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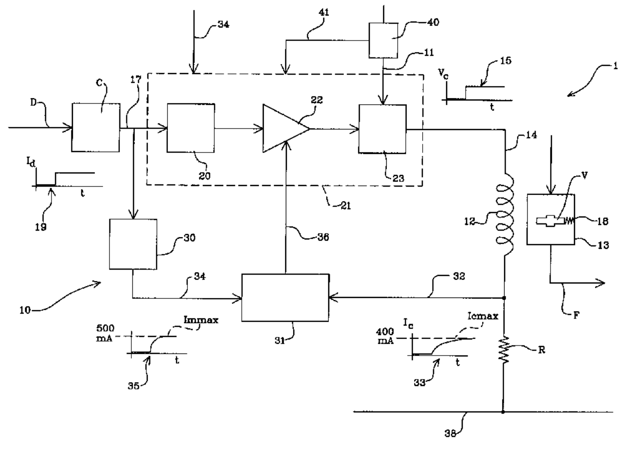
(54) **Title:** ADAPTIVE CONTROL METHOD AND SYSTEM FOR AN ELECTRICALLY OPERATED ACTUATOR



(57) **Abstract:** A method of controlling a system (1) which includes an electrically operated actuator (12) the operation of which is dependant upon the current applied, using a control apparatus (10) which includes a controller (C) which responds to a demand input Signal (D) which depends upon system demand by providing a demand signal (19) which indicates a desired current (I_d) to be applied to the actuator (12), processing the demand signal (19) in a signal processor (21) to control the voltage of a supply (11) to produce a control signal (15) which is calculated to have the desired current(I_d) to operate the actuator (12) to change a variable of the system (1) to match system demand, the method including providing the demand signal (19) simultaneously to a modelling device (30) which is programmed to model the actuator (12) and to produce a modelled control signal (35), comparing the currents of the actual control signal (I_c) and the modelled control signal (I_m), and modifying the processing of the demand signal (19) to change the actual control signal current (I_c) to compensate for variations between the currents of the modelled control signal (I_m) and the actual control signal (I_c).

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ADAPTIVE CONTROL METHOD AND SYSTEM FOR AN ELECTRICALLY OPERATED ACTUATOR

Description of Invention

This invention relates to a method of controlling a system and more particularly but not exclusively to a method of controlling a proportional fluid valve of the kind in which a varying electrical signal is applied to a valve actuator which moves a valve member in response, typically against the force of a spring or other resilient biasing means, to vary the fluid pressure in and flow through the valve.

Such valves typically are controlled by so called closed loop systems in which a valve controller responds to a demand input signal indicative of the fluid pressure or flow required in the system, to generate a demand signal. The demand signal is processed by a signal processor to produce a control system which is used to operate the valve. The valve controller determines an appropriate current to be delivered to e.g. coils or another actuator of the valve, to cause the valve to open an appropriate amount in order to achieve a desired pressure or flow value in the system. The extent of valve opening is proportional to the applied current, or the average applied current where the control signal is a switched voltage signal i.e. has a current waveform.

In practice the current of the control signal may not be the same as that calculated by the controller, because, for example, as the temperature of the coils or other actuator of the valve varies, the resistance of the coils or other actuator will vary. Also any inductance in the coils or other actuator will affect the applied current where the control signal is applied as a waveform.

In a conventional system, a feedback loop is provided whereby the current of the demand signal, i.e. that desired to operate the actuator so that the fluid pressure or flow matches the system demand, is compared with the actual current of the control signal flowing through the coil or other actuator. The signal processor is arranged to respond to discrepancies between the current of the demand signal and the actually applied current by changing the current of the control signal.

The signal processor may change the current of the control signal by varying the voltage of a supply, and/or where the control signal is a waveform i.e. a switched voltage signal, such as a square wave, the mark-space ratio of the switched voltage control signal may be varied to vary the actually applied average current.

Thus the comparison between the demanded and actually applied current is used to cause the signal processor to modify the applied control signal to deliver a compensated current to the actuator, to match the current of the control signal (or average current) with the demanded current.

Thus the method of control is reactive, in that the controller varies the applied signal in reaction to variations between the demand signal and actually applied control signal.

Such reactive closed loop controls are generally efficient at compensating for large discrepancies between demand signal current and applied control signal current, but are not able efficiently to react to small discrepancies, and in practice, to prevent the valve being caused to "hunt" by the applied control signal being continuously finely varied, small variances between the demand signal and actual applied control signal are ignored, e.g. by electronic filtering, and so the valve member may settle in a non-ideal position for satisfying demand. Moreover, because compensation for e.g. temperature changes in the actuator is reactive, there is inevitably a delay in applying such compensation.

It will be appreciated that the demand for fluid pressure or flow can change rapidly in a fluid system, for example as a fluid operated apparatus is actuated and as the fluid operated apparatus experiences varying loads. Hence the demand signal in practice may continuously vary. Thus the demand may change before the signal processor applies an appropriately compensated control signal to the actuator of the valve.

The problem is accentuated by the nature of a proportional valve, which by virtue of its electrical inductance and resistance and mechanical properties, will not react to control signals instantaneously and thus comparisons between the current of the demand signal and the current of the control signal, or average control signal current may not lead to rapid and accurate control of the valve.

