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(54) A METHOD OF AND A DEVICE FOR AUTOMATICALLY CONTROLLING BRAKING OF A VEHICLE

(71) We, MESSIER-HISPANO BUGATTI, a Body Corporate organised and existing under the laws of France, of 5, rue Louis Lejeune, 92124 Montrouge Cedex, France, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention relates to a method of and a device for automatically controlling braking of a vehicle and is particularly applicable to aircraft.

The invention preferably makes it possible to slow down and if desired stop the vehicle by means of brakes, for example wheel brakes, simplifying the work of the pilot during braking and, particularly in the case of aircraft, during landing, slowing down and if applicable stopping of the vehicle, in accordance with a law of deceleration previously chosen by the pilot.

Such a simplification of the pilot's work is particularly advantageous, in the case of an aircraft, when landing conditions are poor.

Further advantages which can be provided by the invention are that braking can be applied as soon as possible, therefore without loss of time, braking being more comfortable for passengers by virtue of the fact that peaks of deceleration which may be due to other slowing down means such as for example the thrust reversers, parachutes or other equivalent means, may be obviated.

The method and the device according to the invention make it possible also to apply more regular braking, which has the additional advantage of lessening the wear on the elements involved in braking such as the brakes and tyres for a vehicle having braked wheels, and of reducing the fatigue level of those elements of the vehicle which function during the source of braking.

Automatic braking means and methods have previously been proposed, particularly for aircraft, which make it possible to control the deceleration of the aircraft during braking to a preselected rate of deceleration. The deceleration of the aircraft is measured by means of an accelerometer mounted on board in such a way as to provide a signal which is a function of longitudinal deceleration of the aircraft. This measurement is compared with a desired value and a resultant difference signal is used to establish the level at which the braking elements come into operation, for example in order to fix the level of pressure in the wheel brakes so that the measured deceleration corresponds to the desired deceleration.

Such a device has the drawback of requiring the use of an accelerometer which is an expensive item, and which does not make it possible accurately to measure the horizontal acceleration of the vehicle in certain attitudes or configurations of the vehicle, taking into account the acceleration of gravity directly the axis of the accelerometer is not parallel with the ground.

According to a first aspect of the invention there is provided a method of automatically controlling braking of a vehicle, wherein a function of the true speed of the vehicle Va, which may be Va itself, is compared with a programmed speed Vp to obtain a difference signal which is used to control the force applied to braking means, wherein the programmed speed varies according to a predetermined law of deceleration such that braking of the vehicle is carried out according to the predetermined law of deceleration, and wherein, when the predetermined law of deceleration cannot be obtained, the programmed speed Vp is caused to be a reproduction of the true speed of the vehicle and braking is then controlled according to an anti-skid method.

Thus, the method according to the first aspect of the invention comprises making the speed of the vehicle subject to a speed programmed according to time, and making the programmed speed a reproduction of the time speed when braking cannot be effected in accordance with the programme, braking then being taken over by an anti-skid method, which may be a known type of anti-skid braking method.

Thus the programmed speed *Vp*, programmed on the basis of a law γ of specific deceleration, is defined, compared with a function of the real speed of the vehicle *Va*, which may itself be *Va*, and the difference signal obtained therefrom is used to control the force applied to braking means, so that braking of the vehicle occurs according to the specific law of deceleration.

The programmed speed law can be expressed as follows:—

$$Vp = Vo - \int_0^t \gamma(t, Va, D, \ldots)\, dt$$

in which *Vo* represents the initial programme speed and corresponds to the speed of the vehicle at the origin of braking, *t* corresponds to the time, *Va* to the speed of the vehicle as already explained and *d* to the distance available for stopping, the list of the parameters of which acceleration is a function not being limited to those previously defined but being capable of including others, for example those relative to the various braking means provided on the vehicle.

When the braking means include wheel brakes, the initial programme speed *Vo* will advantageously be derived from a measurement of the speed of the wheels adapted to be braked prior to application of the brakes, but *Vo* may likewise be derived from the speed of wheels which are not capable of being braked or from any other means of detecting the speed of the vehicle, notable Doppler radar, ground beacons, special speed calculating means, inertial station for example.

According to a second aspect of the invention there is provided an automatic braking device for a vehicle, to effect braking by a method according to the first aspect of the invention, comprising a programmer formed as an integrator and arranged to be charged, at the initiation of braking, by sensing means operative to generate a signal representing the speed of the vehicle, a regulator operative to deliver a difference signal to means to operate brakes of the vehicle, the regulator constantly receiving, in use, a programme speed signal emanating from the programmer and a vehicle speed signal emitted by said sensing means, and an anti-skid braking device operative to take over the control of braking when the predetermined law of deceleration cannot be obtained.

The brakes with which the vehicle is equipped may be constituted in conventional manner by wheel brakes of which a control pressure or rate of control flow are controlled or, more particularly, any sort of shoe of which the force of application is controlled, thrust reversers or air brakes of which the angle of deflection is controlled. Measurement of the true speed of the vehicle which constitutes a return half of the control loop will be obtained, in the same way as the initial programme speed, from the speed of wheels which are not capable of being braked, special means already quoted or even possibly the speed of the braked wheels.

The automatic braking order may be an order external of the automatic braking device which will follow or precede triggering of the device by the pilot. This external order will be processed by a suitable manual or automatic logic assembly. For example, for an aircraft, it might be processed on a basis of an output command of lift dischargers (air brakes or spoilers). In a particularly simple form of embodiment of the invention, the desired deceleration will be a constant and its value will be chosen preferably by the pilot from within a given range comprising for example three levels of deceleration; a low level at 0.15 g, a medium level at 0.2 g and a high level at 0.3 g. Once it has been preselected by the pilot, a fixed or variable rate of deceleration will be represented by an order, for example an electrical voltage in the event of the programmer and regulator taking electronic form, applied to the input of the integrator immediately the automatic braking order is given. The integrator will then apply an output order representing the desired speed programme.

The programme may be dispensed with or modified at the will of the pilot or automatically at any time. If it is dispensed with, the integrator will return to its initial condition in order to be ready for further use. In particular, it will reproduce the speed of the vehicle to have a fresh initial programme value available, required for a fresh use of the automatic braking device.

If during the course of braking the deceleration which it is desired to impose on the vehicle by implementing the automatic braking programme cannot be obtained by reason of insufficiency of braking originating either from the braking means or from low adhesion to the ground, the method and the device according to the invention will effect anti-skid braking and will not allow the programmed speed to fall below a true speed of the vehicle while anti-skid braking is taking place. In this case, the programmed speed will reproduce the real speed of the vehicle in such a way as to be able to guarantee that the vehicle will undergo the selected deceleration as soon as the braking capacity of the vehicle becomes adequate (i.e. as soon as anti-skid braking is no longer required), without giving rise to any sudden transitory regime and with no loss of time.

