

POSITION CONTROL SYSTEM AND
POSITION CONTROL METHOD THEREOF

FIELD OF THE INVENTION

5 This invention relates to position control systems and position control method thereof for various motor drives such as servo controllers, spindle controllers and position controller of numerical control machines.

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BACKGROUND OF THE INVENTION

Fig. 13 is a block diagram showing the flow of a servo system control signal in a conventional position control system by using transfer functions. Referring to the Figure, designated at 1 is a position loop gain operational unit having a gain K_p , at 2 a speed loop proportional integral compensation unit, at 3 an inertia unit, and at 4 an integrator. In Fig. 13, a position feedback signal is subtracted from a position command at point A, and the difference is amplified in the position loop gain operational unit 1, which has a transfer function k_p and outputs a speed command. From the speed command, a speed feedback signal is subtracted at point B, and the difference is amplified in the speed loop proportional integral compensation unit 2, which has a transfer function $K_v + K_i/s$ and outputs a torque command. The torque command represents the motor speed corresponding to the

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inertia component, less a reduction corresponding to a load torque, as seen at point C. The speed is negatively fed back from point D as the speed feedback signal as noted above. The position value, which is
5 the time integral of the speed, is taken out at point E from the integrator 4, which has a transfer function $1/S$ and generates the position feedback signal.

When a machine is actually operated in the above system, the operation of the machine is
10 equivalently approximated by the position loop response as shown in Figs. 14A, 14B because the position loop response is sufficiently high compared to the speed loop response. The characteristic of the position loop shown in Fig. 14A is given as a transfer function $G(S)$

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$$G(S) = \frac{1}{1 + \frac{1}{k_p} S} \quad \dots (1)$$

20 Next a description is made for Fig. 14B. When a positional command for moving to a specified position at a timing to (migration length S) is given, actual movement of a machine (motor) follows with a follow-up delay of the positional loop (by the
25 positional loop time constant). A speed command for the position at this point of time is inputted as shown in the figure, and this area provides the specified position (time x speed). When the input as described

above is provided, a rotation of the motor is executed with a time-lag of the first order, as shown in the figure. Also, the motor generates a steep torque when acceleration is started and when deceleration is started.

In the above position control system, the position loop has a first degree delay time constant and follows the command. Thus, with a real circle drawn with two axes (X and Y axes), as shown in Fig. 15, the orbit of the actual motor draws a circle on the inner side of the real circle in accordance with the first degree delay time constant. The radius reduction ΔR in this case is given as

$$\Delta R = \frac{1}{2} \times \frac{F^2}{R} \times \left(\frac{1}{kp^2} \right) \quad \dots (2)$$

Here, R is the radius of the circle, and F is the speed in the tangential direction. Conventionally, feed forward control as shown in Fig. 16 is used to compensate for the radius error ΔR which is generated due to the delay. By using this feed forward control, the radius reduction ΔR is compensated for to

$$\Delta R = \frac{1}{2} \times \frac{F^2}{R} \times \frac{(1-\alpha^2)}{kp^2} \quad \dots (3)$$

By canceling the first degree delay having

the first degree differential with the feed forward controller 7, and with the feed forward coefficient α set to 1, a motor orbit free from delay with respect to the command can be obtained.

5 Here, k_p is a position loop gain, $1/k_p$ is a time constant of the position loop, and S is a Laplace operator.

 As other reference technical literature pertaining to the invention, there is "Acceleration and
10 Deceleration Control System" disclosed in Japanese Patent Laid-Open No. 209812/85.

 In the above feed forward control, however, the command is differentiated before being added. Therefore, command operation error is also
15 differentiated, resulting in a waveform having many oscillating components. Consequently, by setting $\alpha = 1$, machine vibrations are liable to be induced. Therefore, it is difficult to provide total compensation of for ΔR by using α above.
20 Consequently, a smooth response waveform can not be obtained, resulting in vibrations of the machine.

 Further, although the feed forward control is effective so far as the property of following commands, it has no suppression effect on external disturbances
25 to the position feedback system. To enhance the suppression effect on external disturbances to the position feedback system, it is necessary to provide a high position loop gain k_p . Doing so, however, leads

to increased motor speed changes as in the torque waveform shown in Fig. 14B. Consequently, increased shocks are given to the machine, and also the tendency of picking up high frequency components (such as resonance of the machine system and noise) is increased. For the above reasons, stable gain increase can not be obtained.

