

## SPECIFICATION

## MOTOR SPEED CONTROL DEVICE

TECHNICAL FIELD

This invention relates to a motor speed control device.

BACKGROUND ART

Heretofore, for motor speed feedback control, a speed detector such as a tachometer generator is popularly employed. However, recently a system has been intensively employed in which a feedback speed signal is calculated from position data which is detected, for instance, with an encoder. In this speed feedback signal calculating method, the following formula is generally employed:  $v = \Delta y / T_s$  where  $\Delta y$  is an increment during a sampling period  $T_s$  of a position signal.

However, the method suffers from the following difficulties: The phase of the speed signal thus calculated lags the actual speed, and, accuracy in a range of low speeds is considerably deteriorated. The latter problem that the accuracy in a range of low speeds is considerably deteriorated, has been solved by obtaining a moving average of a plurality of past points. However, in this case, the phase lag is further increased. In the case where the sampling period is long, or the position detection is delayed, the phase lag is further increased. If the feedback control is carried out with the signal which lags in phase in the above-described manner, it is impossible to set the feedback gain to a high value, and

accordingly the response speed becomes low.

On the other hand, Japanese Patent Unexamined Publication No. Hei. 4-9767 has disclosed a method in which the speed at a calculation time instant is predicted and detected.

5 However, the method is disadvantageous in the following points:  
In the method, the operating characteristics of the motor, and the torque command are not taken into account; that is, the prediction is carried out only on the basis of the position data detected by an encoder or the like, and therefore the  
10 predicted value may be different from the actual value.

#### DISCLOSURE OF THE INVENTION

In view of the foregoing, an object of the invention is to provide a motor speed control device in which a speed is predicted from position data detected with an encoder or the  
15 like, the operating characteristics of a motor, and a torque command, and a weighted moving average thereof is calculated, so that the feedback signal is less deteriorated in accuracy when the motor is in a range of low speeds, and has no phase lag.

20 The foregoing object of the invention has been achieved by the provision of a motor speed control device in which, at the present time instant  $i$ , a motor position  $y(i-K)$  which was provided  $K \cdot T_s$  before (where  $K \geq 0$ , and  $T_s$  is the sampling period) is detected to provide a detection signal, and feedback control  
25 is carried out with a motor speed feedback signal  $V_{fb}$  which is calculated from the detection signal, which, according to the

invention, comprises:

means for calculating a torque command  $u(i)$  from a speed command and the motor feed back signal  $v_{fb}$ ;

5 means for calculating a speed  $v(i-K)$  from the position  $y(i-K)$ ;

means for storing the speed  $v(i-m)$  (where  $m=K, \dots, M'$ ) which occurs from a past  $M'$ -th sampling to a time instant  $i-K$ ;

10 a predictor for obtaining a speed prediction value  $v^*(i+m)$  (where  $m = -K+1, \dots, M$ ) at a future  $M$ -th sampling from a motor's dynamic characteristic model, the torque command  $u(i)$  and the position  $y(i-K)$ ; and

means for calculating the speed feedback signal from the following formula:

$$v_{fb}(i) = \sum_{m=-K+1}^M W_m v^*(i+m) + \sum_{m=K}^{M'} W'_m v(i-m)$$

15 With the above-described means, a speed feedback signal which is less deteriorated in accuracy, and has no phase lag is obtained. Hence, the feedback loop gain is high, and the speed control system is high in response frequency.

#### BRIEF DESCRIPTION OF THE DRAWINGS

20 FIG. 1 is a block diagram showing a specific embodiment of the invention;

FIG. 2 is an internal block diagram showing the arrangement of an example of a predictor of the invention;

FIG. 3 is an internal block diagram showing the

arrangement of another example of a predictor of the invention;

FIG. 4 is an internal block diagram showing the arrangement of an example of a control calculator of the invention; and

5           FIG. 5 is a block diagram showing another embodiment of the invention.

#### BEST MODE FOR CARRYING OUT THE INVENTION

10           First, an example of a motor speed control device, which constitutes a first embodiment of the invention, will be described.

