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(54) Railroad car body rotation control system

Steuersystem für die Neigung eines Eisenbahnwagenkastens

Système de contrôle d'inclinaison d'une caisse d'un véhicule ferroviaire

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Description

[0001] The present invention relates to a system for controlling rotation of a railroad car body.

[0002] In particular, the present invention relates to a control system for rotating the body about a longitudinal axis of the car to reduce the acceleration to which the passengers are subjected.

[0003] Variable-trim railroad cars are known which, when cornering, permit the body to rotate about a longitudinal axis of the car to compensate by gravitational acceleration the centrifugal transverse acceleration to which the passengers are subjected.

[0004] When cornering, the passengers of a variable-trim railroad car are therefore subjected to a lateral force equal to the difference between the transverse centrifugal force and the transverse weight force.

[0005] Known control systems comprise actuating devices (e.g. hydraulic) for regulating the tilt angle of the body on the basis of a drive signal.

[0006] More specifically, control systems are known which comprise regulating circuits for generating the drive signal according to predetermined laws and on the basis of a number of input parameters measured on the car.

[0007] Known regulating circuits comprise electronic circuits for generating a reference signal representing a reference body tilt angle pattern on the basis of a number of input parameters.

[0008] The reference signal is compared with a signal indicating the actual tilt angle of the body, and the resulting error signal is used in closed-loop manner to calculate the drive signal.

[0009] During the transient states at the start and end of the curve, known control systems fail to provide for accurate convergence of the reference and actual tilt angle signals, so that the actual tilt angle of the car often differs considerably from the reference angle, thus resulting in a lateral force sufficient to impair the comfort of the passengers.

[0010] It is an object of the present invention to provide a control system designed to overcome the drawbacks typically associated with known systems.

[0011] According to the present invention, there is provided a railroad car body rotation control system, as claimed in Claim 1.

[0012] The present invention will be described with reference to the accompanying drawings, in which:

Figure 1 shows a schematic cross section of a railroad car featuring the control system according to the present invention;

Figure 2 shows a schematic diagram of an electronic circuit implementing the control system according to the present invention;

Figures 3 and 4 show graphs of a number of quantities of the system according to the present invention;

Figure 5 shows a schematic diagram of an electronic circuit implementing a known control system.

[0013] Number 1 in Figure 1 indicates a control system applied to a variable-trim railroad car 3 substantially comprising two or more trucks 5, each connected elastically by a suspension 7 to axles 8 fitted with wheels 9 running along rails 10, and a body 11 tiltable by means of a hydraulic device 12 about a longitudinal axis (G) of car 3.

[0014] Device 12 substantially comprises a right and left hydraulic actuator 13r, 13l interposed between body 11 and truck 5, and a servovalve 15 for supplying actuators 13r, 13l.

[0015] When cornering, as shown schematically in Figure 1, the passengers (not shown) are subjected to non-compensated transverse acceleration A_{nc} roughly according to the equation:

$$A_{nc} = V^2/R - g\phi \quad [1]$$

where V is the traveling speed of car 3, R the curve radius, g the gravitational acceleration, and ϕ the angle between the supporting surface P of rail 10 and horizontal plane H.

[0016] Non-compensated acceleration A_{nc} may be reduced by rotating body 11 by angle ϑ about barycentric axis G, as shown in Figure 1, so that A_{nc} equals:

$$A_{nc} = V^2/R - g(\phi + \vartheta) \quad [2]$$

which is obviously less than value [1].

[0017] System 1 comprises an electronic control unit 14 supplied with a number of parameters measured on car 3, and which generates a drive signal for servovalve 15 (shown schematically). Servovalve 15 presents an inlet 15a supplied with pressurized fluid 16, and at the outlet supplies hydraulic actuators 13r, 13l to regulate the tilt angle ϑ of body 11.

[0018] More specifically, servovalve 15 presents a first outlet 15r communicating with actuator 13r via a conduit 17r; a second outlet 15l communicating with actuator 13l via a conduit 17l; and a recirculating outlet 18u.

[0019] Servovalve 15 comprises a hollow outer casing (not shown) housing a central slide valve (not shown) movable axially in a straight direction X by a pressure difference as a function of a drive signal supplied to an electric driver 21.

[0020] More specifically, servovalve 15 is an open-center type, i.e. when slide valve is positioned centrally ($X=0$) and driver 21 is not supplied, outlets 15r, 15l communicate with recirculating outlet 18u.

[0021] The slide valve is also movable by driver 21 between a left limit position wherein inlet 15a communicates with outlet 15l and outlet 15r communicates with recirculating outlet 18u, and a right limit position wherein inlet 15a communicates with outlet 15r and outlet 15l communicates with recirculating outlet 18u.

[0022] When servovalve 15 moves into the left limit position, pressurized fluid is supplied to actuator 13l, and actuator 13r is drained to rotate body 11 clockwise; and when servovalve 15 moves into the right limit position, pressurized fluid is supplied to actuator 13r, and actuator 13l is drained to rotate body 11 anticlockwise.

[0023] Number 22 in Figure 2 indicates a regulating circuit of control unit 14, in accordance with the teachings of the present invention.

