

Description

This invention relates to apparatus for producing process control signals from process variable signals, typically in the form of proportional plus integral plus differential (PID) controllers.

Proportional plus integral plus derivative (PID) control is well known. This type of control, while originally used in time mechanisms and steam engine governors, was first described in a mathematical context early in the 20th century. Utilisation of PID control led to further development of the concept resulting in the incorporation of PID controllers in a substantial majority of process control applications. PID control algorithms are discussed in an article entitled "A Comparison of PID Control Algorithms" published in Control Engineering, Volume 34, No 3, March 1987, US, pp102-105, and examples of PID control systems are provided by US patents numbers US-A-4 390 942 and US-A-4 630 178.

Evolution of the PID controller has led to a current abundance of variants of the basic control algorithm. These variants have resulted from restrictions imposed by available hardware. Three principle forms of the PID algorithm are the parallel algorithm (equation 1), the non-interacting algorithm (equation 2), and the interacting algorithm (equation 3), shown below:

$$U(t) = k_c (e(t) + k_i \frac{e(t)}{S} + k_D S e(t)) \quad (1)$$

$$U(t) = k_p e(t) + k_i \frac{e(t)}{S} + k_D S e(t) \quad (2)$$

$$U(t) = k_c [k_p e(t) + k_D S e(t)] [1 + \frac{k_i}{S}] \quad (3)$$

where

$U(t)$ = control signal calculated by PID at time t

$e(t)$ = error between process variable measurement and reference trajectory at time t

k_c = overall controller gain (output units/error units)

k_p = proportional gain (output units/error units)

k_i = integral gain (output units/minutes - error units)

k_D = derivative gain (output units - minutes/error units)

S = Laplace operator.

Three variants of these basic PID algorithms exist. These algorithm variants can be either position or velocity type; the derivative can be calculated on an error signal or an actual measurement, and the derivative can be calculated directly or through the use of a lead lag.

Equations 1, 2 and 3, as shown above, are written in positional form. In corresponding velocity equations, the error signal is replaced with a change in the error signal and a change in control effort is calculated according to the standard equations 1, 2 and 3. This change in control effort is integrated over time to generate a control effort. In normal operating modes there is no performance difference between the positional algorithm and its velocity counterpart. However, during saturation, when the control effort becomes constrained by one of its limits, the behaviour of the foregoing two algorithms is quite different. The velocity type algorithm will move away from its constraints as soon as the absolute value of the error signal on which it is acting decreases. In contrast, a positional type algorithm will not move away from its constraints until the sign of the error signal changes.

Equations 1, 2 and 3 are written to apply derivative action to the error signal. One variant of these algorithms is to replace the error signal with the process measurement in the derivative calculation. This change results in a smoother transition of the process between setpoint values while not adversely affecting disturbance rejection.

In addition, equations 1, 2 and 3 are written in a form that calculates the derivative contribution directly. Typically, this calculation is implemented in conjunction with a first order filter operating at a time constant of 10% of the derivative time. Equation 4, shown below, illustrates this implementation of the derivative calculation. This modification is made to minimise the effect of process noise on the control signal:

$$\text{Derivative Contribution} = \frac{k_D S}{0.1 k_D S + 1} \quad (4)$$

Another modification of the PID algorithm is external reset. This variation of equation 3 substitutes an external measurement for the control output in the integral equation. This modification is used to prevent wind-up of the integral term resulting from saturation of the inner loop of cascade control strategies.

Previously-proposed industrial PID controllers allow a user to select between the various algorithm forms only by selection of actual hardware. Thus, the hardware utilised determines the forms of algorithms available in a controller.

According to this invention there is provided apparatus for producing an interacting proportional, derivative

and integral process control signal, or a proportional, derivative and external reset signal, from a process variable signal, the apparatus comprising:

means for converting the process variable signal into a first signal which is proportional to said process variable signal;

5 means for converting the process variable signal into a second signal which is a function of the derivative of said process variable signal;

means for converting the process variable signal into a third signal which is a function of the integral of said process variable signal; and

10 means for combining said first, second and third signals to produce said process control signal, wherein variation of any one of said first, second and third signals causes a variation in the remainder of said first, second and third signals in accordance with an interacting algorithm, characterised by:

switch means for selectively supplying an external reset signal to the combining means instead of the said third signal.