Figs. 17A and 17B show graphs for a comparison between the gain increase provided by a first order system and that provided by the high-order system according to the present invention. In gain increase with a conventional type of first order system, when a band required for control is raised, the system becomes like that shown with a dotted line in Fig. 17A. Also, a disturbance component becomes adapted to gain increase, so it comes to vibrate more easily. Namely, in a conventional type of first-order lag system, a band is attenuated by -20 dB. For this reason, when the gain is increased, a higher band width is required. However, the gain of the high frequency component also becomes higher, and the system is disadvantageously affected by a high-frequency noise more easily.

25 SUMMARY OF THE INVENTION

It is an object of a position control system and position control method thereof, in which the internal control loop gain is set to an adequate value

in order to provide a high response, a stable control loop and a smooth response waveform, as well as to prevent vibrations of the machine.

According to the invention, there is provided
5 a position control system for feeding back position information detected by position detection means for detecting the position of a machine movable part, the position control system including a second order system position control loop formed by providing an internal
10 second control loop.

According to the invention, there is also provided a position control system for feeding back position information detected by position detection means for detecting the position of a machine movable
15 part, the position control system including a third control loop formed by providing an internal second and an internal third control loop.

According to the invention, a second control loop or a second and a third control loop are provided
20 in the position control loop. Thus, the degree of the position control loop is elevated, and the gains of the second and third control loops are set to minimum values free from overshoot with respect to the position loop gain.

25 As has been described in the foregoing, with the position control system according to the invention it is possible to obtain high response and stable position loop characteristic free from the influence of



high frequency components. It is thus possible to obtain smooth acceleration and deceleration waveforms as the response waveform of the motor, and thus stable and shock-free control of the machine can be realized.

5 Thus, for the conventional position loop gain K_p , it is possible to obtain higher position loop gain and realize gain increases in the servo loop control.

Other objects and features of this invention will become understood from the following description
10 with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram showing a construction of the position control system according
15 to the invention;

Fig. 2 is a flowchart showing an operation of the position control system shown in Fig. 1;

Fig. 3 is a block diagram showing a different construction of the position control system according
20 to the invention;

Fig. 4 is a flowchart showing an operation of the position control system shown in Fig. 3;

Fig. 5 is a block diagram showing a further construction of the position control system according
25 to the invention;

Fig. 6 is a block diagram showing a still further construction of the position control system according to the invention;

Fig. 7 is a block diagram showing a yet further construction of the position control system according to the invention;

Fig. 8 is a block diagram showing a yet
5 another construction of the position control system according to the invention;

Figs. 9A and 9B are block diagrams showing a further construction of the position control system according to the invention;

10 Fig. 10 is a block diagram showing a further construction of the position control system according to the invention;

Fig. 11 is a graph showing the relation between the speed and step response waveform in first
15 to third order system position control systems;

Figs. 12A and 12B are graphs showing a motor speed waveform when smoothing input is set to "0" time constant state;

Fig. 13 is a block diagram showing a
20 construction of the conventional position control system;

Figs. 14A and 14B are views for explaining a position loop characteristic of the conventional position control system;

25 Fig. 15 is a view for explaining the motor orbit in the conventional position control system;

Fig. 16 is a block diagram showing conventional feed forward control;

Fig. 17A is a graph comparing the conventional first order system gain increase and high harmonic system gain increase; and

Fig. 17B is a graph comparing the first degree system gain increase and high harmonic system gain increase according to the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Now, a first embodiment of the invention will be described. Fig. 1 shows a position control system having an internal second control loop. Referring to the Figure, designated at 1 is a position loop gain operational unit (kp), and at 1a is a second control loop gain operational unit (kp1). A position feedback loop is formed at 10, providing position information from the controlled object to a summing node A. And speed loop is formed at 11, providing speed information to a summing node B. Integration 4 are caused to generate speed and position feedback values. With the provision of the internal second control loop in unit 1a, the transfer function G (S) is given as

$$G(S) = \frac{k_p \cdot k_{p1}}{S^2 + k_{p1}S + k_p \cdot k_{p1}} \quad \dots (4)$$

and has a second order system position loop characteristic.