The order emanating from the integrating programmer is passed as a desired speed value to the input of the regulator which also receives a signal representing the speed of the vehicle and emanating from generator means chosen to carry out such measurement, for example a tachometric generator.

The programme speed signal *Vp* is compared with a function of the vehicle speed signal *Va*, which may be the signal *Va* itself, and the regulator issues a difference signal which is used to regulate the intensity of braking. In the frequently encountered case of braking resulting from hydraulic operation, this difference signal suitably amplified in *per se* known manner is passed to one or more electrohydraulic distributors having a proportional or stepped action in such a way as to adjust the level of the pressure or possibly the rate of flow to the braking members so that the true speed of the vehicle conforms to that required by the programme.

Hereinafter will be more particularly described the method and the apparatus according to the invention as applied to a vehicle the braking of which is achieved by hydraulic control, but their application to a vehicle which is braked by other means is to be regarded as included within the scope of the invention as defined in the claims.

In addition, let it be assumed that the various elements such as the integrator and the regulator are made by the use of electronic components of any suitable kind, either analogue or digital, without thereby limiting the invention to the said form of embodiment, for which an embodiment employing fluid or pneumatic components may be substituted.

In a first particular form of embodiment and of implementing the method and the apparatus according to the invention, the braking means are simultaneously applied with hydraulic fluid through an electrically operated valve, regulation of the level of pressure required being carried out by an electrohydraulic distributor, for example a servo-valve, which will adjust the pressure in the braking means to the level corresponding to the strength of the electric control current constituting the order which it receives.

The term electro-valve and servo-valve relates to an assembly establishing the interface between the electronic part and the hydraulic part of our example, an assembly comprising one single or a plurality of distinct items known *per se*.

The application to the braking means either of a normal braking pressure or a pressure modulated by the intervention of the automatic braking device will be determined by means of apparatus of known technology reflecting the art of hydraulic control systems, such as shuttle valves, for example.

In a second particular form of embodiment of the invention, two electrohydraulic servo-valves are used, one of which controls the pressure applied to a first series of braking means while the other controls the pressure applied to a second series of braking means of the vehicle, for example respectively the left and right-hand brakes of an aircraft. These two servo-valves may receive either the same order emanating from the automatic brake regulator or different orders in order to act differently on the braking means of the vehicle. This differential action may be used, still within the same example, in order to correct the path followed by an aircraft on a landing runway according to external parameters, for example taking into account the effect of a cross wind, alignment of the path of the aircraft on the axis of the runway or any other parameter which will make it possible to steer the aircraft along a particular path.

According to another particular form of embodiment, the invention applies to vehicles which are braked at the level of at least one wheel which is fitted with brakes and equipped with an anti-skid device.

Generally, these vehicles are already equipped with at least one electrohydraulic distributor which makes it possible to modulate the pressure in the brake or brakes as a function of an electrical command given by an anti-skid regulator.

When the electrohydraulic distributors of the anti-skid device are not progressive in action, the vehicle may still be fitted with the automatic braking device according to the invention subject to the addition of one or more electrohydraulic servo-operated valves. This will however constitute a heavy and expensive solution due to the additional equipment required. When the electrohydraulic distributors of the anti-skid device are progressive in action, they may be used directly to control the pressure of the brakes according to the order originating from the automatic brake regulator.

The anti-skid device will still remain in a condition of controlling the behaviour of the wheels braked by the automatic braking device and will cut in to bring down the pressure in the brake or brakes corresponding to the wheel or wheels capable of skidding.

The coexistence of the automatic braking order and of the anti-skid order may be brought about by any means which makes it possible for either function to occur normally not simultaneously, and with no sudden transition.

The invention is diagrammatically illustrated by way of example in the accompanying drawings, in which:—

Figure 1 shows a circuit for producing a programme in an automatic braking device according to the invention;

Figure 2 shows similarly a logic arrangement preventing the programme speed from being less than the true speed of the vehicle;

Figure 3 shows a loop for controlling the vehicle speed as a function of the programme speed;

Figure 4 shows means for controlling the speed of a vehicle with hydraulically operated brakes;

Figure 5 shows a device for selecting the method of hydraulic control of the brakes;

Figure 6 shows a device which permits of differential operation of the brakes;

Figure 7 shows the installation of the device according to the invention on a vehicle which is fitted with an anti-skid device;

Figures 8 and 9 respectively illustrate a two-coil servo-valve operating installation in a device according to Figure 7 and also the characteristics of such a servo-valve;

Figures 10 and 11 are similar to Figures 8 and 9, relating to a servo-valve which has only one coil;

Figures 12 and 13 show two alternative ways of discriminating speed signals supplying the regulator which is common to the anti-skid and automatic braking devices;

Figure 14 repeats the conventional curve linking the coefficient of adhesion with slip;

Figure 15 shows a particular embodiment intended to obtain an initial programme speed V_o;

Figure 16 shows an assembly intended for a vehicle fitted with at least one left wheel and at least one right wheel, the wheels being separately controlled;

Figure 17 shows the pattern of speeds and pressure during the transitory condition of automatically braking a wheel; and

Figure 18 shows correspondingly the pattern of speeds and pressure during passage of an automatically braked wheel through a zone of low adhesion which causes the anti-skid device to operate.

Referring to the drawings and firstly to Figure 1, a programme of speed as a function of time is provided by an electronic integrator 1 which is known *per se* and which is charged at the initiation of braking through a switch 2 with an electrical voltage V_o representing the speed of the vehicle at the origin of braking, and is supplied with a signal γ, corresponding to the deceleration chosen by the pilot from among three values, for example constant values (high H, medium M and low B) by operating a selector 3. The automatic braking order is triggered by a phenomenon external of the device simultaneously operating the switch 2 and a switch 4, the switch 4 being mounted in series with the selector 3. The integrator then furnishes the signal V_p representing the programme speed according to the equation $V_p=V_o-\gamma t$.

According to Figure 2, so that the programme may be modified or discontinued at any time, there is provision for the switch 4 to be operated automatically or by the pilot. If the switch 4 is open, the integrator 1 will reproduce a vehicle speed signal V_a to have available a suitable initial speed value needed for fresh use of the automatic braking system. A diode 5 will prevent V_p falling below V_a during the course of braking if the deceleration γ required by the programme cannot be obtained. In this case, V_p will be a reproduction of V_a in order to avoid sudden transitions when the requested deceleration may again be obtained by intervention of the automatic braking system.

Referring to Figure 3, the signal V_p is passed to the input of a regulator 6 which likewise receives a signal which is a function of the vehicle speed V_a which may be the vehicle speed signal V_a itself, generated by a unit 7 detecting the speed of the vehicle.