According to one aspect of the invention we provide a method of controlling a system which includes an electrically operated actuator the operation of which is dependant upon the current applied, using a control apparatus which includes a controller which responds to a demand input signal which depends upon system demand by providing a demand signal which indicates a desired current to be applied to the actuator, processing the demand signal in a signal processor to control the voltage of a supply to produce a control signal which is calculated to have the desired current to operate the actuator to change a variable of the system to match system demand, the method including providing the demand signal simultaneously to a modelling device which is programmed to model the actuator and to produce a modelled control signal, comparing the currents of the actual control signal and the modelled control signal, and modifying the processing of the demand signal to change the actual control signal current to compensate for variations between the currents of the modelled control signal and the actual control signal.

Thus for example, where the control signal is calculated by the controller to apply a desired current to the actuator, but because of a changing parameter, such as the temperature of the actuator which may vary the resistance of the actuator, the actual current applied by the signal processor is not the desired current, comparing the modelled response and the actual response enables the control apparatus rapidly to apply a compensated control signal in order to achieve the desired current.

Thus by utilising a modelled actuator, rather than comparing the demand signal current with the actual applied control signal current, the system may be controlled to respond to changing demand more rapidly and accurately. Thus particularly where system demand is constantly changing, the actual variable value at any instant may more closely be controlled to correspond to the instant demand value.

It will be appreciated that an actuator will have a characteristic response to any control signal, depending upon, for example, where the actuator is electrically operated, an inherent resistance, inductance or capacitance, as well as the actuator mechanical response. These characteristic factors which will affect the current of the control signal may be modelled in the modelling device so that the current of the modelled control signal more closely corresponds to the current of the actual control signal applied to the actuator, than the demand signal current at any instant.

The voltage of the supply may be controlled to change the current of the applied control signal, by simply varying the level of the applied voltage, but where the applied control signal is a switched voltage waveform, the mark-space ratio of the waveform may be varied to vary the average current of the control signal over a predetermined time period.

In the latter case, notwithstanding the applied control signal may be of a switched voltage waveform, the demand signal may indicate an absolute current level to achieve a desired actuator response, and the comparitor may compare the absolute current level with the average current of the waveform over a predetermined time period.

In one embodiment an applied waveform control signal may be a square waveform. It will be appreciated that in addition to the resistance of the actuator varying, e.g. in response to temperature, the average current applied to the actuator in an applied waveform control signal will vary due to the reaction time of the actuator in response to increasing and decreasing current step changes. Moreover the actuator reaction time to these step changes may be different in response to increasing and decreasing current, i.e. positive and negative step changes in the square waveform, so thus again the average current applied to the actuator by the signal processor may not be in accordance with the desired current of the demand signal determined by the controller.

In accordance with the invention, the modelling device may be programmed to model the effect of the actuator on both positive and negative step changes in the applied waveform control signal.

The invention has been devised for particular use where the actuator is an actuator of a fluid valve, e.g. a proportional valve, in which the pressure or flow of fluid in or through the valve is dependent upon e.g. proportional to, the current applied to actuator windings of the valve, and movement of a valve member in response to the electrical current is in opposition to a resilient biasing means such as a spring.

Such a valve may be used in many hydraulic circuits, for example in a hydraulic circuit operable to shift gears in a power shift gear box or to achieve steering of a vehicle.

According to a second aspect of the invention we provide a system which includes an electrically operated actuator the operation of which is dependant upon the current applied, and a control apparatus, the control apparatus including a controller which responds to a demand input signal which depends upon system demand by providing a demand signal which indicates a desired current to be applied to the actuator, a demand signal processor for processing the demand signal to control the voltage of a supply to produce a control signal which is calculated to have the desired current to operate the actuator to change a variable of the system to match system demand, the system further including a modelling device to which the demand signal is fed simultaneously with the demand signal being fed to the signal processor, the modelling device being programmed to model the actuator and to produce a modelled control signal, the control apparatus further including a comparitor for comparing the currents of the actual control signal and the modelled control signal, and to provide a correction signal to the signal processor to modify the processing of the demand signal to change the actual control signal current to compensate for variations between the currents of the modelled control signal and the actual control signal.

According to a third aspect of the invention we provide a method of programming a modelling device of the apparatus of the second aspect of the invention, the method including for predetermined actuator conditions, applying to the actuator a control signal, adjusting the control signal until the actuator responds so that a predetermined system demand is satisfied by the actuator operation, determining the current of the applied control signal, and correlating in the modelling device a relationship between the current of the demand signal and the current of the applied control signal for the actuator at the predetermined conditions, thus modelling the actuator response for the predetermined conditions.

Thus the modelling device may be programmed by applying test stimuli to the system, for example under laboratory or other closely controlled conditions. Thus when the system is in a practical situation, when the actuator conditions e.g. temperature, may vary, discrepancies between the expected current of the applied control signal and the current of the demand signal due to such changed actuator conditions may be readily identified and compensated for.

According to a further aspect of the invention we provide a method of determining a measure of a parameter of the actuator environment which affects the actuator response to the control signal, including performing the method of the third aspect of the invention for different predetermined actuator conditions to create data relating to discrepancies between the demand signal current and the current of the applied control signal for different actuator environmental conditions, determining the magnitude of the discrepancy and comparing this with the data.

