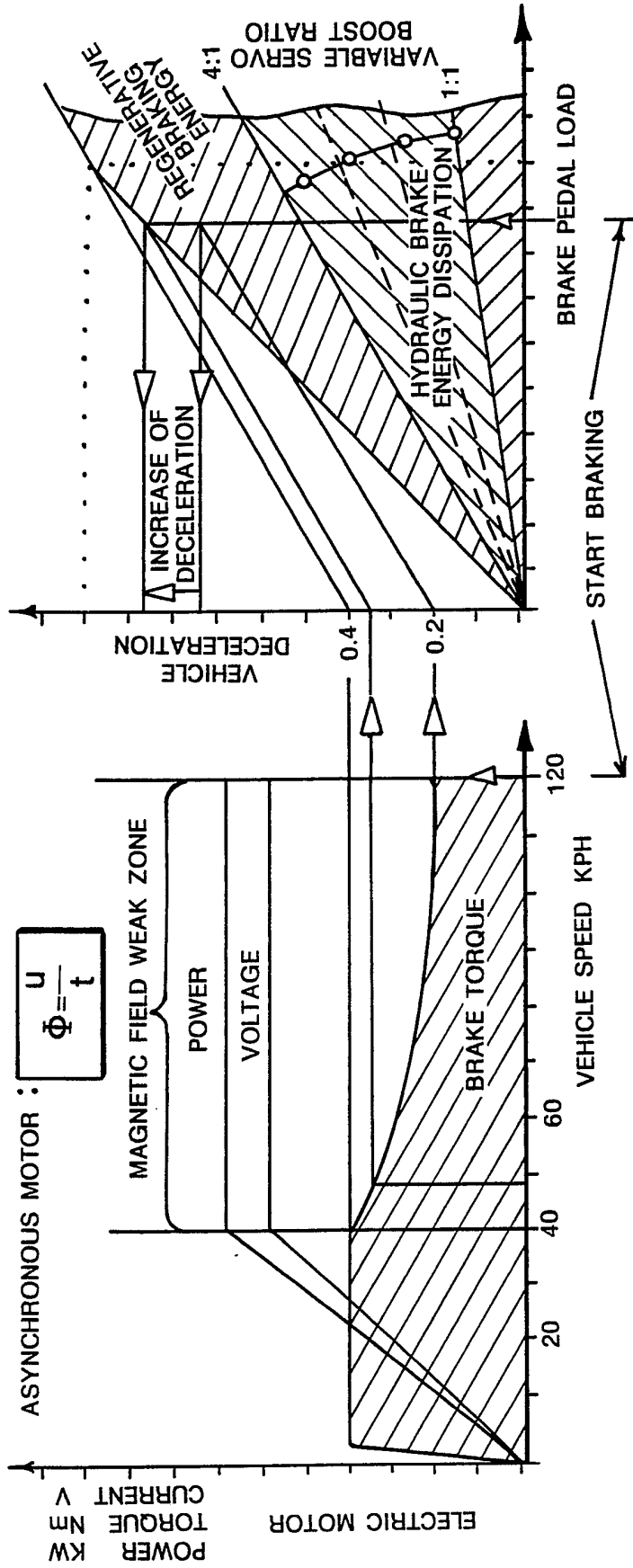ACHIEVING ACCEPTABLE RECUPERATION AND