The regulator 6 produces a difference signal ε transmitted to a power stage 8 furnishing a control signal to braking means 9, operation of which brings about braking of the vehicle 10 in accordance with the deceleration of the vehicle chosen by the pilot.

When the braking means 9 are hydraulically operated, a first particular embodiment of the automatic braking device comprises, Figure 4, simultaneously supplying all the braking means 9 with hydraulic fluid originating at *A* from a hydraulic source (not shown) and having means of return to tank at *R*, operated by means of a distributing assembly 11, comprising an electrically operated valve 12 which plays the part of a cock operated by a switch 13, closure of which is brought about by the automatic braking order, and also an electrohydraulic distributor 14, of the servo-valve kind, receiving the difference signal ε transmitted from the regulator 6 to modulate the pressure level required at the level of the braking means 9.

As it is necessary that the braking means 9 be capable of being operated in the normal way, for example manually, so that they can function even when the automatic brake means is not called upon to act, preferably a shuttle valve 15, Figure 5, is used, which may be of any suitable known kind, transmitting to the braking means 9 the operating pressure which it receives, that is to say either the operating pressure originating from a conventional hydraulic brake control unit 16, when braking is applied manually, or the modulated operating pressure emanating from the distributor assembly 11 and in particular from the electrohydraulic distributor 14 when the automatic braking device is in operation.

Figure 6 relates to another particular embodiment which employs two servo-valves 14*a* and 14*b* which respectively control the pressure applied to the right 9*a* and left 9*b* braking means with which the vehicle is fitted. The two servo-valves 14*a* and 14*b* supplied by one or perhaps even two electrovalves (not shown) will be controlled in parallel by a distributor 17 receiving the order from the regulator 6 and sensitive to one or more external parameters *X*, for example the effect of the cross wind. This device therefore permits differential braking control.

Figure 7 illustrates a particularly interesting embodiment of automatic brake device for a vehicle fitted with wheels capable of being braked and equipped with an anti-skid device, this latter comprising an electrohydraulic servo-valve 14 connected to a supply *A* and a tank *R* which serves as a source of hydraulic fluid, and modulating the pressure level which it delivers to the wheel brakes 9 according to a signal *S* processed in an anti-skid regulator 18 sensitive to the behaviour of the braked wheels of the vehicle 10. Parallel with the signal *S*, the servo-valve 14 receives the signal ε processed in the automatic brake regulator 6 from the programme speed *Vp* and the chosen function of the vehicle speed obtained by the unit 7. This embodiment is interesting in that it makes it possible to use mostly elements which are already present in the anti-skid device in order to bring about automatic braking. In this association, the anti-skid regulator 18 will operate to bring down the pressure in the brakes 9 if any tendency to skid is detected, the automatic brake device being operative or inoperative.

Referring to Figure 8, when the electrohydraulic servo-valve or valves 14 is or are equipped with two electrical control coils, one of these coils 19 is used to receive the signal ε of strength $i\varepsilon$, emanating from the automatic brake regulator 6 at the output of which there is in known manner a voltage-strength transformation and the other coil 20 is used to receive the signal *S* of strength *iS* originating from the anti-skid regulator 18 at the outlet of which there is likewise a voltage-strength transformation. If each servo-valve has more than two coils, several of them may receive the signal ε and others the signal *S*. As in general the servo-valves used in anti-skid devices are controlled by pressure and have an inverse characteristic, these servo-valves respond to brake releasing orders. That is to say that, on the one hand, in the absence of an operating current *ic*, they allow the full supply pressure to pass on to be used, braking then being at its maximum and, furthermore, the pressure delivered is minimal for a maximum electrical order *icm*, the pressure at use being regulated according to a diminishing function of the electrical input order to each coil. Every electrical control order is therefore a brake releasing order. Coming back to the device of Figure 7, it can be seen that the orders sent by each regulator (6 and 18) will have their effects added together algebraically to operate the servo-valve 14, the total brake releasing order being the sum of the brake releasing orders issued in one case by the anti-skid regulator 18 and in the other by the automatic brake regulator 6, each of these orders by itself being capable of bringing about total brake release, whatever the other may be. The pressure intensity characteristic of a servo-valve receiving such an order is illustrated by Figure 9.

When the electrohydraulic servo-valves 14 are not equipped with more than just a single control coil 21 (see Figure 10), or when it is desired to operate a servo-valve by means of only one of its coils, it is appropriate to allow only the maximum brake release order to pass, since it is this which will ensure proper operation of the assembly.

This issue will be ε, originating from the operative automatic braking regulator 6, so long as the required deceleration can be obtained. The order *S* from the anti-skid regulator 18 will then be nil and will not operate. However, in the event of the deceleration required not being obtainable, the braking effect operated by the automatic brake regulator 6 is likely to produce skidding and locking of the wheels. In order to limit such skidding, it is then necessary for the order S from the anti-skid regulator 18 to be the one which operates the servo-valve 14. The brake releasing order ε from the automatic brake regulator 6 will then become null and void since the pressure at the brakes will be less than that which would have been necessary to bring about the deceleration required by the programme. The solution comprises allowing only the greatest brake releasing order to pass and this, without any risk of instability, permits of very progressive changes in the pressure at the brakes in the case of one or other of the automatic brake 6 and anti-skid 18 regulators operating. In this case, the servo-valve having the pressure-intensity characteristic shown in Figure 11, still controlled by the regulator which issues the greatest brake release order, is unaware of the order from the other regulator, which order is generally contradictory to the first. The movement from one regulator to the other can take place only after there has been a state of equality between the two brake releasing orders and then when one of them has become greater than the other. The embodiment allowing the choice of the greatest brake releasing order will preferably employ a diode discriminator circuit as illustrated in Figure 10. The orders ε and S will arrive at a discriminating point 22 after having respectively traversed diodes 23 and 24. The discriminator point 22 will therefore be at the potential of the greater brake releasing order which will suffer a voltage-current conversion in a unit 25 which delivers an operating current ic to the coil 21 of the servo-valve 14. Discrimination of the greatest brake releasing order might likewise be effected by any other electronic means providing the same result, for example by means of one or more separator amplifiers.