[0024] Regulating circuit 22 comprises a first node 23 presenting an adding input 23a and a subtracting input 23b. Adding input 23a is supplied with a reference signal φ_c generated by a circuit 26 (e.g. an electronic map) supplied with a number of signals P1, P2, ..., Pn relative to parameters measured on car 3 (e.g. speed and acceleration of the car).

[0025] Signal φ_c represents the ideal pattern (Ref) of angle φ as a function of time t, and as shown by the Ref curve in Figure 3, which presents a first portion A (between time $t=0$ and $t=T1$) in which angle φ increases steadily, and a second portion B in which angle φ assumes a constant value φ_{lim} (for $t>T1$).

[0026] Subtracting input 23b is supplied with a feedback signal φ_z generated by a sensor 28 for measuring the instantaneous angle φ of body 11.

[0027] Node 23 presents an output 23u communicating with the input 31a of a circuit 31 presenting a constant proportional gain G_p , and which generates a signal equal to the product of the input signal multiplied by proportional gain G_p .

[0028] Output 23u presents an error signal $\varphi_e = \varphi_c - \varphi_z$ representing the error between the angle φ requested by the control system (φ_c) and the actual angle (φ_z) of body 11 of car 3.

[0029] Circuit 31 presents an output 31u communicating with a first adding input 34a of a node 34, which presents an output 34u presenting a signal I which, when amplified, forms the drive signal of driver 21.

[0030] According to the present invention, regulating circuit 22 comprises a differentiating circuit 37 presenting an input 37a communicating with output 23u of node 23, and an output 37u communicating with a second adding input 34b of node 34. Circuit 37 generates a signal equal to the derivative of the input signal multiplied by a derivative gain term G_d .

[0031] The derivative gain G_d of circuit 37 is a function of the derivative in time ($d|\varphi_e|/dt$) of the error signal φ_e modulus, as shown in Figure 4, which shows three portions:

- a first portion (K) between a first value (0) and a second value (e.g. 0.2 degrees/seconds) of the derivative of the error signal modulus ($d|\varphi_e|/dt$), and wherein derivative gain G_d is zero;
- a second portion (L) between a second value (e.g. 0.2 degrees/seconds) and a third value (e.g. 2.2 degrees/seconds) of the derivative of the error signal modulus ($d|\varphi_e|/dt$), and wherein derivative gain

G_d increases steadily with a constant slope; and

- a third portion (M) wherein the derivative of the error signal modulus ($d|\varphi_e|/dt$) exceeds the third value (e.g. 2.2 degrees/seconds) and derivative gain G_d assumes a constant value (0.5 mA°/second).

[0032] Operation of circuit 22 will be described with reference to Figures 2 and 5, and commencing, for the sake of clarity, with a description of the operation of known control systems.

[0033] A first known type of (proportional) control system comprises a node 23 (Figure 5) supplied with a reference signal φ_c indicating the ideal pattern of angle φ , and a feedback signal φ_z indicating the actual angle φ of the car body; node 23 supplies an error signal φ_e , equal to the difference between the reference and feedback signals, to a proportional circuit 31 presenting a constant proportional gain G_p ; and circuit 31 generates a drive signal which, when converted and amplified, controls the solenoid valve supplying the hydraulic actuators to regulate the tilt angle φ of the body.

[0034] The reference signal may be as shown by the Ref curve in Figure 3, and comprise a first portion A in which angle φ increases steadily, and a second portion B in which angle φ assumes a constant value φ_{lim} .

[0035] During the transient states at the start and end of the curve, proportional control systems fail to provide for effectively "tracking" reference signal Ref, so that, for physical reasons not gone into here, the actual angle φ of the body differs considerably from the reference angle, as shown by the dot-and-dash curve Mis in Figure 3 indicating the actual pattern of angle in relation to time. As can be seen, at the start of the time scale (portion W), i.e. at the initial control stage, the Mis curve differs considerably from the Ref curve, and comes closer to it as reference signal Ref assumes a constant value (portion V). As a result, the non-compensated acceleration at the initial control stage is far from negligible, to the extent of impairing the comfort of the passengers.

[0036] To overcome the above drawback, proportional-derivative control systems have been used, which feature a differentiating circuit D (shown by the dotted line in Figure 5) parallel to proportional circuit 31 and generating a signal proportional to the error signal derivative. Since this is positive at portion W and negative at portion V, the differentiating circuit reduces the error at portion W, but increases it at portion V, by adding to the Mis curve a positive term (error derivative greater than zero) at portion W, and a negative term (error derivative of less than zero) at portion V. The angle φ signal achieved using proportional-derivative systems is shown by the dotted-line curve Ref2, which shows a distinct error increase at portion V.

[0037] The regulating circuit according to the present invention provides for effectively eliminating the drawbacks of both proportional and proportional-derivative systems.

[0038] As shown in Figure 3 and the Figure 2 circuit:

- at portion W (in which the error signal derivative is positive), the gain G_d of circuit 37 increases alongside the error derivative, as shown in Figure 4, so that the positive signal produced by circuit 31 is added (at node 34) to the signal (Mis) generated by circuit 31, thus reducing the total error;
- at portion V (in which the error signal derivative is negative or barely positive), the gain G_d of circuit 37 is zero (or very small), as shown in Figure 4, so that to the signal (Mis) generated by circuit 31 is added (at node 34) a small (or zero) signal having very little effect on the Mis signal, and the error remains small.