In one embodiment, provided the voltage of the supply remains constant, the actuator response to the control signal is temperature dependent, and by comparing the current of the modelled control signal to the current of the applied control signal, a measure of the temperature of the actuator can be determined from the data. Thus where it is determined that the actuator is overheating, a warning may be given to an operator, and/or a control function may be effected to reduce the temperature of the actuator, such as increased cooling of the actuator or, where the actuator operates a fluid valve, of fluid flowing through the valve, or in an extreme condition, system shutdown may be effected.

Embodiments of the invention will now be described with reference to the accompanying drawings in which:-

FIGURE 1 is an illustrative view of a first embodiment of a system including a control apparatus for controlling the system, by a method according to the invention;

FIGURE 2 is an illustrative view of a second embodiment of a system which may be operated by the method of the invention;

Referring to figure 1 there is shown a system 1 including a control apparatus 10 for controlling the system 1. The system 1 includes an actuator 12 which in the present example, is a coil operative to move a valve member V in a fluid valve 13 to vary the pressure in a fluid circuit F in which the valve 13 is provided, and /or to vary the fluid flow in the fluid circuit F. The valve 13 is proportional in this example, by which we mean that the valve member V movement and hence fluid pressure and/or flow is proportional to the current of a control signal which is applied to the actuator 12 along a line 14, which current flows through the actuator 12. In another example, the valve member V movement need not be proportional may otherwise be dependant upon applied current, i.e. the valve member V movement need not be linearly proportional to the applied current.

As is well known in the art, the control signal 15 is in this example a step function, current flowing when a positive voltage v is applied as is indicated in figure 1 at 15, e.g. as a supply 11 is switched on at a time t.

The valve member V of the valve 13 is moveable against the force of a spring or other resilient biasing means 18 in this example, and the extent of movement of the valve member V and thus the fluid pressure/flow in and through the valve 13, is controlled by varying the current flowing through actuator 12, by controlling the voltage v of the control signal 15.

The control signal 15 on line 14 is provided from a signal processor 21 of the control apparatus 10, which controls the supply 11 to produce a control signal 15 with an appropriate current, in response to a demand signal 19 from a controller C.

The controller C, in response to a demand input signal D e.g. from a control device such as joystick control, generates the demand signal 19 on line 17 with a desired current I_d which is calculated to be that required, to operate the fluid valve 13 to achieve a desired fluid pressure or flow in the fluid circuit F. As the valve 13 is in this example a proportional valve, valve member V movement will always be proportional to the applied current.

The signal processor 21 in a first stage 20, determines an appropriate voltage V_c for the control signal 15 for the particular actuator 12, to achieve a control signal 15 with the desired current I_d to achieve a desired valve member V movement. This information is buffered e.g. in an amplifier 22 before being provided to a third processor stage 23 of the signal processor 21, which actually controls the voltage of the supply 11.

The actual current flowing through the coils of the actuator 12 will be affected by the resistance of the actuator coil 12 which in turn is temperature dependant, and the coil 12 inductance, and thus the actual current of the control signal 15 as applied may not be as determined by the controller C. Also, because of the innate resistance and inductance of the coil 12, the current in line 14 will never correspond exactly with the step-function demand signal 19 provided by the controller C.

The current of the control signal 15 applied to the actuator along line 14 is monitored by providing a feedback signal 33 along line 32, of the actual control signal current I_c applied to the actuator 12, to a comparitor 31 for comparison with a modelled control signal 35 fed to the comparitor 31 along line 34.

The modelled control signal 35 is provided from a modelling device 30 to which the demand signal 19 is fed simultaneously with the demand signal 17 being fed from the controller C to the signal processor 21.

The modelling device 30 typically is a computer which is programmed to model the actuator's 12 effect on the actual control signal applied by the signal processor 21 on line 14. For example, the modelling device 30 may be programmed with information concerning the innate inductance L and internal resistance r of the actuator coil 12.

Thus the modelling device 30 is able to provide a modelled control signal 35 which is closer to the actual applied control signal 15, than the demand signal 19. More particularly, by modelling the actuator 12, the modelling device 30 will provide a modelled control signal with a current I_m which is closer at any instant in time, to the current flowing through the actuator coil 12.

Thus for example, if due to the innate inductance L and resistance r of the coil 12, the current I_c of the applied control signal 15 rises gradually to a maximum I_{cmax}, the modelling device 30 will mirror this in the modelled controlled signal 35. However in the event of any discrepancy between the instantaneous current I_c of the applied control signal 15 voltage and the modelled control signal 35 current I_m, which will be determined by the comparitor 31, for example because of a change in the coil 12 temperature, the comparitor 31 may immediately signal the signal processor 21 along line 36 to change the processing of the demand signal 19 to control the voltage of the supply 11, to provide a compensated control signal 15 with a current I_c which more closely matches the current I_m of the modelled control signal 35.

Thus whereas previously, the current I_d of the demand signal 19 has been compared with the current I_c of the applied control signal 15, this would, particularly as the control signal 15 is applied before any steady state is achieved, always result in a large discrepancy as the comparitor 31 would be comparing a stepped demand current I_d with a gradually increasing current I_c of the control signal 15, by the method of the present invention, comparison is made between the applied current I_c and the current I_m of a modelled control signal 35 which more closely mirrors the actual applied current I_c.