A particularly interesting from of embodiment of the invention will now be described in relation to vehicles fitted with a speed control anti-skid device. Such an anti-skid device regulates the braked wheels by maintaining their speed at a desired level equal to a function of the reference speed which is that of the vehicle. Wheel slip g which is expressed by the formula

$$g=\frac{Va-v}{Va},$$

in which Va represents the vehicle speed and v is the true speed of the wheel, is thus maintained at a definite level, generally of the order of 15%, which corresponds to the best wheel-ground coefficient of adhesion. Of course, this coefficient is achieved only if the torque available at the brakes is sufficient (see Figure 14). In the event of the vehicle, braking of which it is desired to automate, is equipped with such an anti-skid device, it will be sufficient to substitute the programme speed for the function of the vehicle speed at the input of the anti-skid regulator for braking to be carried out according to the programme speed which will then become a desired speed so that the speed of the vehicle and thus its deceleration will follow a definite law. This is represented in Figure 12 in which the anti-skid regulator 18 receives through a casing 26 of a discriminating logic system of any known kind either the programme speed signal Vp or a desired speed command signal Vc processed from the vehicle speed signal Va entering a multiplier unit 27 in which according to the example illustrated Va is multiplied by (1–g).

Moreover, and in conventional manner, the regulator likewise receives the true speed signal from the braked wheel v. Therefore, the regulator 18 plays in succession the role of anti-skid regulator and automatic braking regulator by delivering either ε or S. A preferred manner (see Figure 13) of choosing either the signal Vp or the signal Vc by the regulator 16 resides in carrying out, at the input to the regulator 18, discrimination between one or other of the reference speeds, by using a system of diodes 28, 29 as previously described. The reference speed considered by the regulator will be represented by the greater of the signals Vp and Vc. Substitution of the desired speed Vc for the programme speed Vp will thus be automatic and progressive directly the programme speed cannot be followed. The anti-skid device will therefore remain constantly in a state of supervision to afford safety for the automatic braking system. This embodiment, offering considerable simplicity, also provides considerable security because at any moment during the course of braking the speed of each wheel braked will remain monitored by the anti-skid device, the pressure being controlled via the regulator of this device. The speed of the wheel being subject to that of the programme, it will assume a value equal to the programme speed and there cannot be any onset of lock in the event of any one of the braked wheels encountering a part of the road surface or runway which offers low adhesion.

Going to the extreme, if the ground adhesion is so low that the law of deceleration desired is not feasible, the speed of the vehicle will tend to exceed the programme speed and control of wheel slip will be implemented in respect of the true speed of the vehicle, as in the case of non-automatic braking. Thus, further development of the programme will be prevented and *Vp* will remain a reproduction of *Va* so that possibly if the adhesion conditions improve, it will be possible for braking to return to the chosen law of deceleration. Subjugation of the braked wheel speed to one and the same speed programme will help to keep the vehicle on a striaght line. Indeed, the left and right wheels will turn at the same speed and will have a natural tendency to maintain the vehicle on a straight line course. Furthermore, this device makes it possible in principle to counter any risk of sudden swerving as a result of stress on the rudder or steering control of the vehicle.

An example of application of the invention to an aircraft fitted with an anti-skid device functioning by speed control will now be described, though it should be noted that subjugation in speed is similar to subjugation to slip, since slip is mathematically linked to the speeds of the aeroplane and of the braked wheel in question.

For easier understanding, it should be supposed that the anti-skid regulator allows maximum wheel slip *gc* of 15% of the speed of the aircraft *Va*, that is to say it controls the braked wheels so that they turn at a desired speed Vc=Va(1−gc)=0.85 Va.

Let it likewise be assumed that the anti-skid regulator is provided with adequate logic means of known kind to ensure prevention of braking until such time, during landing, as the aircraft has at least set its main wheels down on the ground, and these are running up to speed, and also is fitted with a device for voltage-current conversion.

In a device according to Figure 16 which makes it possible to control the braking of at least one main left-hand wheel 30, and at least one main right-hand wheel 31 of an aircraft, automatic braking is triggered by the simultaneous presence of two orders. The first originates from the pilot having triggered the automatic braking procedure at the level of develeration chosen by means of the selector 3. Let it be assumed that such triggering has been effected prior to landing.

The second order emanates from an external phenomenon and is the result of a combination of suitable logic systems. For example, it may be the output from lift dischargers if braking must take place as soon as the aircraft has touched down, or it may be an order indicating that the nose wheel is on the ground of braking is to be implemented only when the aircraft has all its wheels down.

In the example, let it be assumed that the automatic braking order is the same as the order issued by the lift dischargers, and that it brings about closure of the switches 4 and 13 shown respectively in Figures 1 and 4. It should also be assumed that the aircraft is landing on a dry runway, that is to say the coefficient of adhesion of the tyres to the ground is approximately 0.5 for 15% slip, according to the curve giving the coefficient of adhesion μ as a function of the slip *g* for a dry runway and for a wet runway, respectively at 32 and 33 in Figure 14. Furthermore, it will be assumed that the pilot has chosen a constant rate of deceleration of 2 m/s/s.

When the aircraft prepares to land, the automatic braking device is set up but not triggered. When the main wheels touch the ground, they run up to speed and the electric voltage emanating from measurement of the speed of wheels by means of tachometric generators for example will charge the programming integrator 1 preferably to the value of the fastest wheel, therefore the highest voltage. This is achieved by means of the device according to Figure 15 in which the voltages v_1, v_2, v_3, v_n representing the speeds of wheels Nos. 1, 2, 3, *n* will be furnished through diodes 34, 35, 36, 37 at the output of the integrator 1 charged to the highest voltage *Vn* if the wheel of order *n* is the fastest. This voltage *Vn* constitutes the initial programme value *Vo* at the origin of braking. The running up to speed of the main wheels having dispensed with prevention of the braking action previously given by the anti-skid device, as has already been stated, when the automatic braking order is given, means on the one hand, by closure of the switch 13, that the electro-valve 12 supplying servo-valves 14*a* and 14*b* will be operated, so ensuring pressurising of braking circuits of the wheels 30 and 31 from a hydraulic supply *A* and, moreover, by closure of the switch 4, it will be ensured that integrator 1 furnishes a signal Vp=Vo−γt. The programme speed *Vp* transmitted to the regulators 18*a* and 18*b* being on the decrease, it becomes less than the speed of the wheels 30 and/or 31 and will therefore cause this or these to brake so that there is equality for each wheel between the true speed *v* and the programme speed. The progressive nature of braking is made possible because the true slip of each wheel will be established at approximately 5% for the deceleration chosen, corresponding on the curve 32 in Figure 14 to a coefficient of adhesion of 0.2, so that the braking torque may be transmitted, the regulators 18*a* and 18*b* then work by referring to the programme speed *Vp*.

The desired speed Vc=0.85 Va arrives at the input of each regulator 18*a* and 18*b* but being less than the programme speed which is established at approx. Vp=0.9 Va is not used but remains available for the regulators 18*a* and 18*b* which provide a means of supervision. This is represented in Figure 17. Before automatic braking has been triggered (zone I), the integrator 1 shows a wheel speed *v* from which likewise the speed of the vehicle can be deduced. Therefore Va=Vp=v, and the desired speed *Vc* of the anti-skid regulators 18*a* and 18*b* is equal to 0.85 Va, while the pressure at the brakes *P* is nil. In the zone II which follows triggering of the sequence of automatic braking and corresponds to the transitory stage of automatic braking, the signal *Vp* decreases according to the law $Vp=Vo-\gamma t$, and the pressure *p* applied to the brakes increases. Corelatively, the wheel speed *v* decreases and becomes progressively less than the speed of the aircraft *Va*, approaching the programme speed *Vp*.