CONSTANT VEHICLE DECELERATION

FIG. 7
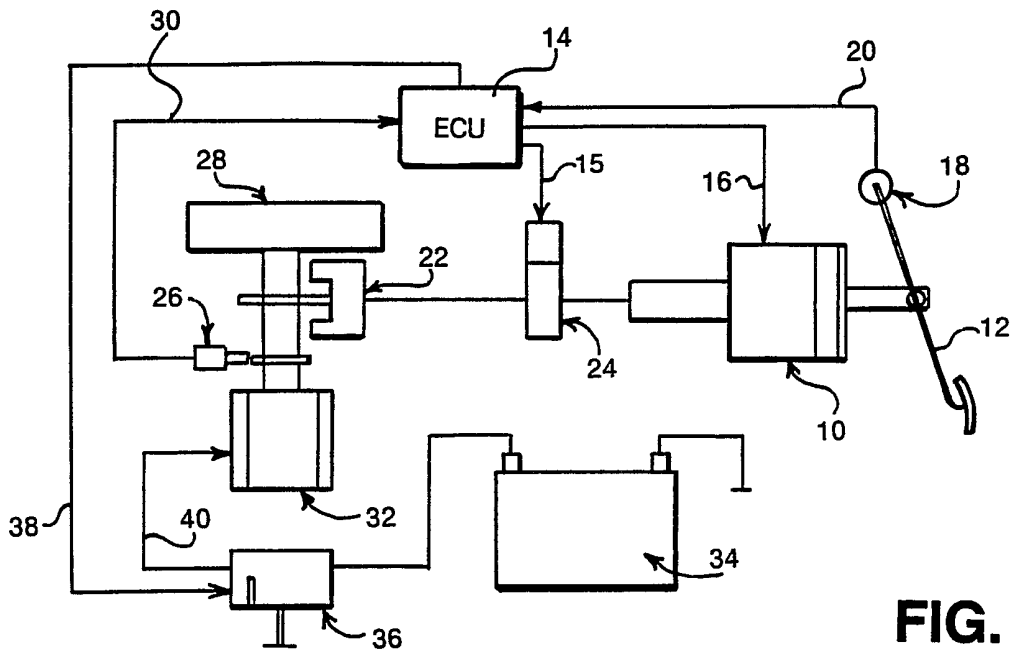
FIG. 8