          In FIG. 1, reference numeral 5 designates a control calculator which receives a speed command and a feedback signal  $v_{fb}$ , and outputs a torque command  $u$ ; and 6, a unit including a torque controller, a motor, and a position detector. The unit  
15           6 receives a torque instruction  $u(i)$  at the present time instant  $i$ , and outputs a motor position detection value  $y(i-K)$  which is obtained  $K \cdot T_s$  before ( $K \geq 0$ , and  $T_s$ : sampling period). Reference numeral 1 designates a predictor which obtains a speed prediction value  $v^*(i+m)$  (where  $m = -K+1, \dots, M$ ) at a  
20           future  $M$ -th sampling from a motor's dynamic characteristic model, torque command  $u$ , and a position  $y$ . Reference numeral 4 designates a calculator which calculates a speed  $v(i-K)$  from a position  $y(i-K)$  according to  $v(i-K) = \Delta y(i-K)/T_s$  ( $\Delta$  represents an increment value during a sampling period  $T_s$ ).  
25           Reference numeral 3 denotes a memory which stores a speed  $v(i-m)$  which is provided from a past  $M'$ -th sampling till a time

instant  $i-K$  (where  $m=K, \dots, M'$ ). Reference numeral 2 denotes a calculator which obtains a speed feedback signal  $v_{fb}$  according to the following Formula (1), and applies it to the control calculator 5.

$$5 \quad v_{fb}(i) = \sum_{m=-K+1}^M W_m v^*(i+m) + \sum_{m=K}^{M'} W'_m v(i-m) \quad (1)$$

With respect to weights  $W_m$  and  $W'_m$ , the average of speeds may be obtained on the basis of  $W_m=W'_m=1/(M+M'+1)$ , or they may be so set as to be one in total by weighting the respective speeds with different weights.  $M$  and  $M'$  function as follows: The difference  $M-M'$  adjusts the phase of the speed feedback signal, the sum  $M+M'$  adjusts the speed resolution, and with  $M \geq M'$ , a feedback signal has no phase lag.

Now, concrete examples of the predictor will be described with reference to FIGS. 2 and 3.

15 In FIG. 2, reference numeral 11 designates the predictor; 13, a memory for storing prediction coefficients  $A_{mn}$  and  $B_{mn}$ ; 14 and 15, memories for storing past torque command  $u$  and past position increment values  $\Delta y$  which occur until the present time instant, respectively, and 16, a differential unit which obtains a position increment value  $\Delta y$  from a position  $y$ .

20 Further in FIG. 2, reference numeral 12 designates a calculator, which calculates and outputs a speed prediction value  $v^*(i+m)$  according to the following Formulae (2a) and (2b):

$$25 \quad v^*(i+m) = \Delta y^*(i+m)/T_s \quad (2a)$$

$$\Delta y^*(i+m) = \sum_{n=K}^{Na+K-1} A_{mn} \Delta y(i-n) + \sum_{n=0}^{Nb+K-1} B_{mn} u(i-n)$$

$$m = -K+1, \dots, M \quad (2b)$$

In FIG. 3, reference numeral 21 designates the predictor; 23, a memory for storing prediction coefficients  $A_{mn}$  and  $B_{mn}$ ; 24 and 25, memories for storing past torque instruction increment values  $\Delta u$  and past position increment values  $\Delta y$  which occurs until the present time instant, respectively, and 26 and 27, differential units which obtain increment values.

Further in FIG. 3, reference numeral 22 designates a calculator, which calculates and outputs a speed prediction value  $v^*(i+m)$  according to the following Formulae (3a) and (3b):

$$v^*(i+m) = \Delta y^*(i+m)/T_s \quad (3a)$$

$$\Delta y^*(i+m) = \sum_{n=K}^{Na+K-1} A_{mn} \Delta y(i-n) + \sum_{n=0}^{Nb+K-1} B_{mn} \Delta u(i-n)$$

$$m = -K+1, \dots, M \quad (3b)$$

Now, the prediction coefficients in Formulae (2b) and (3b) will be described.

It is assumed that a transfer function model from a torque command  $u$  till a position increment value  $\Delta y$  is of a discrete-time system as follows:

$$Gv(z) = (b_1 z^{-1} + \dots + b_{Nb} z^{-Nb}) / (1 - a_1 z^{-1} - \dots - a_{Na} z^{-Na})$$

Then, its input/output model is as indicated in the following

Formula (4):

$$\Delta y(i) = \sum_{n=1}^{Na} a_n \Delta y(i-n) + \sum_{n=1}^{Nb} b_n u(i-n) \quad (4)$$