The speed of the aircraft *Va* decreases progressively remaining greater than *v* and *Vp* and the desired speed remains parallel with it. When *Vc* has aligned on *Vp*, the automatic braking system is established (zone III) and *Va*, *Vp* or *v* and *Vc* evolve in parallel with a slope corresponding to the desired rate of deceleration of the aircraft. The pressure *P* is then at a given and almost stabilised level.

In the event of the aircraft having its tail down, it is essential that braking should not be too powerful. The deceleration imposed by the programme is possibly limited to a maximum value or may be equal to a fraction or a function of the final deceleration required so long as the aircraft has not set down on all its wheels.

As soon as the front landing wheel sets down, a logic order is emitted to the automatic brake device so that deceleration assumes its final value.

In the example chosen, the programme develops with a deceleration corresponding to 0.2 g and the main braked wheels are maintained at the same speed as in the programme. According to Figure 15, it will be seen that the true slip of the wheels corresponding to a deceleration of 0.2 g is of the order of 5%, the speed of the aircraft is therefore of the order of 105% of the speed of the braked wheels, therefore approximately 105% of the programme speed. The true deceleration obtained by carrying out the programme is therefore not exactly 0.2 g but is corrected to take into account the slip of the wheels, to a value of the order of

$$\frac{1}{1.05} g \times 0.2 = 0.19 \text{ g}.$$

Braking is therefore continued under these conditions until complete stoppage occurs or until such time as the pilot decides to cut out the automatic braking system. He can do this by operating the selector 3 to move it to a stop position, or by some non-specific manoeuvre which will comprise for example of applying a determined amount of effort to one or both brake pedals.

Let it now be assumed that during the course of automatic braking the deceleration required cannot be carried out on a part of the runway of not inconsiderable length where the coefficient of adhesion between the tyres and the ground does not exceed 0.1 (see Figure 18).

Zone III of Figure 18, corresponds in every respect to zone III of Figure 17: *Va*, *Vp* or *v* and *Vc* develop in a parallel relationship. When the wheels enter the zone of low adhesion IV, the braking torque proves to be too high and their speed *v* decreases abruptly and tends to become zero. The regulators 18*a* and 18*b* bring about a drop in pressure *P* at the brakes of the wheels which are running at a speed lower than the programme speed, and these wheels will be restored to speed so that they can be braked again, but at a level of pressure *P*1 less than P when their speed *v* has caught up with the programme speed *Vp*. But as moreover the aircraft cannot follow the deceleration required by the programme since the maximum deceleration possible is only 0.1 g in zone IV, the speed of the aircraft *Va* diminishes far less rapidly than the speed of the programme *Vp* (zone IVa). Therefore, the wheel slip in relation to the aircraft increases. But it is limited to 15%, a level at which the desired speed *Vc* of the anti-skid device developing parallel with *Va*, of which *Vc* is less than 85% *Va* has a tendency to become greater than the programme speed *Vp* (point 38 in Figure 18) and it is *Vc* which will serve as a reference for the regulators 18*a* and 18*b*. Throughout the entire period when the deceleration required cannot be obtained, the speed of the wheel *v* remains subject to that of the aircraft *Va* with 15% slip, as if there were no automatic braking (zone IVb in which braking takes place under the control of the anti-skid device).

As soon as the aircraft again encounters an area with a high coefficient of adhesion (zone V), automatic braking according to programmed speed *Vp* can resume. To avoid any abnormal increase in the actual deceleration of the aircraft which would result if the programme speed were then to become too low, it will be compulsory throughout the entire period of the disturbance for the programme speed *Vp* not to fall below the desired speed *Vc* of the anti-skid regulator. The integrator will reproduce this desired speed *Vc* (zone *IVb* and *Va*) for example simply by reproducing the greatest of the speeds of the braked wheels *Vn*. As soon as the aircraft arrives in zone V which has good adhesion, the wheels will restart, the pressure of the brakes will increase according to *P*2 and therefore also the deceleration of the aircraft will resume. As soon as this deceleration becomes equal to that which has been chosen (commencement of zone Vb), the programme speed *Vp* will be substituted for the desired value *Vc* as a reference speed for the regulator or regulators 18*a* and/or 18*b*, and automatic braking will again take place following the programme, in zone *Vc*, after a transitory zone *Vb* in which the speed of the braked wheel is aligned on *Vp*, *Va* and *Vc* decreasing in parallel.

The pressure at the brakes is restored to level *P* of zone III.

In a manner which is quite similar to that which has just been described, it will be possible to provide an automatic braking device on an aircraft which has electrically operated brake control means. In this case, the electrically operated brake control means acts at the level of the servo-valve which is then used as a pressure distributor, that is to say it delivers a pressure which is for example proportional to the operating angle of the brake pedal. This electrical operation is delivered generally to a servo-valve coil other than that controlled by the anti-skid device but it would likewise be possible to use only a single coil and implement discrimination of the greatest brake release order, as was previously stated, by means of diodes for example. It is evident that no braking should take place when the brake pedal is not depressed by the pilot. Since it is not wished to supply hydraulic power to the servo-valves outside the period of braking, an electro-valve will be mounted upstream thereof in the circuit and the electro-valve will be closed when the brake pedals are not being operated.

On the other hand, the electro-valve is opened and therefore the servo-valves receive a hydraulic supply as soon as one of the pedals is depressed beyond a low threshold. The current which operates the servo-valves in this configuration must therefore be a total brake release order, and this diminishes as the pilot depresses the pedal. At the end of its travel, the electrical order is therefore minimal to correspond to maximum brake pedal pressure.

The installation of an automatic braking device such as described requires no modification of the electrical control system.

If the hydraulic circuit already comprises an electrically operated valve to feed hydraulic power to the servo-valves, the automatic braking device can use it and in this case no hydraulic equipment has to be added.

If it is desired that the electrical braking apparatus under no circumstances interfere with the automatic braking device, it will be sufficient to render the latter inoperative as soon as one of the pilot's brake pedals is depressed so that it allows the order to energise the electro-valve to pass. Braking then becomes completely subject to the pilot's will, subject to intervention of the anti-skid device.

On the other hand, if it is desired that the pilot be able slightly to influence automatic braking in order for example to create differential braking, it must be possible for both orders to coexist and therefore to add themselves together algebraically at the level of the two servo-valve coils.