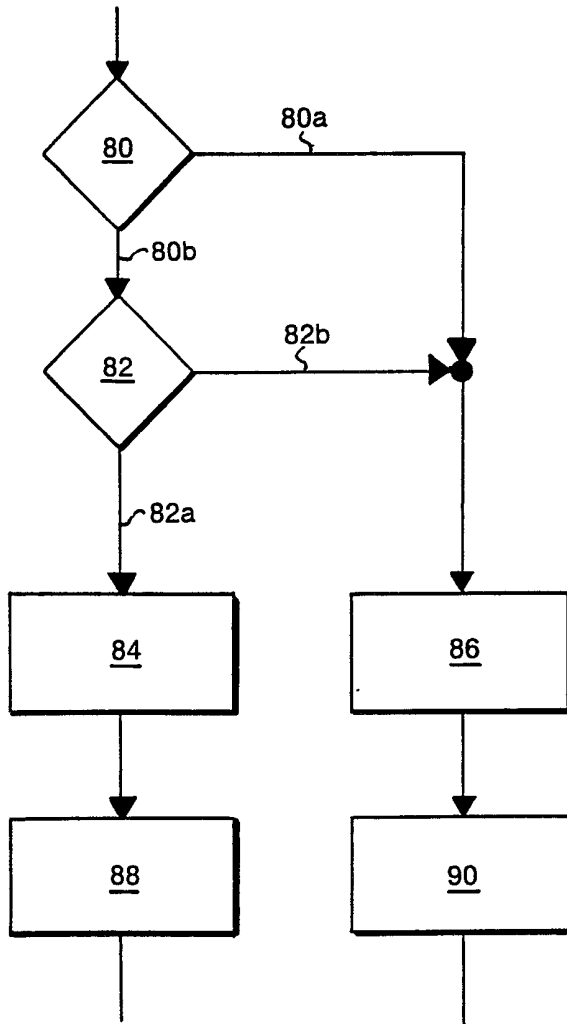
FIG. 10
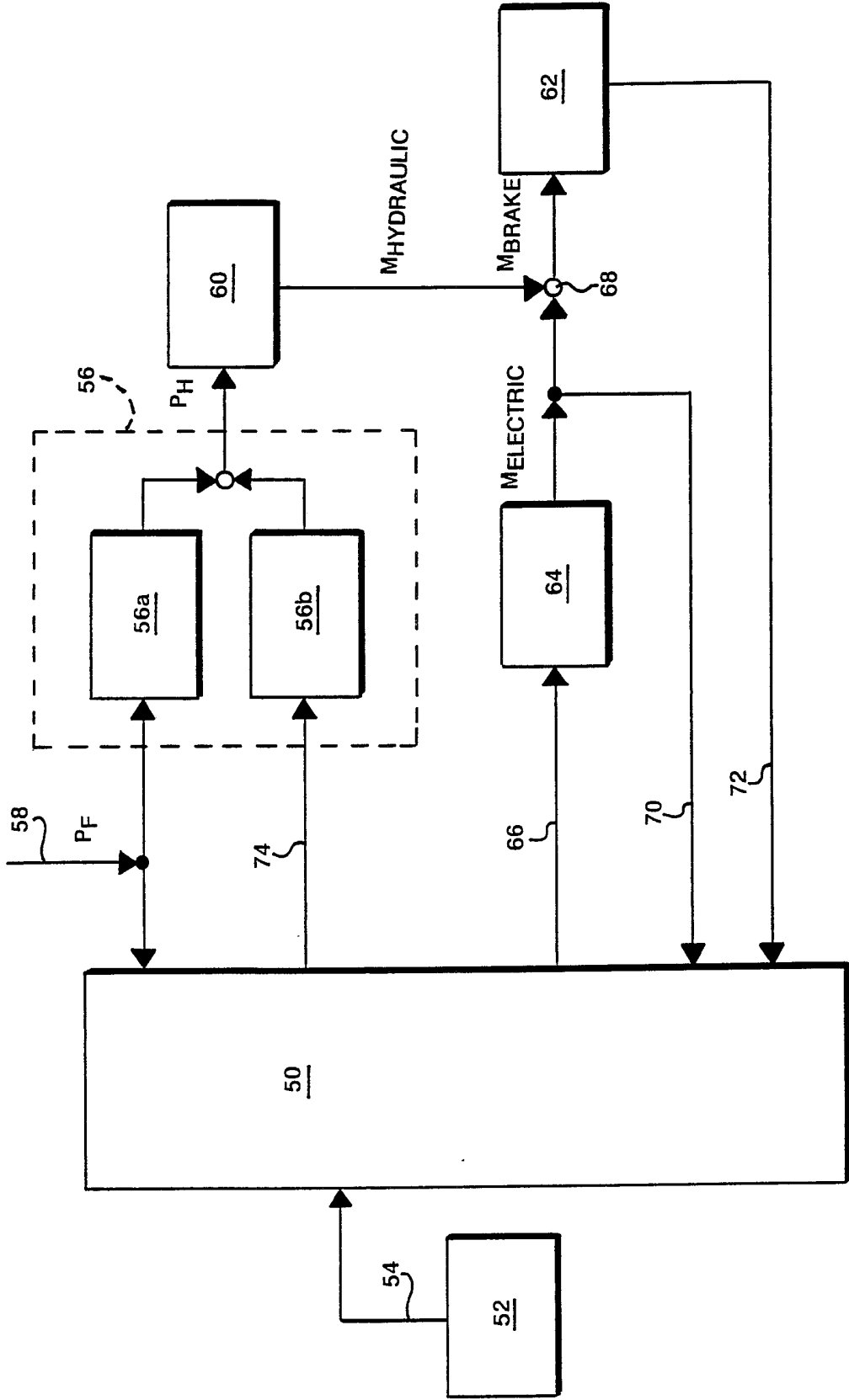
FIG. 9