Thus the current of the control signal 15 reaches a steady state I_{cmax}, if this is less than the steady state current I_{mmax} of the modelled control signal 35, the comparitor 31 will determine this and the signal processor 21 may respond by modifying the voltage of the supply 11, thus modifying the current of the applied control signal 15, appropriately.

For example, the buffer 22 of the signal processor 21 may be arranged to apply a standard correction factor to the information from the first stage 20 of the processor 21 of say, one. In the event that at a given instant the comparitor 31 determines that the current I_c of the applied control signal 15 is only say 400mA whereas the expected current I_m included by the modelled control signal 35 is 500mA, the buffer amplifier 22 may apply a correction factor of 0.25 to the information from the first stage 20 of the processor 21, making a total correction factor of 1.25.

The comparison of the current between the actual applied control signal 15 and the modelled control signal 35 may be continuous, or may be at a sampled rate, for example every 10 microseconds.

If desired, the demand signal 19 may not have a current I_d but may simply indicate, by supplying data that the current I_d is desired by the actuator 12 for system demand to be satisfied. Thus the modelling device 30 would need to process the demand signal 19 to derive the desired current I_d and then to create the modelled control signal 35 with a current I_m dependent on the model of the actuator 12.

Although as described with reference to figure 1, the control signal 15 has been a simple step function voltage signal, i.e. the voltage of the supply 11 is simply switched on and reduced to provide the control voltage V_c, the voltage of the supply 11 may otherwise be controlled to achieve a control signal 15 with a desired current, as described below with reference to figure 2.

The modelling device 30 may contain programmed algorithms so that for any demand signal 19 the effect of the actuator 12 on the control signal 15 may be modelled, although but the modelling device 30 may be programmed by applying known test stimuli to the system 1 under laboratory or other closely controlled conditions.

For example, for a known actuator coil 12 temperature, a control signal 15 may be applied by adjusting the voltage of the supply 11 until the control signal 15 achieves a valve member V movement in the valve 13 to match a test system demand indicated by an appropriate test demand input signal on line D. Thus for example, for an actuator coil 12 temperature of 25° C and an available supply 11 voltage of 12 volts, correlating in the modelling device 30 a relationship between the current I_d of the demand signal 19 and the current I_c of the applied control signal 15 for the actuator 12 for these predetermined conditions, a model of the actuator 12 may be created.

Moreover, by collecting data relating to discrepancies between the current of the modelled control signal 35 and the actual current I_c of the applied control signal 15 for different known temperatures or other parameters of the actuator coil 12, in use, by determining the magnitude of any discrepancy between the current of the modelled control signal 35 and actually applied control signal 15, and consulting the data, a measure of the actuator coil 12 temperature may be derived, provided the supply voltage remains constant.

Such temperature information may be used for control functions of the system 1, e.g. to warn an operator when the windings of the actuator coil 12 are overheating, and/or to effect cooling or additional cooling of the coil 12 of the actuator, or of fluid flowing through the valve 13, thus to cool the actuator coil 12. In an extreme event, the temperature information may be used to, effect system shut down.

Alternatively or additionally, the temperature information may be provided to the signal processor 21 which may be adapted to respond to an indication that the temperature in the coil 12 windings is above a threshold value, by ceasing to provide a control signal 15, or by providing some other control function.

In figure 2 an alternative system 1 is indicated with similar parts to those of the system 1 of figure 1 indicated by the same reference numerals. In this embodiment, the voltage of the supply 11 is controlled by the signal processor 21 to provide a control signal 15 with a current I_c calculated to operate the actuator 12 to match system demand, by switching the supply 11 voltage on and off at a predetermined rate, such that it is the average current in a given time which is calculated to be the desired current I_d indicated in the demand signal 19.

As is well known in the art, the control signal 15 is in this example a square waveform switched voltage signal. The supply 11 voltage is switched on and off substantially instantaneously, so as to provide a series of positive steps where the current I_c is switched on, as indicated at 16a, 16b etc., and negative steps where the current I is switched off, as indicated at 17a, 17b etc.

Again, the valve member V of the valve 13 is moveable against the force of a spring or other resilient biasing means 18 in this example, and the extent of movement of the valve member V and thus the fluid pressure/flow in and through the valve 13, is controlled by varying the average current flowing through actuator 12, in this example by varying the so called mark-space ratio of the square waveform switched voltage control signal 15, that is by varying the relative durations of the "on" times between respective pairs of positive 16a etc. and negative 17 a etc. steps, to the "off" times between respective pairs of negative 17a etc. and positive 16a etc. steps.

The processor 21 generates the square waveform switched voltage control signal 15 with a mark-space ratio determined by the processor 21 to result in the actuator 12 operating to provide a fluid pressure/flow in accordance with system demand indicated by the demand input signal on line D.

A modelling device 30 is again provided, and a comparitor 31. The modelling device 30 receives the demand signal 19 simultaneously with the demand signal 19 being fed to the processor 21, and models the actuator 12 to produce a modelled control signal 35. The comparator 31 then compares the current of the modelled control signal 35 with the average current I_c of the applied alternating control signal 15 over a period of time. Thus in this example, comparison of the current I_m of the modelled control signal 35 and actual control signal35 is not continuous but at a sampled rate.

Where the actual average current I_c flowing through the coil 12 is less than or more than is required to match the fluid pressure or flow through the valve 13 to the demand, the signal processor 21 responds to a signal from the comparator 31 by increasing or decreasing the mark-space ratio of the control signal 15 to increase or decrease the average current flowing through the coil 12.