At the time instant  $i$ , the actually measured value  $\Delta y(i-n)$  ( $n \geq K$ ) of the position increment value which is provided until the time instant  $i-K$ , is obtained. Hence, prediction is made according to the following Formulae (5a) and (5b) by use of the measured position increment value:

$$\Delta y^*(i-K+1) = \sum_{n=1}^{Na} a_n \Delta y(i-K+1-n) + \sum_{n=1}^{Nb} b_n u(i-K+1-n) \quad m = -K+1 \quad (5a)$$

$$\Delta y^*(i+m) = \sum_{n=1}^{m+K-1} a_n \Delta y^*(i+m-n) + \sum_{n=m+K}^{Na} a_n \Delta y(i+m-n) + \sum_{n=1}^{Nb} b_n u(i+m-n) \quad (5b)$$

$$m > -K+1$$

As a result, the position increment value prediction value  $\Delta y^*(i+m)$  is represented by Formula (2b), and if it is assumed that a future torque command is  $u(j)=0$  ( $j>i$ ), then the prediction coefficients  $A_{mn}$  and  $B_{mn}$  are as follows:

$$A_{(-k+1)n} = a_{(n-K+1)} \quad m=-K+1, K \leq n \leq Na+K-1 \quad (6a)$$

$$A_{mn} = \sum_{j=1}^{m+K-1} a_j A_{(m-j)n} + a_{(n+m)} \quad m > -K+1, K \leq n \leq Na+K-1 \quad (6b)$$

$$B_{(-k+1)n} = b_{(n-K+1)} \quad m=-K+1, 0 \leq n \leq Nb+K-1 \quad (7a)$$

$$B_{mn} = \sum_{j=1}^{m+K-1} a_j B_{(m-j)n} + b_{(n+m)} \quad m > -K+1, 0 \leq n \leq Nb+K-1 \quad (7b)$$

Where,  $a_n=0$  ( $n>N_a$ ), and  $b_n=0$  ( $n<1$  and  $n>N_b$ ).

If  $u(j)=u(i)$  (where  $j>i$ ), then  $B_{mo}$  in Formula (7b) is as follows:

$$B_{mo} = 0 \quad -K+1 < m \leq 0$$

$$5 \quad B_{mo} = \sum_{j=1}^{m+K-1} a_j B_{(m-j)0} + \sum_{j=1}^m b_j \quad m \geq 1 \quad (7b')$$

In the case where a transfer function model from a torque command increment value  $\Delta u$  to a position increment value  $\Delta y$  is  $Gp(z)=(b_1 z^{-1} + \dots + b_{N_b} z^{-N_b})/(1 - a_1 z^{-1} - \dots - a_{N_a} z^{-N_a})$ , then its input and output model is represented by the following Formula (8):

$$10 \quad \Delta \hat{y}(i) = \sum_{n=1}^{N_a} a_n \Delta \hat{y}(i-n) + \sum_{n=1}^{N_b} b_n \Delta u(i-n) \quad (8)$$

Formula (3b) is obtained by predicting a position increment value similarly as in the case of Formula (5). And if a future torque command increment value is  $\Delta u(j)=0$  (where  $j>i$ ), then prediction coefficients  $A_{mn}$  and  $B_{mn}$  are as follows:

$$A_{(-k+1)n} = a_{(n-K+1)} \quad m=-K+1, K \leq n \leq N_a+K-1 \quad (9a)$$

$$A_{mn} = \sum_{j=1}^{m+K-1} a_j A_{(m-j)n} + a_{(n+m)} \quad m > -K+1, K \leq n \leq N_a+K-1 \quad (9b)$$

$$B_{(-k+1)n} = b_{(n-K+1)} \quad m=-K+1, 0 \leq n \leq N_b+K-1 \quad (10a)$$

$$20 \quad B_{mn} = \sum_{j=1}^{m+K-1} a_j B_{(m-j)n} + b_{(n+m)} \quad m > -K+1, 0 \leq n \leq N_b+K-1 \quad (10b)$$

where  $a_n=0$  ( $n>N_a$ ), and  $b_n=0$  ( $n<1$  and  $n>N_b$ ).

When, with  $K=0$  and with a continuous transfer function model from torque command to position as  $1/JS^2$ , discretion is effected with the zero-th order hold and sampler taken into account, then the coefficients of the model  $G_v(z)$  of the predictor shown in FIG. 2 are  $N_a=1$ ,  $a_1=1$ ,  $N_b=2$ ,  $b_1=b_2=b=T_s^2/2J$  and the coefficients of the model  $G_p(z)$  of the predictor shown in FIG. 3 are  $N_a=2$ ,  $a_1=2$ ,  $a_2=-1$ ,  $N_b=2$ ,  $b_1=b_2=b=T_s^2/2J$ .