DESCRIPTION

ELECTRIC VEHICLE HAVING A HYDRAULIC BRAKE SYSTEM

The present invention is concerned with electric-powered vehicles having a drive system which includes one or more electric motors controlled and monitored by an electronic control system, and which also includes an hydraulic braking system which is operated by the vehicle driver which operates on at least the front wheels of the vehicle.

Drive systems in electrically powered vehicles are usually of one of two types, namely the type where there is a respective electric motor drive unit associated with each of a plurality of wheels (referred to as motor-in-wheel drive units) and the type which has a single central electric motor and gearbox, with a conventional differential and drive shafts. The present invention is applicable equally well to both of these motor drive configurations, although the motor-in-wheel arrangement is probably preferred.

For deceleration of such a vehicle, in addition to the hydraulic brake torque $M_{Hydraul}$, which is effected by the driver-operated brake system, an electric brake torque $M_{Electr.}$ from the electric propulsion motor(s) is available and usable. This arises from the well known effect that certain motors,

when mechanically driven with the energising current removed, operate as dynamos and generate a current but with a resultant braking moment acting against the applied mechanical effort, so effectively acting as a brake.

As a consequence, the total brake torque M_{Brake} on a vehicle wheel is given by:

$$M_{Brake} = M_{Hydraul.} + M_{Electr.}$$

Since a vehicle battery has only a limited available capacity, it is found useful to charge the vehicle battery by supplying to it the "dynamo" current generated by the electric brake torque $M_{electr.}$. This process is referred to as "regenerative braking".

With such a braking system, a simple anti-lock (ABS) braking arrangement can be realized by modulation of the electric current applied to the electric driving motor(s) and hence of the brake torque.

With a conventional hydraulic ABS, the brake torque is proportional to brake pressure. Similarly, electric brake torque is largely proportional to electric motor current which can be controlled by, for example, pulse width modulation techniques. Thus, if excessive wheel slip occurs, the electric motor torque is arranged to be reduced. After wheel recovery, the

electronic control unit (ECU) controlling the braking system reactivates the electric drive. The ABS algorithm can be substantially the same as for hydraulic brakes and vehicle performance will be maintained if electric motor torque reduction is sufficient for wheel recovery (see accompanying Fig. 1).

Anti-lock (ABS) braking is always required if the brake torque M_{brake} exceeds the anti-lock torque M_{lock} at which the wheel locks and which depends inter alia on the coefficient of friction between the tyre and the road surface, ie when

$$M_{Brake} > M_{Lock}$$

For anti-lock braking, two basic cases must be distinguished. Firstly, in the case that

$$M_{Lock} > M_{Hydraul}$$

which occurs on road surfaces of high coefficient of friction (high mu), the modulation of the brake torque M_{Brake} required for the anti-lock operation can be effected by variation of the electric torque component M_{Electr} by controlling the electric current supplied to the relevant electronic motor. In this case, the anti-lock procedure would be executed wholly within the "regenerative range" of operation, without additional consumption of electrical energy.

If, on the other hand, $M_{Lock} < M_{Hydraul}$

which may occur on surfaces of low coefficients of friction (low mu), the electric motor has to be arranged to produce a counteracting torque M_{Contra} (= M_{Lock}-$M_{Hydraul}$) because the wheel must be driven against the hydraulic torque $M_{Hydraul}$ if wheel lock is to be avoided. This procedure would happen outside of the "regenerative range" and cause an additional consumption of electrical energy.

Such a process would in principle still be practicable in the case of an extremely small electrical counter torque M_{contra}, but in the case of an extremely low coefficient of friction (adhesion), which would occur for example with a road surface covered with snow or ice, and hence producing a very small anti lock torque M_{Lock}, such a procedure would be inoperative because the counter torque M_{contra} to be overcome would be too great.

As the advantages of anti-lock systems are mainly effective in the case of low coefficients of adhesion, it would thus be necessary to include already known means for the purpose of hydraulic pressure modulation, which would result in disadvantages such as an increase in weight, a requirement for additional installation space, increased expenditure in connection with the assembly and hence an overall increase in costs.

It is an objective of the present invention to avoid these disadvantages of the above described basic system.

In accordance with the present invention, the hydraulic braking torque, $M_{Hydraul}$, produced by the driver by way of the hydraulic braking system, is adjusted in such a manner that, for the purpose of modulating the braking torque M_{Brake}, the variation of the electric torque M_{Elect} always lies within the "regenerative range".