[0039] Regulator 22 therefore provides for effectively "tracking" the reference signal by maintaining a very small error between the reference and feedback signals at both portions W and V, so that the actual angle assumed by the car comes very close to the reference angle.

[0040] Regulating circuit 22 also comprises an integrating circuit 40 presenting an input 40a connected to node 23 via the interposition of a threshold circuit 42, and an output 40u connected to an adding input 34c of node 34 via the interposition of a limiting circuit 44.

[0041] Circuit 40 forms the integral of the input signal, and multiplies it by an integral gain term G_i ; and circuit 42 is a threshold comparing circuit, which blocks any input signals with an absolute value below a threshold value ϵ .

[0042] Operation of circuit 40 will now be described with reference to the physical operation of servovalve 15.

[0043] The slide valve of an ideal servovalve is theoretically set to the central position ($X=0$; hydraulic zero) when no drive current is applied to driver 21 (electric zero), so that fluid is supplied at the same pressure to actuators 13r, 13l.

[0044] In actual practice, however, for various physical reasons (e.g. variation in temperature of the servovalve components, acceleration of the servovalve, machining tolerances), the hydraulic zero does not correspond to the electric zero. That is, in a real servovalve (i.e. of the type fitted to railroad cars), the hydraulic zero is reached with a drive current of other than zero (bias current), and at any rate does not correspond to a zero drive current.

[0045] Consequently, if regulating circuit 22 were not provided with integrating circuit 40, a zero drive current would be generated when the error is eliminated (balanced position of the system), servovalve 15, for the above reasons, would not be set to the hydraulic zero position, the pressure of actuators 13r, 13l would not be the same, and a position error of other than zero would remain.

[0046] Circuit 40, however, provides for eliminating the above drawback by continually forming the integral of

error signal ϑ_e and generating a signal increasing continually as long as error signal ϑ_e is present. Upon the balanced position being reached, the error is zeroed, the output of circuits 31, 37 is zero, but node 34 is supplied with the output signal of integrator 40.

[0047] A drive current is thus generated which, by appropriately sizing gain G_i , forms the bias current for correctly positioning the slide valve and achieving hydraulic zero in the balanced position of the system.

[0048] Clearly, changes may be made to the control system as described and illustrated herein without, however, departing from the scope of the present invention.

Claims

1. A system for controlling rotation of a railroad car body to reduce the non-compensated acceleration to which the passengers are subjected; the railroad car comprising a body (11) housing the passengers, and a rotation device (12, 13r, 13l, 15, 14) for rotating the body (11) about at least one longitudinal axis (G) of the car (3);

said rotation device (12, 13r, 13l, 15, 14) rotating said body (11) by a given angle (ϑ) as a function of a drive signal (I);

said control system (1) comprising electronic computing means (14, 22) for generating said drive signal (I);

said electronic computing means (22) comprising:

- reference means (26) for generating a reference signal (ϑ_c) indicating the required pattern of said angle;
- first node means (23) supplied at the input (23a) with said reference signal (ϑ_c) and a feedback signal (ϑ_z) indicating the actual value of said angle;

said first node means (23) generating at the output an error signal (ϑ_e) equal to the difference between said reference signal (ϑ_c) and said feedback signal (ϑ_z);

- proportional means (31) supplied with said error signal (ϑ_e) and generating at the output (31u) a signal equal to the product of said input signal (ϑ_e) multiplied by a proportional gain (G_p);
- differentiating means (37) presenting an input (37a) supplied with said error signal (ϑ_e), and generating at the output (37u) a signal equal to the derivative of the input signal (ϑ_e) multiplied by a derivative gain (G_d);
- second node means (34) supplied with the

output signal (31u) of said proportional means (31) and the output signal (37u) of said differentiating means (37);

said second node means (34) generating at the output (34u) said drive signal; characterized in that said differentiating means (37) present a derivative gain (G_d) which is a function of the derivative in time ($d|g_e|/dt$) of the modulus of said error signal (g_e). 10

2. A system as claimed in Claim 1, characterized in that said derivative gain (G_d) decreases alongside a reduction in the derivative in time of the modulus of said error signal (g_e). 15

3. A system as claimed in Claim 1 or 2, characterized in that said derivative gain (G_d) presents a pattern presenting at least three portions: 20

- a first portion (K) between a first value (0) and a second value (0.2 degrees/seconds) of the derivative of the error signal modulus ($d|g_e|/dt$), and wherein the derivative gain (G_d) is substantially zero; 25
- a second portion (L) between the second value (0.2 degrees/seconds) and a third value (2.2 degrees/seconds) of the derivative of the error signal modulus ($d|g_e|/dt$), and wherein the derivative gain (G_d) increases steadily with a constant slope; and 30
- a third portion (M) wherein the derivative of the error signal modulus ($d|g_e|/dt$) exceeds the third value (2.2 degrees/seconds), and the derivative gain (G_d) assumes a constant value (0.5 mA/°/second). 35