To ensure the progressive nature of any correction, it is necessary when electrical braking is triggered to create an operational offset equal to the operating current supplied by the electrical control system at the commencement of pedal travel.

Ths offset may be achieved by any known electronic means at the level of the servo-valve operating stage.

Finally, the automatic braking device according to the invention may be fitted on any aircraft which has torque operated brakes.

Indeed, torque operating braking is virtually electrically operated braking when regarded from the view point of the servo-valve. The only difference inside the control system is that the order corresponding to depression of the brake pedal is similar to a desired torque, it is then compared with an order corresponding to a measurement of torque so that the electrical order transmitted to the servo-valve makes it possible to obtain the required torque at brake level.

The automatic braking device will therefore be combined with a torque operating system exactly as with an electrically operated braking system since at the end of the chain the servo-valve still receives equivalent orders.

There, too, it will therefore be possible for the automatic braking device to be fitted directly with no link to the torque control system in the event of this latter not making it possible to provide a slight correction at the pilot's option.

In the event of such a correction being desired, triggering of the torque operating means must bring about a compensation of current at servo-valve level to ensure the progressive nature of this correction.

It is evident that servo-valves having characteristics other than those described in the examples might well be used without departing from the scope of the invention, since it would be sufficient to adapt the operating means so that the servo-valves function in the same way.

Finally, the functioning of a certain number of particular automatic braking devices has been described. It goes without saying that one might possibly instal any combination of the particular cases on a vehicle without departing from the scope of the invention as defined by the appended claims.

WHAT WE CLAIM IS:—

1. A method of automatically controlling braking of a vehicle, wherein a function of the true speed of the vehicle *Va*, which may be *Va* itself, is compared with a programmed speed *Vp* to obtain a difference signal which is used to control the force applied to braking means, wherein the programmed speed varies according to a predetermined law of deceleration such that braking of the vehicle is carried out according to the predetermined law of deceleration, and wherein, when the predetermined law of deceleration cannot be obtained, the programmed speed *Vp* is caused to be a reproduction of the true speed of the vehicle and braking is then controlled according to an anti-skid method.

2. An automatic braking device for a vehicle, to effect braking by a method according to Claim 1, comprising a programmer formed as an integrator and arranged to be charged, at the initiation of braking, by sensing means operative to generate a signal representing the speed of the vehicle, a regulator operative to deliver a difference signal to means to operate brakes of the vehicle, the regulator constantly receiving, in use, a programme speed signal emanating from the programmer and a vehicle speed signal emitted by said sensing means, and an anti-skid braking device operative to take over the control of braking when the predetermined law of deceleration cannot be obtained.

3. An automatic braking device according to Claim 2, for a vehicle equipped with hydraulically operated brakes, including a hydraulic distribution assembly comprising an electrically operated valve operative to feed all the brakes via a servo-valve arranged to receive the difference signal emitted by the brake regulator to modulate the level of hydraulic pressure applied to the brakes.

4. An automatic braking device according to Claim 2 or Claim 3, including two servo-valves of which one is operative to modulate the level of pressure applied to a first braking means assembly while the other is operative to modulate the level of pressure applied to a second braking means assembly, the servo-valves being connected to receive respective operating orders from a distributor arranged to receive the difference signal emitted by the brake regulator and orders which represent the action of external phenomena affecting the vehicle.

5. An automatic braking device according to any one of Claims 2 to 4, for a vehicle of which at least one wheel is capable of being braked by hydraulically operated brakes, wherein the anti-skid device comprises a regulator operative to deliver an anti-skid signal to at least one electrohydraulic servo-valve arranged to modulate the pressure delivered to the brakes, capable of likewise receiving the difference signal from the brake regulator.

6. An automatic braking device according to Claim 5, in which each servo-valve is fitted with at least two operating coils, of which at least one is connected to receive the difference signal from the automatic brake regulator and of which at least one other is connected to receive the signal emanating from the anti-skid regulator so that the servo-valve is operated by the algebraic sum of the two signals.

7. An automatic braking device according to Claim 5, in which each servo-valve is arranged to be operated by a single coil receiving the greater of the two brake release signals formed by the difference signal from the automatic brake regulator and the signal emitted by the anti-skid regulator, the discrimination being effected by a set of diodes.

8. An automatic braking device according to any one of Claims 5 to 7, in which the anti-skid device is of the speed regulating kind regulating the speed of the braked wheels to a desired speed processed from the speed of the vehicle and of which the regulator is arranged to receive either a signal representing te desired speed or the signal representing the programmed speed in order to deliver to at least one servo-valve either the difference signal which implements automatic braking or an anti-skid signal when the deceleration required by operation of the programmed speed cannot be achieved.

9. An automatic braking device

according to Claim 8, in which the regulator input signal is discriminated by a set of diodes.

10. A method of automatically controlling braking of a vehicle as claimed in Claim 1 and subsequently as hereinbefore described.

11. An automatic braking device according to Claim 2, substantially as hereinbefore described with reference to the accompanying drawings.

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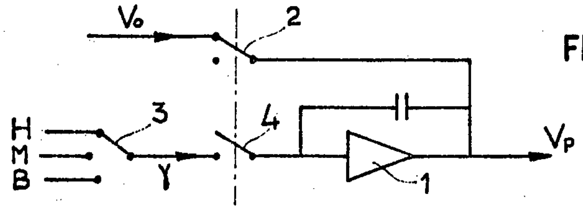