It will be appreciated that because of the inherent inductance L in the windings of the actuator coil 12, the current response in the actuator 12 to the stepped voltage waveform of the applied control signal 15 will not be instantaneous. For example, when a positive step 16a etc. in the switched voltage control signal 15 occurs, the current I_c applied, will rise gradually rather than instantaneously i.e. will take a finite time to respond, and as a result, the current I_c in the windings 12, will not be of a corresponding square waveform, but may for example follow the waveform indicated at 25a, 25b etc. Thus the actual average applied current I_c will not be the desired current I_d as calculated for by the processor 21.

Moreover, when a negative step function 17a etc. occurs, and the current I_c is switched off, the current in the windings of the actuator 12 will take a finite time to reduce to zero, as indicated by the waveforms indicated at 26a, 26b etc.

Thus because of the mechanical performance of the valve 13, but more particularly because the square waveform of the switched voltage control signal 15 is distorted by the inherent inductance L of the coil 12 and the temperature of the windings of the coil 12, there will be a characteristic delay in the current response of the actuator 12 to the control signal 15, and accordingly the actuator 12 will impose a characteristic distortion on the control of the system 1.

Again by modelling the actuator 12 in the modelling device 30 the modelling device 30 may provide a modelled control signal 35 which compensates for the actuator 12 characteristic.

The modelling device 30 may include an algorithm by means of which the natures of the induced current waveforms 25a etc. and 26a, etc. may be modelled for any given control signal 15, i.e. for a control signal 15 with any mark-space ratio as determined by the processor 21. Because the inductance L of the windings of the coil 12 will affect the induced waveforms differently in response to positive 15a etc. and negative 17a etc. steps, preferably the modelling device 30 is programmed with at least two different algorithms by means of which the waveforms 25a etc. and 26a etc. may independently be modelled.

Typically the modelling device 30 will model the actuator coil 12 and produce a modelled control signal 35 with an absolute and constant current; the comparator 31 compares this absolute current valve I_m at any instant with an average current I_c of the applied control signal 15 over a period of time.

In each of the embodiments described, the modelling device 30 may be programmed with other system information relevant to the manner the actuator 12 responds to and thus affects the current of the applied control signal 15 which is applied, so that the actual response of the system 1 to actuator 12 operation in accordance with any given demand signal 19 may be modelled.

By virtue of the invention, the actuator 12 will be operated to change the system 1 variable, i.e. fluid pressure/flow, more closely to achieve the demanded pressure or flow both in terms of speed of response, but also accuracy. Hence by virtue of the invention, the control apparatus 10 is more able to cope with small discrepancies between actual and demanded system variables than systems which are solely current reactive, particularly as actuator environmental conditions, such as temperature, change.

It will be appreciated that the control apparatus 10 described requires a generally constant supply 11 voltage, but particularly where the invention is applied to a vehicle or machine system, a constant and steady voltage cannot always be guaranteed, particularly where the supply is generated by e.g. an engine driven generator. For example where the system 1 is powered by a battery, e.g. in a vehicle or mobile machine, the voltage produced by the battery may vary as other electrical services of the vehicle or machine or switched on and off.

If desired, the system 1 may include a voltage determination device 40 which may provide an input 41 to the processor 21 which may thus vary the control of the supply 11 voltage appropriately in generating the control signal 15. Also if desired, particularly where the control signal 15 is a switched voltage signal as indicated in figure 2, such information may continuously or intermittently be provided to the modelling device 30 which may update the model according to such sensed condition changing. Thus the modelling device 30 may more accurately model the effect of the actuator 12 on the current of the control signal 15.

Other inputs may be provided to the processor 21, for example an input along line 34 indicative of the speed of an engine which is driving e.g. a hydraulic pump which generates fluid pressure and flow in the system 1 to be controlled. Thus in the event that the engine is turning too slowly for a demanded fluid pressure and/or flow to be achieved in the fluid system, the control apparatus 10 may be arranged to respond either by not attempting to open the fluid valve 13, and/or to provide a warning to an operator, and/or to increase engine speed to a speed that is able to achieve a fluid pressure and/or flow in the system appropriate to the demand.

It will be appreciated that as the resistance of the windings of the actuator coil 12 changes in response to local environmental temperature changes in the windings of the actuator, the discrepancy between the modelled response on line 34, determined at a normalised temperature, and the actual response, may be used by the processor 21 to achieve a measure of the temperature in the windings of the actuator 12.

Referring again to figure 1, a stable and known resistance R is provided between the actuator 12 and a supply rail 38 to enable monitoring of the current I_c of the applied control signal 15.

Various modifications may be made without departing from the scope of the invention. For example, although the invention has specifically been described in relation to the control of a system 1, where an actuator 12 is of a fluid control valve 13, the invention may be applied in other situations where there is an actuator which has a characteristic which distorts system response to a given control signal. Thus such an actuator 12 need not have an inherent inductance L and resistance r, but may for example have an inherent capacitance and/or resistance which affects the response of the actuator 12 and hence of the system 1 in a characteristic way.

The control apparatus 10 described may be included within a management system e.g. an vehicle/machine/engine management system in which case the control apparatus 10 may include additional inputs relating to the performance of a system to be controlled, and such further information may be utilised by the modelling device 30 or other component(s) of the control apparatus 10, for the purpose of updating the model of the actuator 12, and/or by the processor 21 in order to provide or improve a control function.