4. A system as claimed in any one of the foregoing Claims, characterized in that said reference means (26) generate a reference signal (g_c) indicating the ideal pattern of said given angle (g) as a function of time (t); said pattern comprising a first portion (A) wherein said angle (g) increases steadily, and a second portion (B) adjacent to the first portion (A) and wherein said angle (g) assumes a constant value (g_{lim}). 45

5. A system as claimed in any one of the foregoing Claims, characterized in that it comprises integrating means (40) presenting an input (40a) communicating with the output (23u) of said first node means (23), and an output (40u) communicating with an input (34c) of said second node means; 50

said integrating means (40) generating at the output (40u) a signal equal to the integral of the input signal (g_e) multiplied by an integral gain (G_i). 55

6. A system as claimed in any one of the foregoing Claims, characterized in that said rotation device (12, 13r, 13l, 15, 14) comprises at least first and second actuators (13r, 13l) for rotating said body (11) in opposite directions; and a servovalve (15) for supplying said actuators (13r, 13l);

said servovalve (15) presenting at least one inlet (15a) supplied with pressurized fluid (16); and a first and second outlet (15r, 15l) communicating respectively with said first and second actuators (13r, 13l); characterized in that said servovalve is an open-center type.

Patentansprüche

1. System zum Steuern der Drehung eines Eisenbahnwagenkastens, um die nicht kompensierte Beschleunigung, der die Fahrgäste unterliegen, zu reduzieren; wobei der Eisenbahnwagen einen Wagenkasten (11), in dem die Fahrgäste untergebracht sind, Und eine Drehvorrichtung (12, 13r, 13l, 15, 14) zum Drehen des Wagenkastens (11) wenigstens um eine Längsachse (G) des Wagens (3) enthält;

wobei die Drehvorrichtung (12, 13r, 13l, 15, 14) den Wagenkasten (11) in Abhängigkeit von einem Treibersignal (I) um einen gegebenen Winkel (g) dreht; wobei das Steuersystem (1) eine elektronische Recheneinrichtung (14, 22) zum Erzeugen des Treibersignals (I) enthält; wobei die elektronische Recheneinrichtung (22) enthält:

- eine Referenzeinrichtung (26) zum Erzeugen eines Referenzsignals (g_c), das das erforderliche Muster des Winkels angibt;
- eine erste Knoteneinrichtung (23), die an ihrem Eingang (23a) mit dem Referenzsignal (g_c) und mit einem Rückkopplungssignal (g_z), das den Ist-Wert des Winkels angibt, versorgt wird;

wobei die erste Knoteneinrichtung (23) an ihrem Ausgang ein Fehlersignal (g_e) erzeugt, das gleich der Differenz zwischen dem Referenzsignal (g_c) und dem Rückkopplungssignal (g_z) ist;

- eine Proportionaleinrichtung (31), die mit dem Fehlersignal (g_e) versorgt wird und an ihrem Ausgang (31u) ein Signal erzeugt, das gleich dem Produkt aus dem Eingangssignal (g_e) und einer proportionalverstärkung (G_p) ist;

- eine Differenziereinrichtung (37), die einen Eingang (37a) aufweist, der mit dem Fehlersignal (ϑ_e) versorgt wird, und an ihrem Ausgang (37u) ein Signal erzeugt, das gleich dem Differential des Eingangssignals (ϑ_e), multipliziert mit einer Differentialverstärkung (G_d), ist;
- eine zweite Knoteneinrichtung (34), die mit dem Ausgangssignal (31u) der Proportionaleinrichtung (31) und mit dem Ausgangssignal (37u) der Differenziereinrichtung (37) versorgt wird;

wobei die zweite Knoteneinrichtung (34) an ihrem Ausgang (34u) das Treibersignal erzeugt; dadurch gekennzeichnet, daß die Differenziereinrichtung (37) eine Differentialverstärkung (G_d) aufweist, die von der zeitlichen Ableitung des Absolutbetrags ($d|\vartheta_e|/dt$) des Fehlersignals (ϑ_e) abhängt.

2. System nach Anspruch 1, dadurch gekennzeichnet, daß die Differentialverstärkung (G_d) zusammen mit einer Reduzierung der zeitlichen Ableitung des Absolutbetrags des Fehlersignals (ϑ_e) abnimmt.

3. System nach Anspruch 1 oder 2, dadurch gekennzeichnet, daß die Differentialverstärkung (G_d) ein Muster aufweist, das wenigstens drei Abschnitte enthält:

- einen ersten Abschnitt (K) zwischen einem ersten Wert (0) und einem zweiten Wert (0,2 Grad/Sekunde) der Ableitung des Absolutbetrags des Fehlersignals ($d|\vartheta_e|/dt$), in dem die Differentialverstärkung (G_d) im wesentlichen null ist;
- einen zweiten Abschnitt (L) zwischen dem zweiten Wert (0,2 Grad/Sekunde) und einem dritten Wert (2,2 Grad/Sekunde) der Ableitung des Absolutbetrags des Fehlersignals ($d|\vartheta_e|/dt$), in dem die Differentialverstärkung (G_d) mit konstanter Steigung ständig zunimmt; und
- einen dritten Abschnitt (M), in dem die Ableitung des Absolutbetrags des Fehlersignals ($d|\vartheta_e|/dt$) den dritten Wert (2,2 Grad/Sekunde) übersteigt, in dem die Differentialverstärkung (G_d) einen konstanten Wert (0,5 mA/(°/s)) annimmt.