Also, the loop is characterized by a dangling coefficient ζ and a speed ω_n , where

$$G(S) \quad \zeta = \sqrt{\frac{k_{p1}}{4k_p}}, \quad \omega_n = \sqrt{k_p \cdot k_{p1}} \quad (5)$$

To obtain a characteristic free from overshoot, it is necessary that $\zeta \geq 1$. To obtain a threshold $\zeta = 1$ free from overshoot, we may set

$$k_{p1} = 4k_p \quad \dots (5)$$

By substituting equation 5 into equation 4 we have a second degree position loop characteristic given as

$$G(S) = \frac{4k_p^2}{S^2 + 4k_p S + 4k_p^2} = \frac{1}{(1 + \frac{1}{2k_p} S)^2} \quad \dots (6)$$

In this case, the radius reduction ΔR is given as

$$\begin{aligned} \Delta R &= \frac{1}{2} \cdot \frac{F^2}{R} \times \left(\frac{1}{4k_p^2} + \frac{1}{4k_p^2} \right) \quad \dots (7) \\ &= \frac{1}{2} \times \frac{F^2}{R} \times \frac{1}{2k_p^2} \end{aligned}$$

Thus, the first degree position loop radius reduction may be one half the value in the conventional

art. Further, with respect to the feed forward effect, it is possible to obtain a 70 % ($\alpha = 0.7$) feed forward effect.

Next description is made of the loop operations. Fig. 2 is a flow chart illustrating operations of the position control system shown in Fig. 1. At first, a difference between a position feedback (D) and a position command is computed (S201), a position loop gain k_p is multiplied with the difference, and a given speed command (B) is outputted (S202). Then, a difference between the given speed command (B) and a given speed feedback (C) is computed (S203), and a gain k_{p1} is multiplied with the difference to output an acceleration component as a command (S204). Furthermore the given speed feedback component (C) is outputted by integrating the given acceleration component ($1/S$) (S205), and also said given speed feedback component (C) is integrated ($1/S$) to output a given position feedback component (S206).

Now, a second embodiment of the invention will be described. Fig. 3 shows a position control system having a second and a third internal control loop. Designated at 1 is a position loop gain operational unit (k_p), at 1a a second control loop gain operational unit (k_{p1}), at 1b a third control loop gain operational unit (k_{p2}), at 10 is a first control loop, at 11 is a second control loop, and at 12 is a third control loop.

With the position control system shown in Fig. 3, having the second and third internal position loops 11, 12, the transfer function $G(S)$ has a third order system position loop characteristic given as

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$$G(S) = \frac{k_p \cdot k_{p1} \cdot k_{p2}}{S^3 + k_{p2}S^2 + k_{p1}k_{p2}S + k_p \cdot k_{p1} \cdot k_{p2}} \dots (8)$$

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The third order system is generally given as

$$G_2(S) = \frac{P_r \cdot \omega_n^2}{(S + P_r)(S^2 + 2\zeta\omega_n S + \omega_n^2)} \dots (9)$$

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where P_r is first degree root.

In order that this third order system is free from overshoot, it is necessary that P_r is small with respect to the real number part of the conjugate complex root of $S^2 + 2\zeta\omega_n S + \omega_n^2$. Hence, it is necessary to meet a relation

25

$$P_r \leq \zeta\omega_n \dots (10)$$

The threshold value of the freedom from overshoot is

$$P r = \zeta \omega n \quad \dots (11)$$

By substituting equation 11 into equation 9,

5 we have

$$G_2 (S) = \frac{\zeta \omega n^3}{S^3 + 3 \zeta \omega n S^2 + (2 \zeta^2 + 1) \omega n^2 S + \zeta \omega n^3} \quad \dots (12)$$

From equations 9 and 12 we have

10

$$\begin{aligned} k p \cdot k p 1 \cdot k p 2 &= \zeta \omega n^3 \\ k p 1 \cdot k p 2 &= (2 \zeta^2 + 1) \omega n^2 \quad \dots (13) \\ k p 2 &= 3 \zeta \omega n \end{aligned}$$

By eliminating ζ and ωn in equation 13,

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$$2 k p 2^2 - 9 k p 1 k p 2 + 27 k p \cdot k p 1 = 0 \quad \dots (14)$$

A third order system free from overshoot can be obtained by giving $k p 1$ and $K p 2$ satisfying equation

20 14.