The fluid valve 13 may be a valve in a hydraulic circuit which is operable to shift gears in a power shift gear box, in which case the control apparatus 10 described above may control the system to match fluid pressure according to demand.

Alternatively, the fluid valve 13 may be a valve in a hydraulic circuit which is operable for two or four wheel steering, in which case the control apparatus 10 described above may control the system to match fluid flow according to demand.

The features disclosed in the foregoing description, or the following claims, or the accompanying drawings, expressed in their specific forms or in terms of a means for performing the disclosed function, or a method or process for attaining the disclosed result, as appropriate, may, separately, or in any combination of such features, be utilised for realising the invention in diverse forms thereof.

CLAIMS

1. A method of controlling a system which includes an electrically operated actuator the operation of which is dependant upon the current applied, using a control apparatus which includes a controller which responds to a demand input signal which depends upon system demand by providing a demand signal which indicates a desired current to be applied to the actuator, processing the demand signal in a signal processor to control the voltage of a supply to produce a control signal which is calculated to have the desired current to operate the actuator to change a variable of the system to match system demand, the method including providing the demand signal simultaneously to a modelling device which is programmed to model the actuator and to produce a modelled control signal, comparing the currents of the actual control signal and the modelled control signal, and modifying the processing of the demand signal to change the actual control signal current to compensate for variations between the currents of the modelled control signal and the actual control signal.

2. A method according to claim 1 wherein the modelling device is programmed with information relating to at least one of an inherent resistance, inductance or capacitance and actuator mechanical response.

3. A method according to claim1 or claim 2 wherein the voltage of the supply is controlled to change the current of the applied control signal, by varying the level of the applied voltage.

4. A method according to claim 1 or claim 2 wherein the applied control signal is a switched voltage waveform, and the voltage of the supply is controlled to change the current of the applied control signal, by varying the

mark-space ratio of the waveform to vary the average current of the control signal over a predetermined time period.

5. A method according to claim 4 wherein the demand signal indicates an absolute current level to achieve a desired actuator response, and the comparitor compares the absolute current level with the average current of the waveform over a predetermined time period.

6. A method according to claim 4 or claim 5 wherein the applied waveform control signal is a square waveform, and the modelling device is programmed to model the effect of the actuator on both positive and negative step changes in the applied waveform control signal.

7. A method according to any one of the preceding claims wherein the actuator is an actuator of a fluid valve in which the pressure or flow of fluid in or through the valve is dependent upon the current applied to actuator windings of the valve, and movement of a valve member in response to the electrical current is in opposition to a resilient biasing means.

8. A method according to claim 7 wherein the valve is included in a hydraulic circuit operable to shift gears in a power shift gear box or to achieve steering of a vehicle.

9. A method of controlling a system substantially as hereinbefore described with reference to the accompanying drawings.

10. A system which includes an electrically operated actuator the operation of which is dependant upon the current applied, and a control apparatus, the control apparatus including a controller which responds to a demand input signal which depends upon system demand by providing a demand signal

which indicates a desired current to be applied to the actuator, a demand signal processor for processing the demand signal to control the voltage of a supply to produce a control signal which is calculated to have the desired current to operate the actuator to change a variable of the system to match system demand, the system further including a modelling device to which the demand signal is fed simultaneously with the demand signal being fed to the signal processor, the modelling device being programmed to model the actuator and to produce a modelled control signal, the control apparatus further including a comparitor for comparing the currents of the actual control signal and the modelled control signal, and to provide a correction signal to the signal processor to modify the processing of the demand signal to change the actual control signal current to compensate for variations between the currents of the modelled control signal and the actual control signal.

11. A system including a control apparatus substantially as hereinbefore described with reference to and as shown in the accompanying drawings.

12. A method of programming a modelling device of the apparatus of claim 10 or claim 11 wherein the method includes for predetermined actuator conditions, applying to the actuator a control signal, adjusting the control signal until the actuator responds so that a predetermined system demand is satisfied by the actuator operation, determining the current of the applied control signal, and correlating in the modelling device a relationship between the current of the demand signal and the current of the applied control signal for the actuator at the predetermined conditions, thus modelling the actuator response for the predetermined conditions.

13. A method according to claim 12 wherein the method is performed under laboratory or other closely controlled conditions.

14. A method of determining a measure of a parameter of the actuator environment which affects the actuator response to the control signal, including performing the method of the third aspect of the invention for different predetermined actuator conditions to create data relating a discrepancies between the demand signal current and the current of the applied control signal for different actuator environmental conditions, determining the magnitude of the discrepancy and comparing this with the data.