15 A preferred embodiment of the invention, to be described in greater detail hereinafter, provides a PID controller whose ability to produce a multiplicity of algorithms is not limited by the hardware utilised.

A controller can, for example, be any one of the controllers, or variations thereof, discussed in the book Distributed Control Systems by Michael P. Lukas, Van-Nostrand Reinhold Co., 1986. Several options are provided permitting the user to tailor the controller to a specific problem. An algorithm option allows the selection of a non-interacting type of controller or a classical interacting type of controller. A non-interacting type of controller may be characterised by the property that tuning any of the controller's three modes does not affect the tuning of the remaining modes. In contrast, the classical interacting type of controller exhibits interaction among the tuning parameters, thus closely resembling the behaviour of analog controllers.

20 The algorithm option thus selects an external reset controller. This is based upon the classical interacting type of algorithm and provides a mechanism for controlling integration external to the PID algorithm. External reset provides a mechanism for coordinating the action of controllers used in combinations such as cascade configurations.

The invention will now be described, by way of illustrative and non-limiting example, with reference to the accompanying drawings throughout which like parts are referred to by like references, and in which:

30 Figure 1 is a block diagram of a classical interacting type of algorithm for a PID controller;

Figure 2 is a block diagram of the algorithm shown in Figure 1 and in the Laplace domain; and

Figure 3 is a block diagram of the algorithm illustrated in Figure 1 and in the reset mode of operation.

Referring to the drawings, Figure 1 is a block diagram of a classical interacting type of algorithm 10, namely one in which the integral term is a function of the proportional term and the derivative term. As such, Figure 1 comprises an upper portion which represents the integral term, a middle portion which represents the proportional term, and a lower portion which represents the derivative term. Referring firstly to the middle portion, a signal PY representative of the process to be controlled is applied to the negative input to a summer 12 having a setpoint signal SP applied to its positive input. The output of the summer 12, which represents an error signal, is applied to the input to a proportional multiplier 14 wherein the error is multiplied by a factor kk_p . The output of the proportional multiplier 14 is applied to a positive input to a summer 16. The signal representative of the process variable is also applied to the positive input to a summer 18. A signal representative of the previous process variable is supplied by a Z transformation function block 20 to the negative input to the summer 18. The output of the summer 18 is applied to a proportional multiplier 22 which multiplies the incoming signal by a factor kk_A . The output of the proportional multiplier 22 is applied to a positive input to a summer 24 whose other positive input is connected to a Z transformation function block 26 which provides a signal representative of the previous derivative term. The output of the summer 24 is applied to a proportional multiplier 28 which represents the factor $60 k_D / (60 k_D + k_A \Delta t)$. The output of the proportional multiplier 28 is representative of the derivative term and is applied to a high/low limiter 30 whose output is applied to a negative input to the summer 16.

35 With respect to the integral term of the algorithm, the previous algorithm is applied to the negative input to a summer 32 via a Z transformation function block 34 and a switch 36. The previous integral term is applied to the positive input to the summer 32 via a Z transformation function block 38. The output of the summer 32 is applied to a proportional multiplier 40 representative of the function $60 / (60 + k_I \Delta t)$ whose output is applied to the positive input to a summer 42. The other positive input to the summer 42 is connected to the switch 36. The output of the summer 42 represents the integral term and is applied to a high/low limiter 44 whose output is connected to a positive input to the summer 16. The output of the summer 16 is applied to a high/low limiter 46 whose output is connected to a positive input to a summer 48 whose other positive input receives a feed forward signal. The output of the summer 48 is a process control signal CO based on the classical interacting type of proportional plus integral plus derivative algorithm.