In the case where the predictor shown in FIG. 2 is employed and  $M=2$ , the coefficients in Formula (2b) are  $A_{10}=A_{20}=1$ ,  $B_{10}=B_{11}=b$ ,  $B_{20}=3b$ , and  $B_{21}=b$  according to Formulae (6), (7) and (7b').

If, in Formula (1),  $M'=0$ ,  $w_2=0.5$ ,  $w_1=w'_0=0.25$ , then the following Formula (11) is obtained according to Formulae (1) and (2):

$$v_{fb}(i)=[\Delta y(i)+b\{1.75u(i)+0.75u(i-1)\}]/T_s. \quad (11)$$

It goes without saying that, in FIG. 1, the predictor 1 and the calculators 2 and 4 are provided as one unit to obtain  $v_{fb}(i)$ .

In the case where the detection value or prediction value of a disturbance torque  $u_d$  is obtained, the difference which is obtained by subtracting the disturbance torque  $u_d$  from the torque command  $u$  may be employed as a torque command to obtain the speed prediction value. In the case where, in the control calculator 5, the torque command is determined from an operation which includes PID control and I-P control integration operations, the resultant integration operation value may be employed as the aforementioned disturbance torque

prediction value. For instance in the case where, as shown in FIG. 4, the control calculator 5 calculates a torque command by PID operation, the difference obtained by subtracting an integration operation value from a torque instruction; that is, only the PD (proportional and differential) operation value is applied, as a torque command, to the predictor 1.

FIG. 5 is a block diagram for a description of the case where, when a control calculator outputs the PI operation value subjected to primary filtering or n-th order filtering as a torque command  $u(i)$  at the next sampling period, the speed feedback signal  $V_{fb}(i)$  is obtained according to Formula (11). In the circuit shown in FIG. 5, an integration value provided one period before is employed as a disturbance torque  $u_d$ ; however, it may be subjected to filtering to obtain a disturbance torque  $u_d$ . A speed  $v(i)$  is obtained according to  $\Delta y(i)/T_s$ ; however, the invention is not limited thereto or thereby. That is, it may be obtained according to a conventional speed calculating method such as a method of using a speed detector, or a method of calculating the speed by measuring the pulse duration time of an encoder.

As was described above, in the motor speed control device of the invention, the speed feedback signal is employed which is less deteriorated in accuracy when the motor is in a range of low speeds, and has no phase lag. Hence, the motor speed control device is high in feedback loop gain, and high in response characteristic.

INDUSTRIAL APPLICABILITY

The invention is applied to a motor speed control device.



WHAT IS CLAIMED IS:

1. A motor speed control device in which, at present time instant  $i$ , a motor position  $y$  which was provided  $K \cdot T_s$  before (where  $K \geq 0$ , and  $T_s$  is a sampling period) is detected to provide a detection signal, and feedback control is carried out with a motor speed feedback signal  $V_{fb}$  which is calculated from said detection signal, CHARACTERIZED by comprising:

means for calculating a torque command  $u(i)$  from a speed command and said motor feed back signal  $v_{fb}$ ;

means for calculating a speed  $v(i-K)$  from said position  $y(i-K)$ ;

means for storing said speed  $v(i-m)$  (where  $m=K, \dots, M'$ ) which occurs from a past  $M'$ -th sampling to a time instant  $i-K$ ;

a predictor for obtaining a speed prediction value  $v^*(i+m)$  (where  $m = -K+1, \dots, M$ ) at a future  $M$ -th sampling from a motor dynamic characteristic model, said torque command  $u(i)$  and said position  $y(i-K)$ ; and

means for calculating said speed feedback signal from the following formula:

$$v_{fb}(i) = \sum_{m=-K+1}^M W_m v^*(i+m) + \sum_{m=K}^{M'} W'_m v(i-m)$$

where  $W_m$  and  $W'_m$  are weight coefficients.