As a means for adjusting the hydraulic braking torque, it is preferred to use an electronically controlled booster, such as that described in our European Patent Application No. EP-A-0379329, to which reference is hereby directed.

By use of the invention, a reduction of the hydraulic torque $M_{Hyrdaul}$ becomes possible in the case of low and very low coefficients of friction so that the electric component M_{Electr} can be varied within the "regenerative range" to modulate the brake torque M_{Brake} for anti-lock control. The advantage of this is that an anti-lock control is achieved on the one hand without loss of operational efficiency and on the other hand without causing stress on the vehicle battery.

Other advantages result from the fact that the

use of, for example, an electrically controlled booster is more cost-effective than the installation of a conventional anti-lock system.

It is also advantageous that the decrease of the torque of the electric motor, and by this the available electric brake torque M_{Electr} which is caused by the electro-magnetic force during increasing motor speed or vehicle velocity, respectively, can be compensated by increasing the hydraulic torque $M_{Hydraul}$.

Also, it is possible for the hydraulic torque $M_{Hydraul}$ to be varied in dependence upon the state of charge of the vehicle battery during each braking operation. For example, in the situation that the vehicle battery is fully charged, braking within the "regenerative range" is less relevant since the battery could be damaged by over charging in certain circumstances. In this situation, therefore, it is preferable to arrange for the hydraulic component $M_{Hydraul}$ to be more weighted and significant. This would also ensure that the hydraulic brake is applied sufficiently often to prevent corrosion of the brake disc occurring.

The invention is described further hereinafter, by way of example only, with reference to the accompanying drawings, in which:-

Fig. 1 illustrates graphically the difference/similarities in ABS control cycles for hydraulic and electric brake systems;

Fig. 2 illustrates graphically ABS control using an electric traction motor;

Fig. 3 illustrates graphically ABS control using an electric traction motor in combination with an electronically controlled booster;

Fig. 4 shows diagrammatically the installation of a pressure sensor in a vehicle which responds to the pressure in the hydraulic brake system and signals the vehicle ECU accordingly;

Fig. 5 illustrates graphically regenerative braking without the present invention;

Fig. 5a illustrates graphically regenerative brake with the aid of the present invention;

Fig. 6 illustrates graphically sequential application of regenerative and hydraulic brake systems;

Fig. 7 illustrates graphically the interaction between an electric traction motor and an electronically controlled booster;

Fig. 8 is a diagrammatic illustration of a braking system in accordance with the present invention combining hydraulic and electric traction braking with an electronic booster;

Fig. 9 is a further illustration of one possible embodiment in accordance with the invention for performing hydraulic control adjustment to keep the electric braking within the "regenerative range"; and

Fig. 10 is a flow diagram illustrating the operation of the embodiment of Fig. 9.

Referring now to Fig. 8, there is shown in highly diagrammatic form a generalised system view of a vehicle braking system in accordance with the present invention having electric traction braking, hydraulically operated friction braking, and means for enabling the hydraulic boost ratio to be adjusted to enable electric braking in the regenerative range to be retained.

The system of Fig. 8 includes a hydraulic brake comprising a master cylinder and variable electronic booster unit 10, which can be of the type described in our EP-A-0379329, which has a mechanical input from a foot pedal 12 and an electrical input from an electronic control unit (ECU 14) via a line 16. A sensor 18 is associated with the foot pedal 12 to provide an electrical demand/pedal displacement signal to the ECU 14 via a line 20. The hydraulic output of the variable electronic booster and master cylinder assembly 10 is coupled to a conventional friction brake 22 by way of a conventional ABS modulator 24

which is controlled electrically by the ECU 14 via a line 15 in accordance, inter alia, with wheel speed signals from a wheel speed sensor 26 associated with a vehicle wheel 28 to be braked. The signals from the wheel speed sensor are coupled to the ECU 14 via a line 30.