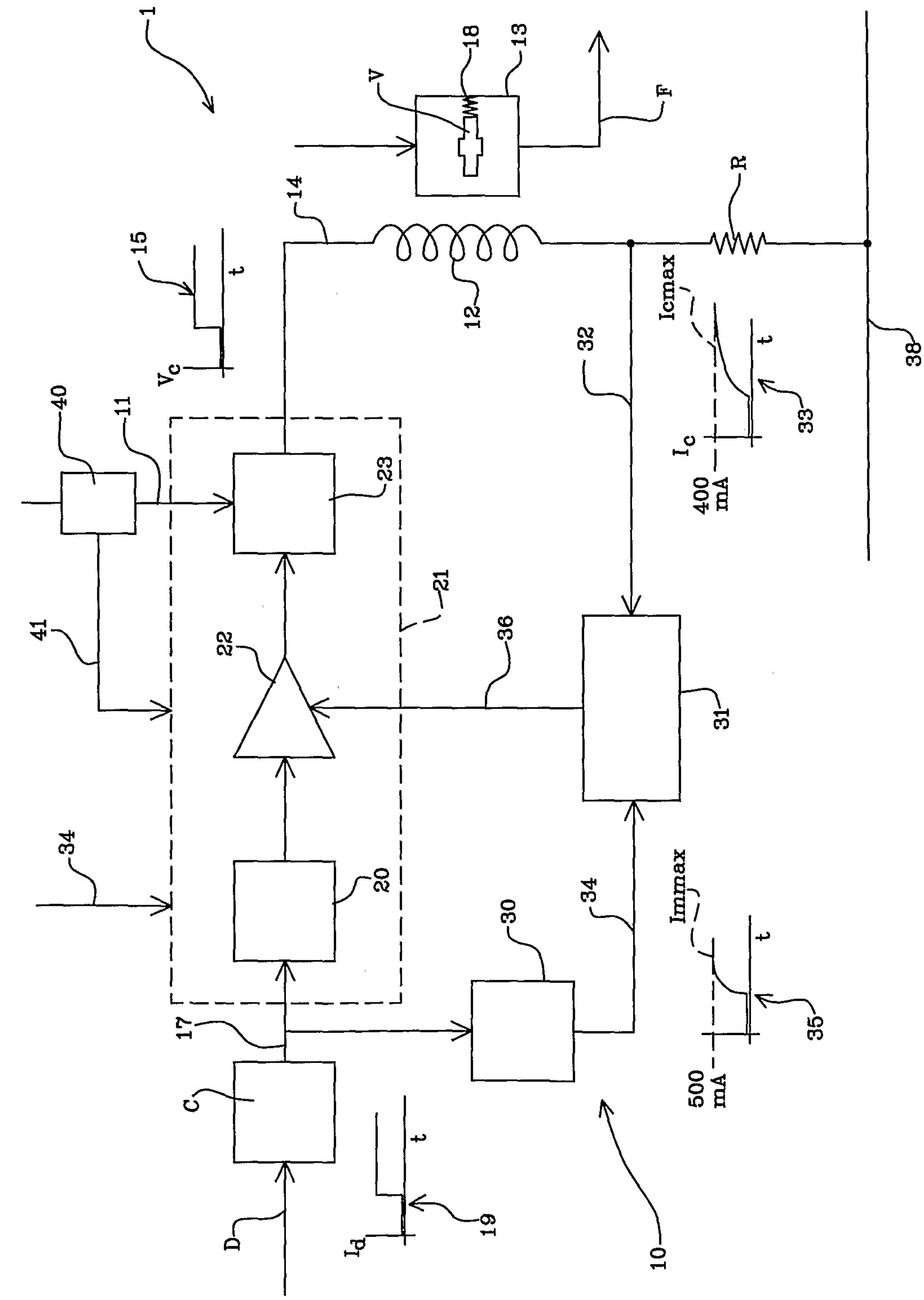
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FIG 1

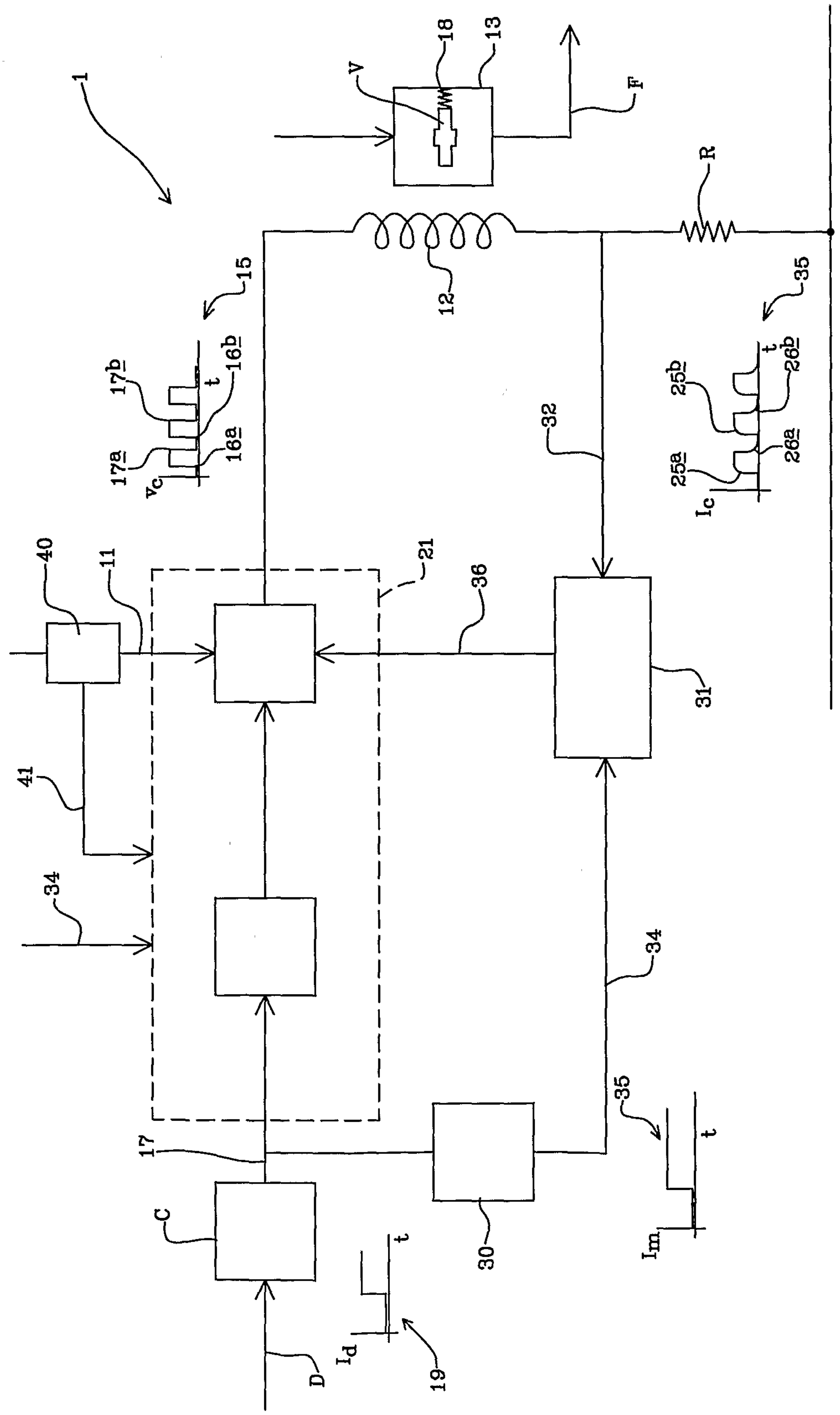
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FIG 2