The conditions that $k p 2$ has the real root are

$$D = 81 k p 1^2 - 216 k p k p 1 \geq 0 \quad (k p 1, k p > 0) \quad \dots (15)$$

25 and

$$k p 1 \geq \frac{8}{3} k p \quad \dots (16)$$

For the minimum real root of $k p 2$,

$$k p 1 = \frac{8}{3} k p$$

In this case, kp_2 is a multiple root, as a result, $kp_2 = 6kp$. By giving kp_1 ($8/3 kp$) and kp_2 , the above equation 8 reduces to an equation

5
$$G(S) = \frac{16kp^3}{(S+2kp)(S^2+4kpS+8kp^2)} \dots (17)$$

In this case, the radius reduction ΔR is given as

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$$\begin{aligned} \Delta R &= \frac{1}{2} \times \frac{F^2}{R} \times \left(\frac{1}{4kp^2} + \frac{1}{\alpha^2} + \frac{1}{\beta^2} \right) \\ &= \frac{1}{2} \times \frac{F^2}{R} \times \frac{1}{4kp^2} \dots (18) \end{aligned}$$

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where α and β are second degree roots.

From equation 18, it will be seen that the radius reduction may be made to be up to $1/4$ of the
20 conventional first degree radius reduction. That is, it is possible to obtain an effect with double the position loop gain kp and also obtain a feed forward effect of 87 % ($\alpha = 0.87$).

Next description is made for operation of the
25 position control apparatus according to the present invention. Fig. 4 is a flow chart illustrating operations of the position control system shown in Fig. 3. At first a difference between the position feedback

(F) and the position command (A) is computed (S401), then the difference is multiplied with the position loop gain k_p , and a command for the second control loop (a given speed command component:B) is outputted 5 (S402). Then, a difference between the given speed command component (B) and the differentiated component (a given speed feedback component:E) is multiplied with the second loop gain k_{p1} to output a command (C) for the third control loop (S403), and a difference between 10 the third control loop command (C) and a two-times differentiated component of the position feedback (a given acceleration feedback component:D) is multiplied with the third control loop gain k_{p2} , and the product is integrated to output a given acceleration feedback 15 component (D) (S404).

Figs. 5 to 10 show further embodiments of the invention. The structure shown in Fig. 5 permits an internal process loop to be obtained when forming a second degree harmonic system by forming an internal 20 second control loop before the speed loop. The external loop is constructed by using data of the external position detector (position feedback from the machine end in the closed specifications). Thus, the inner second control loop 11 has high response compared 25 to the first control loop 10 but permits stable operation to be obtained. Designated at 5 is the speed loop.

In the structure of Fig. 6, the feedback data

of the internal second control loop is formed by using data of the external position detector. Thus, both the first (10) and second (11) control loops are stable. However, taking one-pulse response characteristic, with
5 the input of a one-pulse command the motor can be driven by a command of one pulse $\times k_p \times k_{p1}$ as the speed command in the non-operation state of the machine.

The structure shown in Fig. 7 is a third
10 order system version of the structure shown in Fig. 5. It has the features of high response and high attenuation of high frequencies. The structure of Fig. 8 is a third order system version of the structure shown in Fig. 6. It permits improvement of more
15 forward gain (one pulse $\times k_p \times k_{p1} \times k_{p2}$).

With the structure shown in Fig. 9A, the structure of the first order system is as shown in Fig. 9B. Therefore, the control loop can only provide a component obtained by multiplying the difference
20 between the position command and the position feedback by k_p as the speed command. However, a second order system structure can automatically produce not only the speed component with respect to the command but also a torque component. Thus, for a command of the torque
25 loop, for which the response is most important, a torque command may be produced through correction in advance not only in response to a torque command produced through proportional integral control of the

speed difference but also according to torque information estimated from the speed feedback, that is, by obtaining the error between the command and the torque. Thus, it is possible to obtain more robust speed loop characteristics. In Fig. 9A, 6 is a differentiator.

The structure shown in Fig. 10 is a corrected loop a command torque component using the same third order system as that shown in Fig. 9A.