The vehicle is of the type having an electric propulsion system and in this embodiment, the system comprises a separate driving motor 32 and gearbox with a constant transmission ratio for each of a plurality of vehicle wheels 28 (only one being shown). The motor 32 would normally be of the asynchronous type which will act as a generator when under overrun conditions when it is being driven by the momentum of the vehicle. The motor 32 is energised from a battery 34 via a motor controller and battery monitor device 36 which is coupled to the ECU 14 by a line 38 and to the motor 32 via a line 40.

In the present system, the electric motor 32 is used not just for traction and regenerative braking but also for ABS control by suitable modulation of the brake torque. As mentioned hereinbefore, electric brake torque is essentially proportional to electric motor current, which can be controlled via the ECU 14 by, for example, pulse width modulation. If excessive wheel slip occurs, the torque of the motor 32 is

arranged to be reduced, the drive being re-actuated after wheel recovery.

A hydraulic pressure sensor as shown at 42 in Fig. 4, or the more inexpensive brake pedal travel sensor 18 of Fig. 8, is able to translate the driver braking demand into the ECU 14, so that braking force performed by the electric motor(s) 32 can be varied.

The total brake force is the sum of both hydraulic and electric forces. As illustrated in Figs. 5 and 5A, the maximum brake torque generated by the electric motor is available at, for example, 1g vehicle deceleration, the motors themselves then contributing about 0.3g, depending on vehicle load condition. Because of this sharing of the braking force, the regenerative energy is not fully utilized in all brake applications lower than 1.0g (Fig. 5).

Fig. 7 shows the characteristic curve of an asynchronous electric motor relating performance, torque and voltage, and showing that all of them vary with vehicle speed. A finite amount of motor rotor slip is necessary to obtain a minimum of brake torque from the electric motor. At very low vehicle speed (below say 5Kph), rotor slip cannot be kept up by using the electric motor as a generator, and as a result, the electric brake force cannot be guaranteed any longer. Similar behaviour is found at vehicle

speeds above about 1/3 of the maximum speed. This is
caused due to weakening of the electric magnetic field
in order to reduce motor size and weight and for cost
purposes. Above this speed, there is a constant power
output but reduced motor torque for traction and
braking.

This characteristic of different motor torque
varying with speed would normally lead to variable
vehicle deceleration in spite of constant pedal effort
(Fig. 7). However, the provision of the electronic
booster 10 in the present system can compensate for
this irregular behaviour by virtue of its variable
servo boost ratio which enables the hydraulic braking
torque, deriving from the driver's actuation of the
foot pedal 12, to be adjusted in such a manner that
the variable electric brake torque remains constantly
within the regenerative range, so that electric
braking remains effective, even at low speeds and on
low mu road surfaces.

Referring again to Figs. 5 and 5A, it is seen
that in a typical case the electric motor contributes
about 0.3g to the vehicle deceleration. Fig. 5 shows
an increase of the hydraulic brake force proportional
to the brake pedal force in the event of the use of a
conventional standard (non-variable) booster. This
has the disadvantage that the maximum electronic brake

force (0.3g) is available only when the vehicle

deceleration exceeds 1g. This _dis_ advantage is avoided by

an appropriate adjustment of the hydraulic force as

illustrated in Fig. 5A using, in ⌐ _this_ ⌐the embodiment, the

electronically controlled booster 10. The booster

ratio is arranged to be held on its minimum value of

1:1 until maximum electric motor contribution to

vehicle deceleration is reached. For higher

decelerations above this point an increase of the

booster ratio is adjusted such that the electric motor

can make its maximum contribution to vehicle

deceleration by staying in the regenerative range as

long as possible.

This has another advantage that the maximum

capacity for recharging of the vehicle battery is

provided. The aforegoing arrangement also has the

advantage that it is guaranteed that the hydraulic

brake is always operated at some point in the braking

cycle so that corrosion of the brake disc is

prevented.