4. System nach irgendeinem der vorangehenden Ansprüche, dadurch gekennzeichnet, daß die Referenzeinrichtung (26) ein Referenzsignal (ϑ_c) erzeugt, das das ideale Muster des gegebenen Winkels (ϑ) in Abhängigkeit von der Zeit (t) angibt;

wobei das Muster einen ersten Abschnitt (A), in dem der Winkel (ϑ) ständig ansteigt, und einen zweiten Abschnitt (B) enthält, der an den ersten Abschnitt (A) angrenzt und in dem der Winkel (ϑ) einen konstanten Wert (ϑ_{lim}) annimmt.

5. System nach irgendeinem der vorangehenden Ansprüche, dadurch gekennzeichnet, daß es eine Integrationseinrichtung (40) enthält, die einen Eingang (40a), der mit dem Ausgang (23a) der ersten Knoteneinrichtung (23) kommuniziert, sowie einen Ausgang (40u), der mit einem Eingang (34c) der zweiten Knoteneinrichtung kommuniziert, umfaßt;

die Integrationseinrichtung (40) an ihrem Ausgang (40u) ein Signal erzeugt, das gleich dem Integral des Eingangssignals (ϑ_e), multipliziert mit einer Integrationsverstärkung (G_i), ist.

6. System nach irgendeinem der vorangehenden Ansprüche, dadurch gekennzeichnet, daß die Drehvorrichtung (12, 13r, 13l, 15, 14) wenigstens einen ersten und einen zweiten Aktuator (13r, 13l) zum Drehen des Wagenkastens (11) in entgegengesetzte Richtungen; sowie ein Servoventil (15) zur Versorgung der Aktuatoren (13r, 13l) enthält;

wobei das Servoventil (15) wenigstens einen Einlaß (15a), der mit mit Druck beaufschlagtem Fluid (16) versorgt wird; und einen ersten und einen zweiten Auslaß (15r, 15l), die mit dem ersten bzw. mit dem zweiten Aktuator (13r, 13l) kommunizieren, enthält; dadurch gekennzeichnet, daß das Servoventil vom Typ mit offener Mitte ist.

Revendications

1. Système destiné à commander l'inclinaison de la caisse d'une voiture de chemin de fer afin de réduire l'accélération non compensée à laquelle sont soumis les passagers, la voiture de chemin de fer comprenant une caisse (11) logeant les passagers, et un dispositif de rotation (12, 13r, 13l, 15, 14) destiné à faire pivoter la caisse (11) autour d'au moins un axe longitudinal (G) de la voiture (3),

ledit dispositif de rotation (12, 13r, 13l, 15, 14) faisant pivoter ladite caisse (11) d'un angle donné (θ) en fonction d'un signal d'attaque (I), ledit système de commande (1) comprenant un moyen de calcul électronique (14, 22) destiné à engendrer ledit signal d'attaque (I), ledit moyen de calcul électronique (22) comprenant :

- un moyen de référence (26) destiné à engendrer un signal de référence (θ_c) indi-

quant le profil voulu dudit angle,

- un premier moyen de noeud (23) recevant au niveau de l'entrée (23a) ledit signal de référence (θ_c), ainsi qu'un signal de contre-réaction (θ_z) indiquant la valeur réelle dudit angle,

ledit premier moyen de noeud (23) générant au niveau de la sortie un signal d'erreur (θ_e) égal à la différence entre ledit signal de référence (θ_c) et ledit signal de contre-réaction (θ_z),

- un moyen proportionnel (31) recevant ledit signal d'erreur (θ_e) et générant au niveau de la sortie (31u) un signal égal au produit dudit signal en entrée (θ_e) multiplié par un gain proportionnel (G_p),
- un moyen de différentiation (37) présentant une entrée (37a) recevant ledit signal d'erreur (θ_e), et engendrant au niveau de la sortie (37u) un signal égal à la dérivée du signal en entrée (θ_e) multipliée par un gain de dérivation (G_d),
- un second moyen de noeud (34) recevant le signal en sortie (31u) dudit moyen proportionnel (31) et le signal en sortie (37u) dudit moyen de différentiation (37),

ledit second moyen de noeud (34) engendrant au niveau de la sortie (34u) ledit signal d'attaque, caractérisé en ce que ledit moyen de différentiation (37) présente un gain de dérivation (G_d) qui est une fonction de la dérivée dans le temps ($d|\theta_e|/dt$) du module dudit signal d'erreur (θ_e).

2. Système selon la revendication 1, caractérisé en ce que ledit gain de dérivation (G_d) décroît de façon correspondante à une réduction de la dérivée dans le temps du module dudit signal d'erreur (θ_e).