10 As has been shown, with the above embodiments high response and stable control loops can be obtained by elevating the degree of the position control loop to the second, third and so forth and setting the internal control loop gain to an adequate value. Thus, in the position step response, by elevating the degree of the position control loop, the response waveform can be made smoother, as shown in Fig. 11, thus precluding vibrations of the machine.

20 Figs. 12A and 12B show motor speed waveforms with the smoothing input (of accelerating and decelerating circuit) to the "0" time constant state. As shown, the first and third degree systems have different response characteristics. While the above embodiments concerned up to the third order systems, it is also possible to construct higher degree systems than the third.

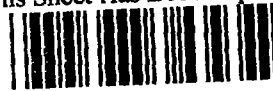
25 By introducing a high order system as described above, a band (responsibility) required for

control is raised as shown in Fig. 17B, while a high-frequency wave component, which is to become a disturbance component, is greatly attenuated. In other words, in a high-order system, a band is attenuated by
5 40 dB in a second order system and by 60 dB in a third order system, and an attenuation factor for a gain of high-frequency wave component is high even if the gain is raised. For this reason, it is possible to realize a stable system which is hardly affected by a high-
10 frequency noise.

Although the invention has been described with respect to a specific embodiment for a complete and clear disclosure, the appended claims are not to be thus limited but are to be construed as embodying all
15 modifications and alternative constructions that may occur to one skilled in the art which fairly fall within the basic teaching herein set forth.

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What is claimed is:

1. A position control system for feeding back position information detected by position detection means for detecting the position of a movable part,
5 said position control system having first and second control loops for forming a position control loop to second order system by providing an internal second control loop.

10 2. A position control system according to claim 1, wherein a transfer function of said second order system position control loop characteristic is:

$$G(S) = \frac{1}{\left(1 + \frac{1}{2kp}S\right)^2}$$

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where S = a Laplace operator

kp = first order loop gain

and the second order loop gain kpl is set to be equal to 4kp.

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3. A position control system for feeding back position information detected by position detection means for detecting the position of a movable part, said position control system having first, second and
25 third control loops for forming a position control loop to third order system by providing an internal second control loop and an internal third control loop.



4. A position control system according to claim 3, wherein a transfer function of said third order system position control loop characteristic is:

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$$G(S) = \frac{16kp^3}{(S+2kp)(S^2+4kpS+8kp^2)}$$

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where S is a Laplace transform operator, and the value of kp1 is set to be substantially equal to 8/3 kp and the value of kp2 is set to be substantially equal to 6kp.

5. A position control system according to claim 4 wherein said second high order gain loop comprises a speed loop.

6. A position control method for servo controlling a movable object in response to input position command, wherein said control is via a system having a system transfer function, comprising:

computing a difference between a position feedback and a position command;

generating a speed component by multiplying a said difference with a position loop gain;

25 computing a difference between said speed command a speed feedback;

generating an acceleration component by multiplying an internal high order loop gain with said





difference;

generating a speed feedback component by
integrating said acceleration component; and

generating a position feedback component by
5 integrating said speed feedback component.

7. The position control method as set forth in
claim 6, wherein said transfer function is for a second
order system and said internal high order loop gain is
10 kp_1 .

8. The position control method as set forth in
claim 7, wherein said system transfer function $G(S)$ is
defined as

15
$$G(S) = \frac{1}{\left(1 + \frac{1}{2kp} S\right)^2}$$

where S = a Laplace operator

kp = first order loop gain

20 and the second order loop gain kp_1 is set to
be equal to $4kp$.

9. A position control method comprising:
a first step to compute a difference between
25 a position feedback and a position command;

a second step to output a command for a
second control loop (speed command component) by
multiplying said difference with a position loop gain;





a third step to output a command for a third control loop by multiplying a difference between said speed command component and a difference between said speed command component and a differentiated component of said position feedback (speed feedback component) with a second control loop gain; and

a fourth step to output an acceleration feedback component by multiplying a difference between said third control loop command and a two timed differentiated component of said position feedback (acceleration feedback component) with a third control loop gain, and by integrating said product by said multiplying.