To enable the necessary control of the electronic

booster 10, in addition to the usual wheel-speed

signals provided by the sensor 26, it is necessary to

obtain signals representative of brake pedal force and

electric motor torque. Brake pedal force is

represented in the present embodiment by the signal

from the pedal displacement transducer 18. Electric

motor torque can be determined from a measurement of

the motor current, for example in the motor controller

unit 36.

The procedure in the case of high and low

coefficients of friction is illustrated in Fig. 2 and

Fig. 3. Specifically, low coefficients of friction

are treated in Fig 3 by the corresponding locking

torque 3.

One possible manner in which the aforegoing

control of the electronic booster in the hydraulic

circuit can be achieved is shown in diagrammatic form

in Fig. 9 to which reference is now made.

Referring now to Fig. 9, there is shown an

electronic unit (ECU) 50 which receives an input from

the vehicle battery 52 on line 54 indicative of the

state of charge of the battery. An electronically

controlled booster 56 is illustrated diagrammatically

as including a part 56a which enables a standard

booster ratio of 1:1 to be selected and a part 56b

which enables an adjustable booster ratio to be

selected. The ECU 50 and standard brake part 56a

receive an input on a line 58 representative of brake

pedal force. The output of both part 56a,56b are

coupled to the vehicle brake 60 which results in a

hydraulic brake torque $M_{Hydraul}$ which is applied to

the vehicle wheel 62. An electric traction motor 64
receives control via line 66 in dependence upon the
electronic drive motor demand determined via the ECU
50, the motor generating an electric braking torque
M_{Elects} which is added at 68 to $M_{Hydraul}$ and applied
to the wheel 62. The electric brake torque M_{Elects} is
also supplied to the ECU 50 via connection 70. Data
derived from the turning behaviour of the vehicle
wheel 62, such as speed and deceleration, which are
required to calculate vehicle speed and vehicle
deceleration, and applied to the ECU 50 via a
connection 72. The ECU 50 also outputs a signal on
line 74 representative of the demand for the
electrically controlled booster 56b.

On operation of the brake pedal by the driver, a
brake pedal force P_F on line 58 is transformed in the
booster device 56 into a hydraulic brake pressure P_H
for actuating the vehicle brake 60 which then provides
a hydraulic brake torque $M_{Hydraul}$.

The electric traction motor which is controlled
by the electronic control unit 50 makes an electric
brake torque M_{Elects} available, so that the total
brake torque M_{Brake} for braking of the vehicle wheel
62 results from the sum of hydraulic brake torque
$M_{Hydraul}$ and electric brake torque M_{Elects}.

In the case of a fully charged battery, steps

should be possible to inhibit regenerative braking
since the battery could be damaged in an attempt to
charge the battery further in this condition.
Monitoring of the state of charge of the battery
(battery voltage) is therefore carried out so that, in
the case of a fully charged battery, the booster
ratio can be increased such that the electric brake
force is replaced by the increase in hydraulic brake
force to maintain the total brake force constant.

In a situation where the vehicle is being braked
on a very low mu surface (low adhesion), it is
advantageous for the electric motor to be driven
against the action of the hydraulic brake torque when,
with a standard booster, the hydraulic brake torque is
greater that the locking torque. This is illustrated
in Figure 2 (locking torque 2). To avoid this
disadvantage, the hydraulic brake torque is adjusted
by in this case the electronically controlled booster
such that the hydraulic brake torque is less than the
locking torque, the ABS control being executed by
variation of electric braking torque (as shown in the
graphs of Fig 3).

Referring now to Fig. 10 there is shown a
simplified flow chart illustrating how the inputs of
electric brake torque M_{Elects} and state of charge of
the vehicle battery are processed in the ECU 50. The

various steps are identified by number as follows:

80   :   decision depending on state of charge of vehicle battery (52),

80a: path in the case that vehicle battery is NOT fully charged,

80b: path in the case that vehicle battery is full charged,

82   :   decision depending on electric brake torque M_{Elect},

82a: path in the case that electric brake torque has NOT reached its maximum value, which corresponds to a contribution in the order of magnitude of 0.3 g of total vehicle deceleration,

82b: path in the case that electric brake torque is already at its maximum,

84   :   action so that electronically controlled booster (3) is NOT demanded to keep booster ratio constant on its minimum of 1:1,

86   :   action so that demand of electronically controlled booster (11) is adjusted to an optimum condition depending on graph of vehicle declaration over brake pedal load,

88   :   action so that demand of electric drive motor (64) is adjusted to an optimum condition depending on the graph of vehicle deceleration over brake pedal load,

90   :   action so that the electric brake torque
is held at its maximum level to make regenerative
braking in optimum condition possible in dependence
upon the state of charge of the battery.