3. Système selon la revendication 1 ou 2, caractérisé en ce que ledit gain de dérivation (G_d) présente un profil présentant au moins trois parties :

une première partie (K) entre une première valeur (0) et une seconde valeur (0,2 degré/seconde) de la dérivée du module du signal d'erreur ($d|\theta_e|/dt$), et dans laquelle le gain de dérivation (G_d) est pratiquement nul,

- une seconde partie (L) entre la seconde valeur (0,2 degré/seconde) et une troisième valeur (2,2 degrés/seconde) de la dérivée du module du signal d'erreur ($d|\theta_e|/dt$), et dans laquelle le gain de dérivation (G_d) augmente régulièrement avec

une pente constante, et

- une troisième partie (M) dans laquelle la dérivée du module du signal d'erreur ($d|\theta_e|/dt$) dépasse la troisième valeur (2,2 degrés/seconde), et le gain de dérivation (G_d) prend une valeur constante (0,5 mA°/seconde).

4. Système selon l'une quelconque des revendications précédentes, caractérisé en ce que ledit moyen de référence (26) engendre un signal de référence (θ_c) indiquant le profil idéal dudit angle donné (θ) en fonction du temps (t), ledit profil comprenant une première partie (A) dans laquelle ledit angle (θ) augmente régulièrement, et une seconde partie (B) adjacente à la première partie (A) et dans laquelle ledit angle (θ) prend une valeur constante (θ_{lim}).

5. Système selon l'une quelconque des revendications précédentes, caractérisé en ce qu'il comprend un moyen d'intégration (40) présentant une entrée (40a) communiquant avec la sortie (23u) dudit premier moyen de noeud (23), ainsi qu'une sortie (40u) communiquant avec une entrée (34c) dudit second moyen de noeud,

ledit moyen d'intégration (40) engendrant au niveau de la sortie (40u) un signal égal à l'intégrale du signal en entrée (θ_e) multipliée par un gain d'intégration (G_i).

6. Système selon l'une quelconque des revendications précédentes, caractérisé en ce que ledit dispositif de rotation (12, 13r, 13l, 15, 14) comprend au moins des premier et second actionneurs (13r, 13l) destinés à faire pivoter ladite caisse (11) dans des directions opposées, et un servodistributeur (15) destiné à alimenter lesdits actionneurs (13r, 13l),

ledit servodistributeur (15) présentant au moins un orifice d'entrée (15a) alimenté en fluide sous pression (16), et des premier et second orifices de sortie (15r, 15l) communiquant respectivement avec lesdits premier et second actionneurs (13r, 13l), caractérisé en ce que ledit servodistributeur est du type à position centre ouvert.