INTERNATIONAL SEARCH REPORT

Ir ational Application No
PCT/GB 02/04117

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G05B13/04

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G05B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 473 914 A (BOSCH GMBH ROBERT) 11 March 1992 (1992-03-11)	1,2,6,9
Y	column 2, line 19 -column 4, line 43; figure 1A	4,7,11
X	FR 2 694 849 A (SAMSUNG ELECTRONICS CO LTD) 18 February 1994 (1994-02-18)	1,2,9
A	page 2, line 29 -page 4, line 2 page 12, line 14 -page 14, line 17; figure 2	11
X	US 4 663 703 A (AXELBY GEORGE S ET AL) 5 May 1987 (1987-05-05) column 3, line 62 -column 5, line 2; figures 1,2	1,2,9
	-/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
2 December 2002	07/01/2003

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Gardella, S

Form PCT/ISA/210 (second sheet) (July 1992)

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
Y	EP 0 762 019 A (AISIN AW CO) 12 March 1997 (1997-03-12) page 3, line 20 -page 4, line 3; figures 1,2	4,7
Y	US 5 844 743 A (FUNCHES OTIS L) 1 December 1998 (1998-12-01) column 6, line 38 -column 7, line 56; figure 4	11
A	H. UNBEHAUEN: "Regelungstechnik III - Identification, Adaption, Optimierung" , VIEWEG VERLAG , 1993 (4. DURCHGESEHENE AUFLAGE) XP002223145 page 57 -page 62 page 105 -page 114	9,11

INTERNATIONAL SEARCH REPORT

International application No.
PCT/GB 02/04117

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☒ Claims Nos.: 8,10,12-14
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:
see FURTHER INFORMATION sheet PCT/ISA/210

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

Continuation of Box I.2

Claims Nos.: 8,10,12-14

The scope of claims 8, 10, 12-14 is unclear, the reasons being the following (Article 6 and Rules 6.2(a) and 6.3(a) PCT).

Claims 8 and 10 merely refer to the drawings and to the description in general terms, without including any technical feature.

Claim 12 is missing, whereas claim 13, which is dependent on claim 12, is obscure as its scope is accordingly not defined.

Claim 14 appears to refer to the description without defining the actual method steps so that it is not possible to ascertain the real scope of the claim.

The applicant's attention is drawn to the fact that claims, or parts of claims, relating to inventions in respect of which no international search report has been established need not be the subject of an international preliminary examination (Rule 66.1(e) PCT). The applicant is advised that the EPO policy when acting as an International Preliminary Examining Authority is normally not to carry out a preliminary examination on matter which has not been searched. This is the case irrespective of whether or not the claims are amended following receipt of the search report or during any Chapter II procedure.

Information on patent family members

Il ational Application No
PCT/GB 02/04117

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
EP 0473914	A	11-03-1992	DE	4025847	A1	20-02-1992
			DE	59105842	D1	03-08-1995
			EP	0473914	A2	11-03-1992
			JP	4234546	A	24-08-1992
			US	5178111	A	12-01-1993
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			CN	1093507	A ,B	12-10-1994
			FR	2694849	A1	18-02-1994
			JP	6197583	A	15-07-1994
			US	5446360	A	29-08-1995
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EP 0762019	A	12-03-1997	JP	2854542	B2	03-02-1999
			JP	9080107	A	28-03-1997
			DE	69620694	D1	23-05-2002
			DE	69620694	T2	22-08-2002
			EP	0762019	A1	12-03-1997
			US	5773981	A	30-06-1998
US 5844743	A	01-12-1998	NONE			