It should be noted that the inputs of vehicle
deceleration and brake pedal load in steps 86 and 88
are available in the electronic control unit from the
brake pedal force and wheel data. The corresponding
graph for adjustment is shown in Fig. 3.

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CLAIMS

1. An electric-powered vehicle having a drive system which includes at least one electric motor which is controlled and monitored by an electric control system for driving at least one vehicle wheel in a traction mode of the motor and also for selectively providing a contribution to overall braking torque when operated in a braking mode and which also includes an hydraulic braking system which is actuated by the vehicle driver and which operates on at least the front wheels of the vehicle, characterised in that hydraulic braking torque, produced by the driver by way of the hydraulic braking system, is adjusted in such a manner that, for the purpose of modulating the overall braking torque effective at said vehicle wheels, the variation of the electric torque is arranged to stay within the "regenerative range" of operation of the electric motor, at least under predetermined operating conditions of the vehicle.

2. An electric powered vehicle as claimed in claim 1, which includes, as a means for enabling said adjustment of the hydraulic braking torque, an electronically controlled hydraulic booster which enables a variable booster ratio to be selected electronically.

3. An electric powered vehicle as claimed in

claim 2, wherein said electronically controlled booster is incorporated into a hydraulic master cylinder unit coupled to a foot operated brake pedal.

4. An electric powered vehicle as claimed in claim 1, 2 or 3 wherein, below a predetermined deceleration level demanded by the driver, the booster ratio is arranged to be held at a minimum value until maximum electric motor contribution to vehicle deceleration has been reached.

5. An electric powered vehicle as claimed in any of claims 1 to 4 wherein the hydraulic torque is varied in dependence upon the state of charge of the vehicle battery in that, if the battery is detected to be at full charge, braking within the regenerative range is restricted and the hydraulic component to brake torque is weighted.

6. An electric powered vehicle as claimed in any of claims 1 to 5, wherein the electric motor used for vehicle propulsion is also adapted to modulate the brake torque for ABS braking whereby if excessive wheel slip occurs, the electric motor torque is arranged to be reduced.

7. An electric powered vehicle as claimed in claim 6, wherein in order to allow ABS control even when the hydraulic brake torque alone exceeds wheel locking torque, the electric brake torque can be

removed completely and additional tractive torque can
then be applied to overcome the hydraulic brake force
generated by the brake.

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Relevant Technical Fields (i) UK Cl (Ed.M) F2F (FBB, FC) (ii) Int Cl (Ed.5) B60L 7/10, 7/12, 7/14, 7/16, 7/18, 7/24, 7/26 B60T 13/74	Search Examiner PETER SQUIRE
Databases (see below) (i) UK Patent Office collections of GB, EP, WO and US patent specifications. (ii) ONLINE DATABASES: WPI	Date of completion of Search 5 DECEMBER 1994
	Documents considered relevant following a search in respect of Claims :- 1-7

Categories of documents

X:	Document indicating lack of novelty or of inventive step.	**P:**	Document published on or after the declared priority date but before the filing date of the present application.
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A:	Document indicating technological background and/or state of the art.	**&:**	Member of the same patent family; corresponding document.

Category	Identity of document and relevant passages		Relevant to claim(s)
A	GB 1444865	(GENERAL SIGNAL) see eg page 2 lines 6-7 and 59-66 and page 3 lines 70-123	
A	US 5294191	(BREMBO) see eg Figures 2 and 4	

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