FIG. 1

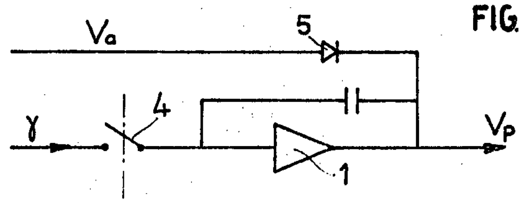


FIG. 2

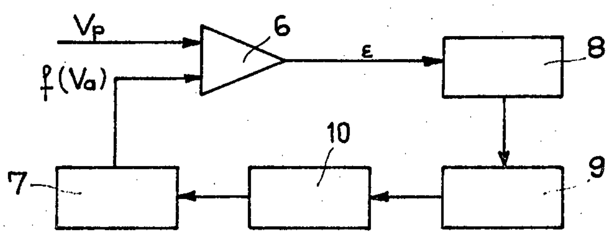


FIG. 3

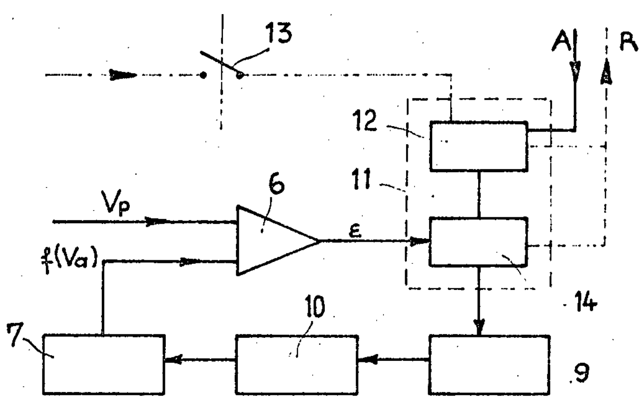


FIG. 4

FIG. 5

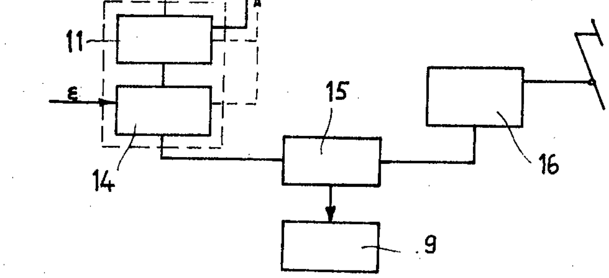


FIG. 6

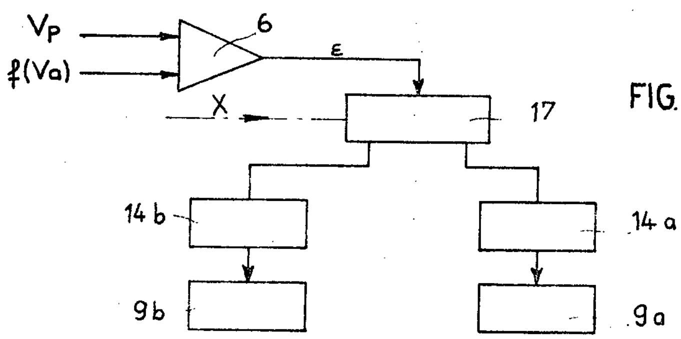


FIG. 7

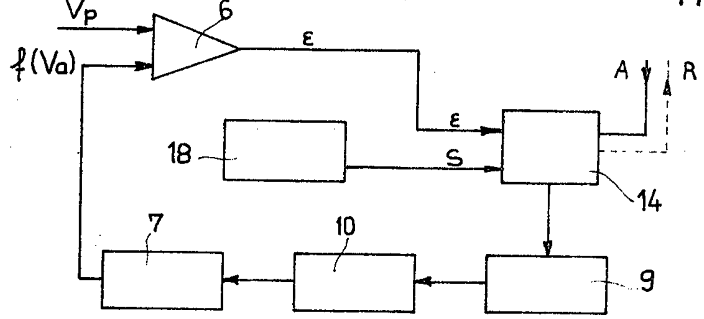
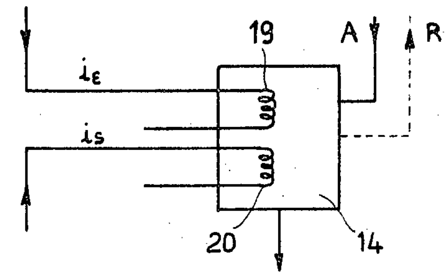


FIG. 8



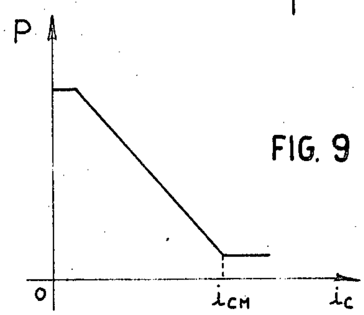
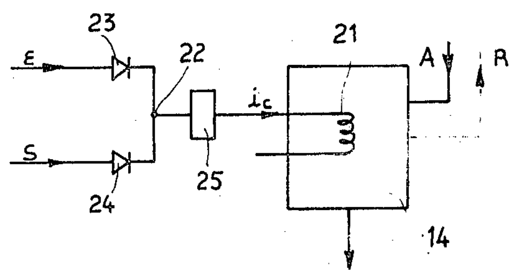


FIG. 9

FIG. 10



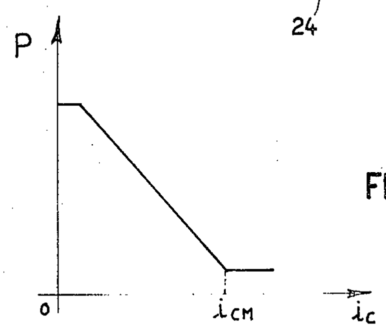


FIG. 11

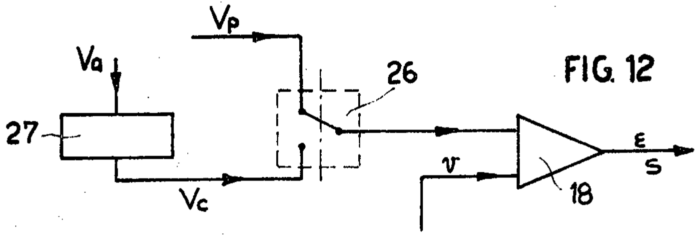
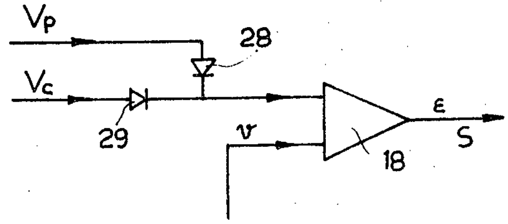