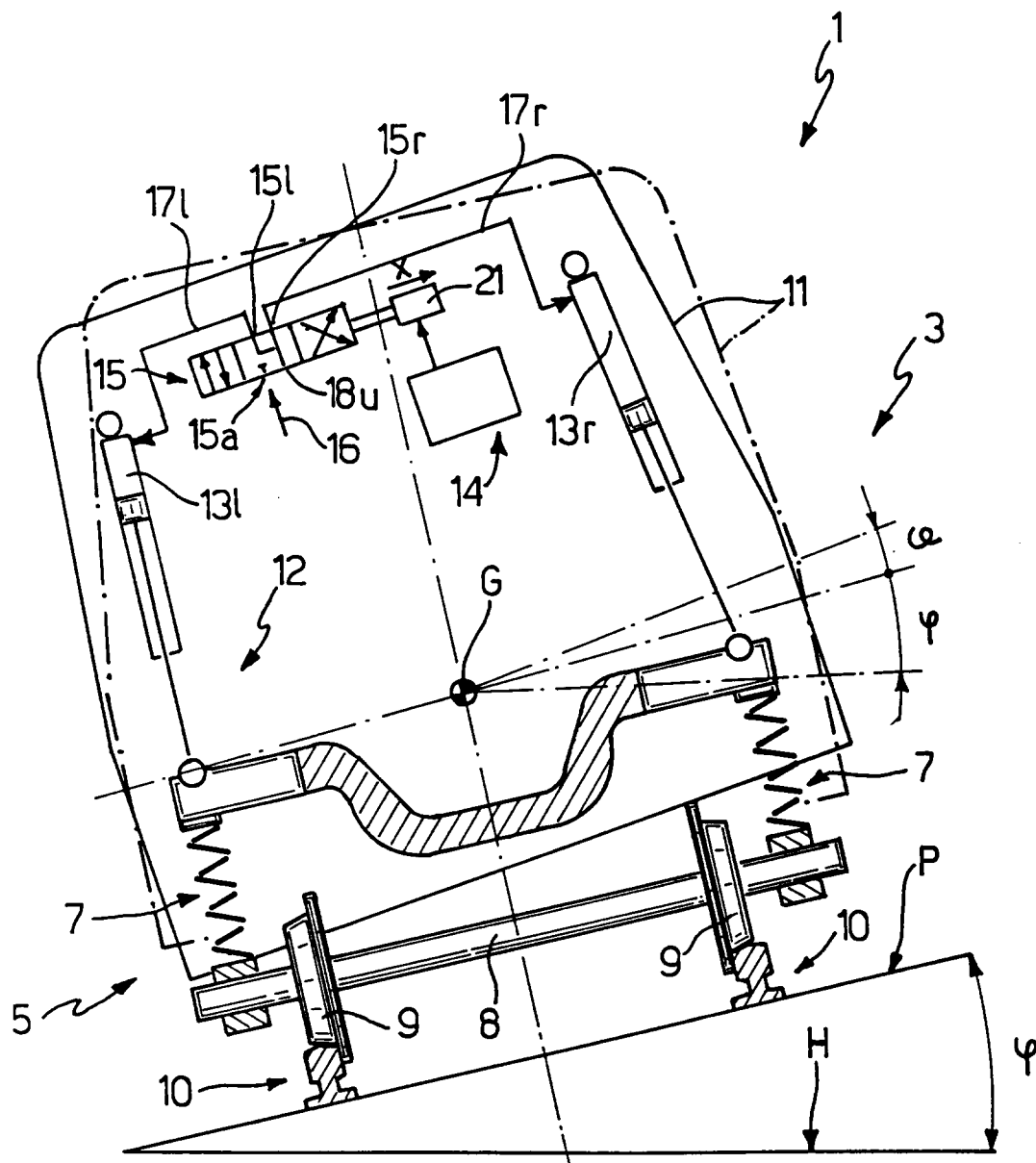


Fig. 1

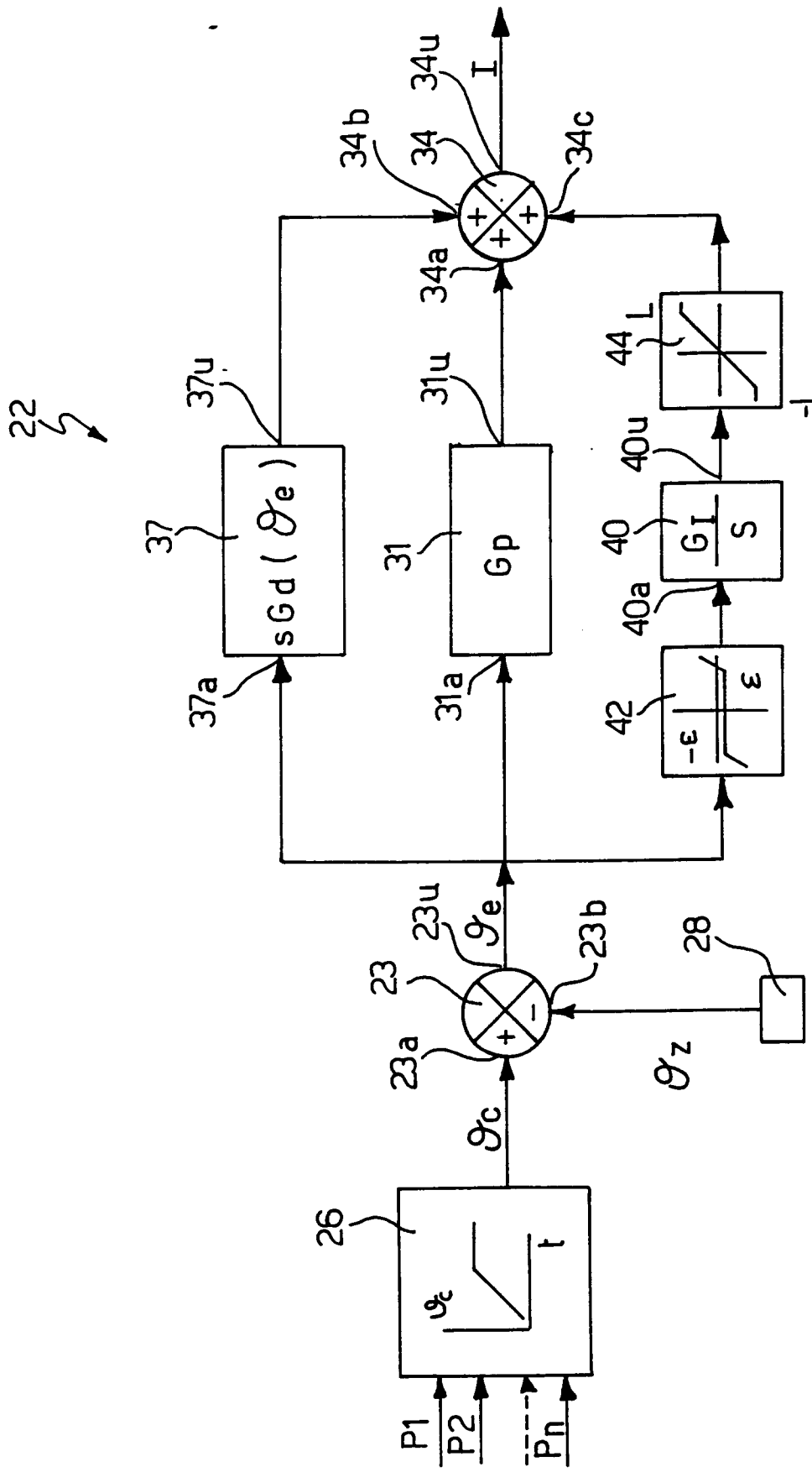


Fig. 2

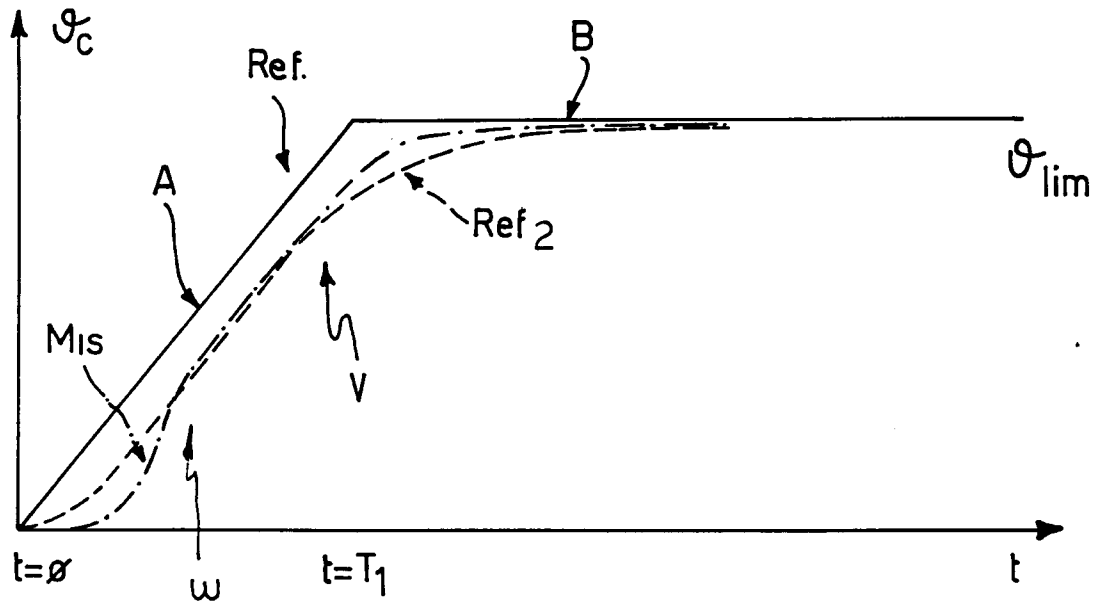