Referring to Figure 2, there is illustrated a block diagram of the algorithm shown in Figure 1 and in the Laplace domain. Those elements which are similar to those shown in Figure 1 have the same reference numerals and will not be discussed further. In Figure 2, the elements which produce the derivative term in Figure 1 have been replaced by proportional multipliers 50 and 52 representative of the functions

$$60 k_d S \text{ and } 1/(60 \frac{k_d}{k_a} S + 1)$$

respectively. The elements which produce the integral term have been replaced by a proportional multiplier 54 representative of the function $60k_i/S$. The output signal CO of the summer 48 represents the control output.

Figure 3 is a block diagram of the algorithm shown in Figure 1 wherein the switch 36 is in the manual reset position. Here again, those elements which are similar to those in Figure 1 have the same reference numerals and will not be discussed further. By placing the switch 36 in Figure 1 in the external reset position, the Z transformation function block 34 is omitted so that Figure 3 differs from Figure 1 only with respect to the upper portion thereof, that is the portion producing the integral term of the algorithm. The algorithm resulting from the switch 36 being in the reset position is used to calculate the output of the feed forward and the algorithm when the algorithm specification is set to 2.

From the foregoing, it will be apparent that the type of algorithm produced depends upon appropriate selection. A selection of 0 causes the PID output to be calculated using a classical interacting algorithm, as shown in Figures 1 and 2. This algorithm is interacting in the sense that tuning any one of the proportional, integral or derivative terms changes the effective value of the other terms. Furthermore, a selection of 2 causes the PID output to be calculated using the classical interacting algorithm, as shown in Figure 1; however, for this selection, the integral term is calculated as a function of the external reset signal, as shown in Figure 3. Lastly, a selection of 3 causes the PID output to be calculated from the proportional and derivative terms only.

Claims

1. Apparatus for producing an interacting proportional, derivative and integral process control signal (CO), or a proportional, derivative and external reset signal (CO), from a process variable signal (PY), the apparatus comprising:
means (12, 14) for converting the process variable signal (PY) into a first signal which is proportional to said process variable signal (PY);
means (18 to 30) for converting the process variable signal (PY) into a second signal which is a function of the derivative of said process variable signal (PY);
means (32 to 44) for converting the process variable signal (PY) into a third signal which is a function of the integral of said process variable signal (PY); and
means (48) for combining said first, second and third signals to produce said process control signal (CO), wherein variation of any one of said first, second and third signals causes a variation in the remainder of said first, second and third signals, in accordance with an interacting algorithm, characterised by:
switch means (36) for selectively supplying an external reset signal to the combining means (48) instead of the said third signal.
2. Apparatus according to claim 1, wherein said process variable signal converting means for producing said first signal comprises an algorithm (14) in the Laplace domain.
3. Apparatus according to claim 2, wherein said algorithm (14) in the Laplace domain is kk_p , where k_p = proportional gain (output units/error units), and k = constant multiplier.
4. Apparatus according to claim 1, claim 2 or claim 3, wherein said process variable signal converting means for producing said second signal comprises an algorithm (50, 52) in the Laplace domain.
5. Apparatus according to claim 4, wherein said algorithm (50, 52) in the Laplace domain is

$$60 k k_d S + 1/(60 \frac{k_d}{k_a} S + 1)$$

where:

- k_d = derivative gain (output units/minutes - error units)
- k = constant multiplier
- k_a = process variable error signal
- S = Laplace operator



Referring to Figure 2, there is illustrated a block diagram of the algorithm shown in Figure 1 and in the Laplace domain. Those elements which are similar to those shown in Figure 1 have the same reference numerals and will not be discussed further. In Figure 2, the elements which produce the derivative term in Figure 1 have been replaced by proportional multipliers 50 and 52 representative of the functions

$$60 k_d S \text{ and } 1/(60 \frac{k_d}{k_e} S + 1)$$

respectively. The elements which produce the integral term have been replaced by a proportional multiplier 54 representative of the function $60k_i/S$. The output signal CO of the summer 48 represents the control output.

Figure 3 is a block diagram of the algorithm shown in Figure 1 wherein the switch 36 is in the manual reset position. Here again, those elements which are similar to those in Figure 1 have the same reference numerals and will not be discussed further. By placing the switch 36 in Figure 1 in the external reset position, the Z transformation function block 34 is omitted so that Figure 3 differs from Figure 1 only with respect to the upper portion thereof, that is the portion producing the integral term of the algorithm. The algorithm resulting from the switch 36 being in the reset position is used to calculate the output of the feed forward and the algorithm when the algorithm specification is set to 2.