10. A position control system for servo controlling a moveable object in response to input commands, wherein said system is defined by a system transfer function, comprising:

means for detecting a position of said moveable object and for generating a position signal;

a first summing junction for arithmetically processing at least a first signal and a second signal, said first signal comprising said input commands and said second signal comprising said position signal, and generating a first difference signal;

means for feeding back said position signal to said first summing junction and defining a first





control loop;

position loop gain means for processing said difference signal and generating a speed command signal, said position loop gain means having a gain k_p ;

5 a second summing junction for arithmetically processing at least a first signal and a second signal, said first signal comprising said speed command signal, and outputting a second difference signal;

10 a high order internal control loop means connected to receive said second difference signal and comprising a control loop gain means;

whereby, said system transfer function has a high order position loop characteristic.

15 11. A position control system according to claim 10, wherein said transfer function is for a second order system and said gain loop means comprises a high order gain loop having a gain k_{p1} .

20 12. A position control system according to claim 11, wherein said system transfer function $G(S)$ is defined as

$$G(S) = \frac{1}{\left(1 + \frac{1}{2k_p} S\right)^2}$$

25

where S is a Laplace transform operator, and the value of k_{p1} is set to be substantially equal to $4k_p$.





13. A position control system according to claim 10, wherein said transfer function is for a third order system and said gain loop means comprises a first high order gain loop having a gain kp_1 and a second high order gain loop having a gain kp_2 .

14. A position control system according to claim 13, wherein said system transfer function $G(S)$ is defined as

$$G(S) = \frac{16kp^3}{(S+2kp)(S^2+4kpS+8kp^2)}$$

where S is a Laplace transform operator, and the value of kp_1 is set to be substantially equal to $8/3 kp$ and the value of kp_2 is set to be substantially equal to $6kp$.

15. A position control method for servo controlling a movable object in response to input position commands, wherein said control is via a servo system having a system transfer function, comprising:

computing a difference between a position feedback and a position command;

generating a speed component by multiplying a said difference with a position loop gain;

computing a difference between said speed command a speed feedback;



generating an acceleration component by multiplying an internal high order loop gain with said difference;

generating a speed feedback component by
5 integrating said acceleration component; and

generating a position feedback component by integrating said speed feedback component.

16. The position control method as set forth in
10 claim 15, wherein said transfer function is for a second order system and said internal high order loop gain is k_{p1} .

17. The position control method as set forth in
15 claim 16, wherein said system transfer function $G(S)$ is defined as

$$G(S) = \frac{1}{\left(1 + \frac{1}{2k_p} S\right)^2}$$

where S = a Laplace operator

20 k_p = first order loop gain

and the second order loop gain k_{p1} is set to be equal to $4k_p$.

18. A position control method comprising:
25 a first step to compute a difference between a position feedback and a position command;
a second step to output a command for a second control loop (speed command component) by





multiplying said difference with a position loop gain;

a third step to output a command for a third control loop by multiplying a difference between said speed command component and a difference between said speed command component and a differentiated component of said position feedback (speed feedback component) with a second control loop gain; and

a fourth step to output an acceleration feedback component by multiplying a difference between said third control loop command and a two timed differentiated component of said position feedback (acceleration feedback component) with a third control loop gain, and by integrating said product by said multiplying.

19. A position control method according to claim 18 wherein said transfer function is for a third order system and said gain loop means comprises a first high order gain loop having a gain kp_1 and a second high order gain loop having a gain kp_2 .

20. A position control method according to claim 19, wherein said system transfer function $G(S)$ is defined as

$$G(S) = \frac{16kp^3}{(S+2kp)(S^2+4kpS+8kp^2)}$$

where S is a Laplace transform operator, and





the value of k_{p1} is set to be substantially equal to $8/3 k_p$ and the value of k_{p2} is set to be substantially equal to $6k_p$.

5 21. A position control system according to claim 13 wherein said second high order gain loop comprises a speed loop.

10 22. A position control system according to claim 13, wherein said position control system comprises a speed loop and said second high order gain loop is formed prior to said speed loop.

15 23. A position control system according to claim 13 wherein said second high order gain loop is responsive to said position detector.

20 24. A position control system, substantially as herein described with reference to figures 1 and 2, figures 3 and 4, or any of figures 5 to 10 of the accompanying drawings.

25 25. A method of position control, substantially as herein described with reference to figures 1 to 12 of the accompanying drawings.