Fig. 3

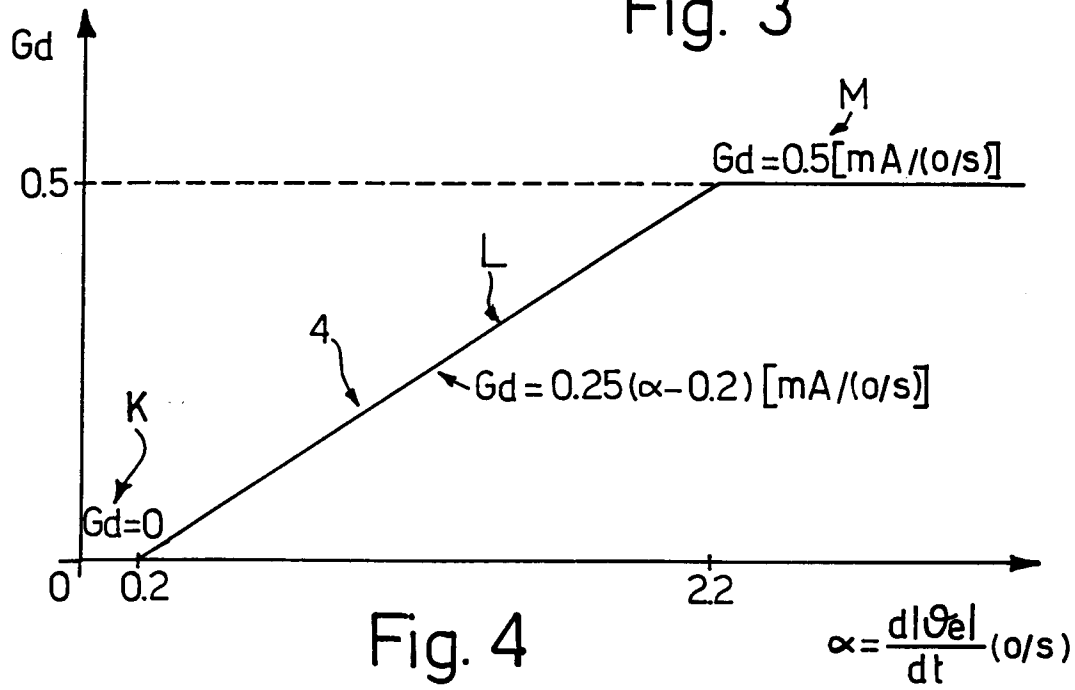


Fig. 4

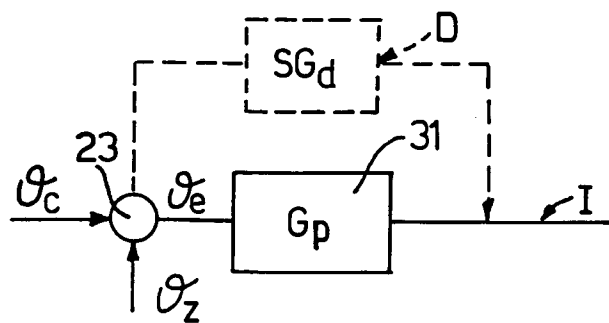


Fig. 5