From the foregoing, it will be apparent that the type of algorithm produced depends upon appropriate selection. A selection of 0 causes the PID output to be calculated using a classical interacting algorithm, as shown in Figures 1 and 2. This algorithm is interacting in the sense that tuning any one of the proportional, integral or derivative terms changes the effective value of the other terms. Furthermore, a selection of 2 causes the PID output to be calculated using the classical interacting algorithm, as shown in Figure 1; however, for this selection, the integral term is calculated as a function of the external reset signal, as shown in Figure 3. Lastly, a selection of 3 causes the PID output to be calculated from the proportional and derivative terms only.

Claims

1. Apparatus for producing an interacting proportional, derivative and integral process control signal (CO), or a proportional, derivative and external reset signal (CO), from a process variable signal (PY), the apparatus comprising:
 - means (12, 14) for converting the process variable signal (PY) into a first signal which is proportional to said process variable signal (PY);
 - means (18 to 30) for converting the process variable signal (PY) into a second signal which is a function of the derivative of said process variable signal (PY);
 - means (32 to 44) for converting the process variable signal (PY) into a third signal which is a function of the integral of said process variable signal (PY); and
 - means (48) for combining said first, second and third signals to produce said process control signal (CO), wherein variation of any one of said first, second and third signals causes a variation in the remainder of said first, second and third signals, in accordance with an interacting algorithm, characterised by: switch means (36) for selectively supplying an external reset signal to the combining means (48) instead of the said third signal.
2. Apparatus according to claim 1, wherein said process variable signal converting means for producing said first signal comprises an algorithm (14) in the Laplace domain.
3. Apparatus according to claim 2, wherein said algorithm (14) in the Laplace domain is kk_p , where k_p = proportional gain (output units/error units), and k = constant multiplier.
4. Apparatus according to claim 1, claim 2 or claim 3, wherein said process variable signal converting means for producing said second signal comprises an algorithm (50, 52) in the Laplace domain.
5. Apparatus according to claim 4, wherein said algorithm (50, 52) in the Laplace domain is

$$60 k_d S + 1/(60 \frac{k_d}{k_e} S + 1)$$

where:

- k_d = derivative gain (output units/minutes - error units)
- k = constant multiplier
- k_e = process variable error signal
- S = Laplace operator



6. Apparatus according to any one of the preceding claims, wherein said process variable signal converting means for producing said third signal comprises an algorithm (54; 70) in the Laplace domain.
7. Apparatus according to claim 6, wherein said algorithm (54) in the Laplace domain is $60 k_i/S$, where k_i = integral gain (output units/minutes - error units) and S = Laplace operator.
8. Apparatus according to claim 6, wherein said algorithm (70) in the Laplace domain is kk_i/S , where k_i = integral gain (output units/minutes - error units); k = constant multiplier; S = Laplace operator.