FIG. 12

FIG. 13



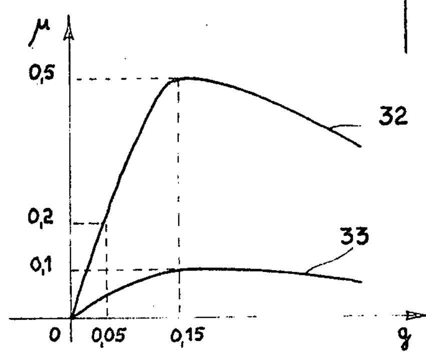


FIG. 14

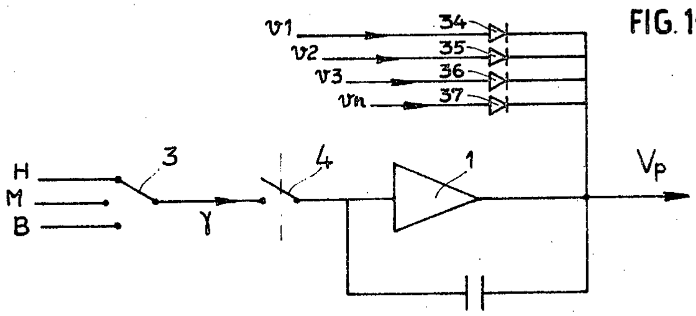
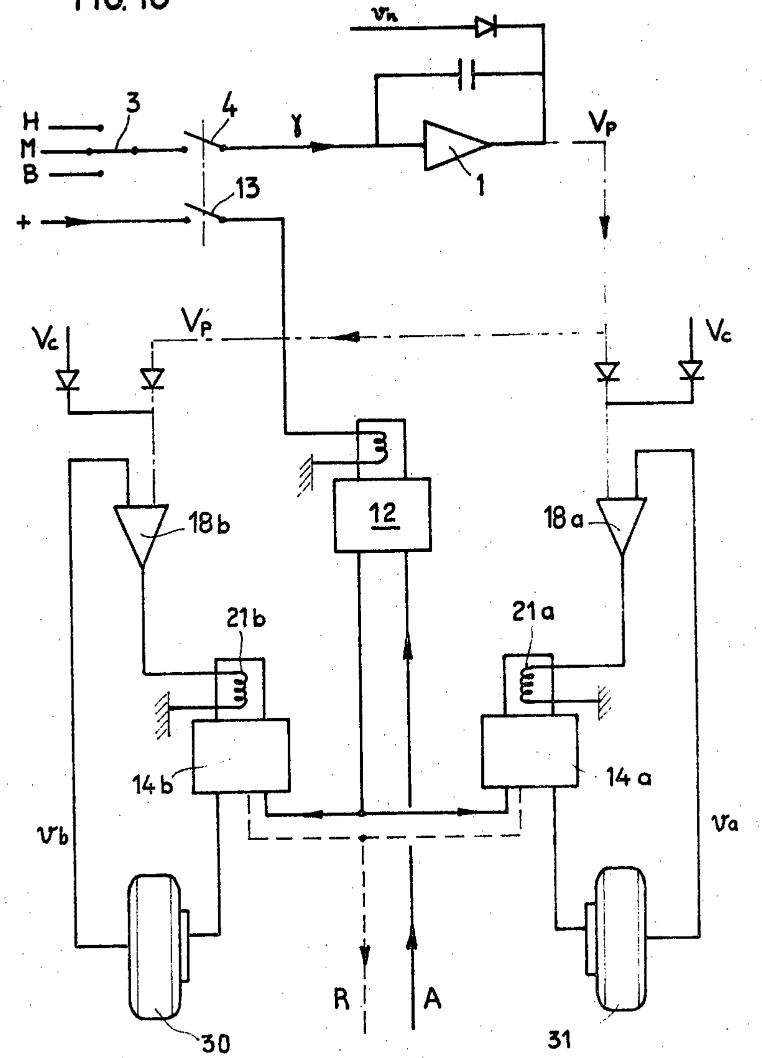


FIG. 15

FIG. 16



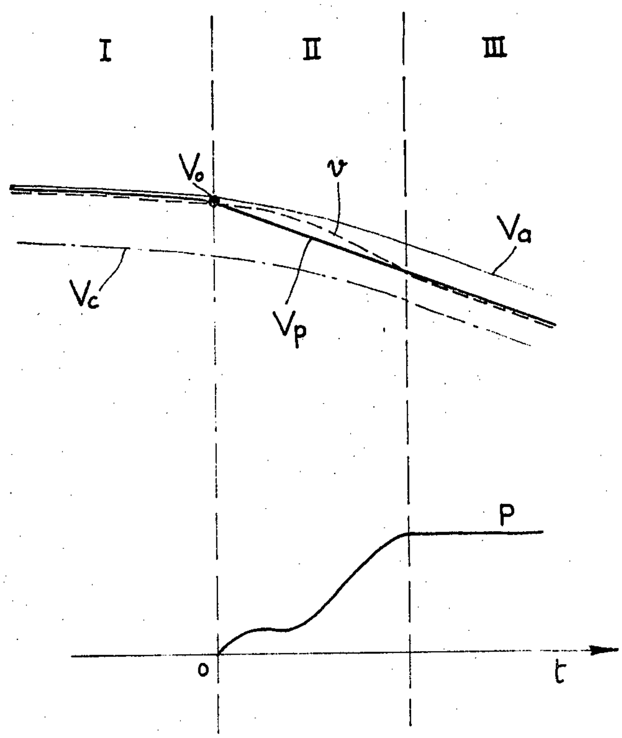


FIG. 17

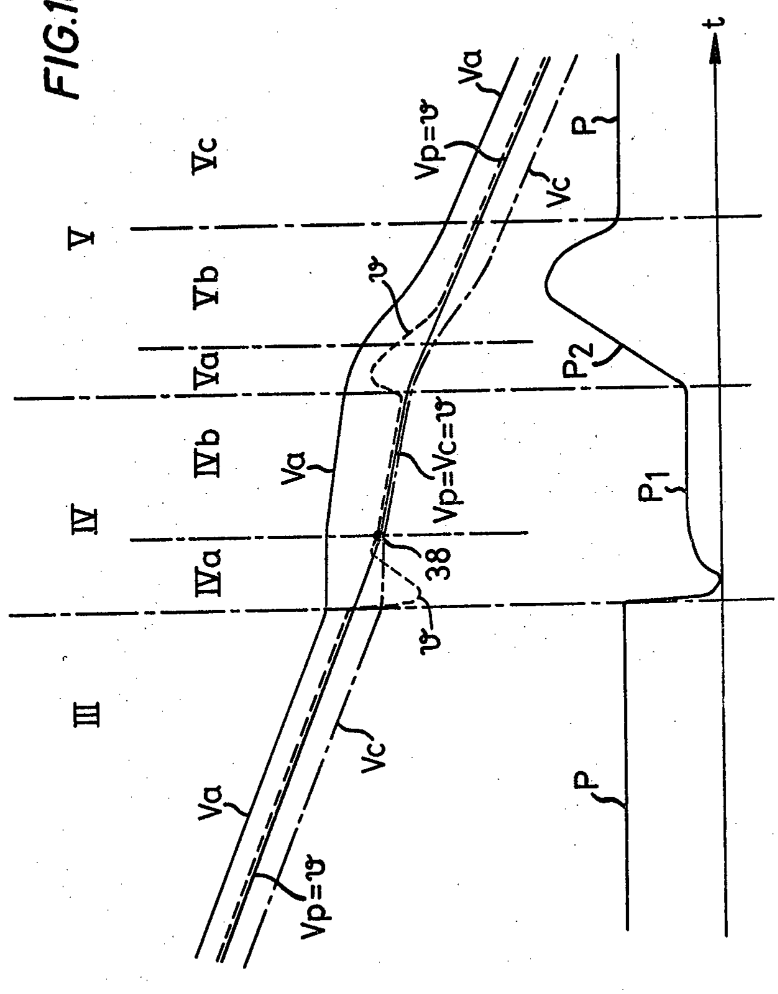


FIG.18