2. A motor speed control device as claimed in claim 2,



CHARACTERIZED in that said predictor comprises:

means for obtaining a position increment value  $\Delta y$  from a position  $y$ , where  $\Delta$  represents an increment value for a sampling period  $T_s$ ;

5 means for determining, on the basis of a transfer function model, from a torque command  $u$  till a position increment value  $\Delta y$ ,  $Gv(z) = (b_1 z^{-1} + \dots + b_{N_b} z^{-N_b}) / (1 - a_1 z^{-1} - \dots - a_{N_a} z^{-N_a})$ , prediction coefficients  $A_{mn}$  and  $B_{mn}$  according to the following formulae

$$10 \quad A_{(-k+1)n} = a_{(n-K+1)} \quad m = -K+1, K \leq n \leq N_a + K-1$$

$$A_{mn} = \sum_{j=1}^{m+K-a} a_j A_{(m-j)n} + a_{(n+m)} \quad m > -K+1, K \leq n \leq N_a + K-1$$

$$B_{(-k+1)n} = b_{(n-K+1)} \quad m = -K+1, 0 \leq n \leq N_b + K-1$$

$$B_{mn} = \sum_{j=1}^{m+K-1} a_j B_{(m-j)n} + b_{(n+m)} \quad m > -K+1, 0 \leq n \leq N_b + K-1$$

15 where  $a_n = 0$  ( $n > N_a$ ), and  $b_n = 0$  ( $n < 1$  and  $n > N_b$ );

means for storing past torque command and position increment values until a present time instant; and

means for obtaining, on the basis of said prediction coefficients, torque command, and position increment values, said speed prediction value according to the following formulae:

$$20 \quad v^*(i+m) = \Delta y^*(i+m) / T_s$$



$$\Delta y^*(i+m) = \sum_{n=K}^{Na+K-1} A_{mn} \Delta y(i-n) + \sum_{n=0}^{Nb+K-1} B_{mn} u(i-n) \quad m=-K+1, \dots, M.$$

3. A motor speed control device as claimed in claim 2,  
CHARACTERIZED by comprising:

5 means for employing, as to said  $B_{mo}$ , the following  
formulae:

$$B_{mo} = 0 \quad -K+1 < m \leq 0$$

$$B_{mo} = \sum_{j=1}^{m+K-1} a_j B_{(m-j)0} + \sum_{j=1}^m b_j \quad m \geq 1$$

4. A motor speed control device as claimed in claim 1,  
CHARACTERIZED in that said predictor comprises:

10 means for obtaining a position increment values  $\Delta y$  and  
a torque command increment value  $\Delta u$  from a position  $y$  and a  
torque command  $u$ ;

15 means for determining, on the basis of a transfer  
function model, from a torque increment  $\Delta u$  till a position  
increment value  $\Delta y$ ,  $Gp(z) = (b_1 z^{-1} + \dots + b_{Nb} z^{-Nb}) / (1 - a_1 z^{-1} - \dots -$   
 $a_{Na} z^{-Na})$ , prediction coefficients  $A_{mn}$  and  $B_{mn}$  according to the  
following formulae, and storing said prediction coefficients  
thus determined:

$$A_{(-k+1)n} = a_{(n-K+1)} \quad m=-K+1, K \leq n \leq N_a + K - 1$$

$$20 \quad A_{mn} = \sum_{j=1}^{m+K-1} a_j A_{(m-j)n} + a_{(n+m)} \quad m > -K+1, K \leq n \leq N_a + K - 1$$

$$B_{(-k+1)n} = b_{(n-K+1)} \quad m=-K+1, 0 \leq n \leq N_b + K - 1$$



$$B_{mn} = \sum_{j=1}^{m+K-1} a_j B_{(m-j)n} + b_{(n+m)} \quad m \geq -K+1, \quad 0 \leq n \leq N_b + K - 1$$

where  $a_n = 0$  ( $n > N_a$ ), and  $b_n = 0$  ( $n < 1$  and  $n > N_b$ );

means for storing past torque command increment values and position increment values until a present time instant; and

5 means for obtaining, on the basis of said prediction coefficients, torque command increment values, and position increment values, said speed prediction value according to the following formulae:

$$v^*(i+m) = \Delta y^*(i+m) / T_s$$

$$10 \quad \Delta y^*(i+m) = \sum_{n=K}^{Na+K-1} A_{mn} \Delta y(i-n) + \sum_{n=0}^{Nb+K-1} B_{mn} \Delta u(i-n) \quad m = -K+1, \dots, M.$$

5. A motor speed control device as claimed in claim 1, CHARACTERIZED by comprising:

means for obtaining the detection value or prediction value of a disturbance torque  $u_d$ ; and

15 means for obtaining a speed prediction value with the difference regarded as a torque command which is obtained by subtracting said disturbance torque  $u_d$  from said torque instruction  $u$ .

20 6. A motor speed control device as claimed in claim 5, CHARACTERIZED in that

in the case where a torque command is determined by an operation including a PID control or I-P control integration operation, an integration operation value is employed as said



disturbance torque  $u_d$ .