Patentansprüche

1. Vorrichtung zur Erzeugung eines wechselwirkenden, Proportional-, Differential- und Integral-Prozeßsteuersignales (CO), oder eines proportionalen, differentiellen und externen Rückstellsignals (CO) aus einem Prozeßvariablenignal (PY), wobei die Vorrichtung aufweist:
 Einrichtungen (12, 14), um das Prozeßvariablenignal (PY) in ein erstes Signal umzuwandeln, welches proportional zu dem Prozeßvariablenignal (PY) ist,
 Einrichtungen (18 bis 30), um das Prozeßvariablenignal (PY) in ein zweites Signal umzuwandeln, welches eine Funktion der Ableitung des Prozeßvariablenignals (PY) ist,
 Einrichtungen (32 bis 44), um das Prozeßvariablenignal (PY) in ein drittes Signal umzuwandeln, welches eine Funktion des Integrals des Prozeßvariablenignals (PY) ist, und
 Einrichtungen (48), um die ersten, zweiten und dritten Signale miteinander zu kombinieren, um das Prozeßsteuersignal (CO) zu erzeugen, wobei eine Veränderung irgendeines der ersten, zweiten und dritten Signale eine Veränderung der übrigen der ersten, zweiten und dritten Signale entsprechend einem Wechselwirkungsalgorithmus verursacht, gekennzeichnet durch Schalteinrichtungen (36) um wahlweise anstelle des dritten Signales ein externes Rückstellsignal auf die Kombiniereinrichtung (48) zu geben.
2. Vorrichtung nach Anspruch 1, wobei die Umwandlungseinrichtung für das Prozeßvariablenignal zur Erzeugung des ersten Signales einen Algorithmus (14) im Laplacebereich aufweist.
3. Vorrichtung nach Anspruch 2, wobei der Algorithmus (14) in dem Laplacebereich kk_p ist, wobei k_p die proportionale Verstärkung (Ausgabeeinheiten/Fehlereinheiten) und k = konstanter Multiplikationsfaktor ist.
4. Vorrichtung nach Anspruch 1, 2 oder 3, wobei die Umwandlungseinrichtung für das Prozeßvariablenignal zur Erzeugung des zweiten Signales einen Algorithmus (50, 52) im Laplacebereich aufweist.
5. Vorrichtung nach Anspruch 4, wobei der Algorithmus (50, 52) in dem Laplacebereich lautet

$$60 k_d S + 1 / (\frac{60 k_d}{k_a} S + 1)$$
 wobei:
 k_d = differentielle Verstärkung (Ausgabeeinheiten/Minuten - Fehlereinheiten)
 k = konstanter Multiplikationsfaktor
 k_a = Fehlersignal der Prozeßvariablen
 S = Laplace Operator
6. Vorrichtung nach einem der vorstehenden Ansprüche, wobei die Umwandlungseinrichtung für das Prozeßvariablenignal zur Erzeugung des dritten Signales einen Algorithmus (54, 70) im Laplacebereich aufweist.
7. Vorrichtung nach Anspruch 6, wobei der Algorithmus (54) in dem Laplacebereich lautet: $60 k_i/S$, wobei k_i die integrale Verstärkung (Ausgabeeinheiten/Minuten - Fehlereinheiten) und S = Laplaceoperator ist.
8. Vorrichtung nach Anspruch 6, wobei der Algorithmus (70) in dem Laplacebereich lautet kk_i/S , wobei k_i = integrale Verstärkung (Ausgabeeinheiten/Minuten - Fehlereinheiten), k = konstanter Multiplikationsfaktor, S = Laplaceoperator.



Revendications

1. Dispositif pour produire, à partir d'un signal de variable de processus (PY), un signal (CO) de commande de processus proportionnel, dérivé et intégral, interactif, ou un signal (CO) proportionnel, dérivé et à remise à zéro externe, le dispositif comprenant :
 - un moyen de conversion (12, 14) pour convertir le signal de variable de processus (PY) en un premier signal qui est proportionnel audit signal de variable de processus (PY) ;
 - un moyen de conversion (18 à 30) pour convertir le signal de variable de processus (PY) en un deuxième signal qui est fonction de la dérivée dudit signal de variable de processus (PY) ;
 - un moyen de conversion (32 à 44) pour convertir le signal de variable de processus (PY) en un troisième signal qui est fonction de l'intégrale dudit signal de variable de processus (PY) ; et,
 - un moyen de combinaison (46) pour combiner lesdits premier, deuxième et troisième signaux pour produire ledit signal (CO) de commande de processus, la variation de l'un quelconque desdits premier, deuxième, et troisième signaux provoquant une variation dans le reste desdits premier, deuxième et troisième signaux selon un algorithme interactif, caractérisé par :
 - un moyen de commutation (36) pour délivrer de manière sélective un signal de remise à zéro externe au moyen de combinaison (46) à la place dudit troisième signal.
2. Dispositif selon la revendication 1, dans lequel ledit moyen de conversion de signal de variable de processus pour produire ledit premier signal comprend un algorithme (14) dans le domaine de Laplace.
3. Dispositif selon la revendication 2, dans lequel ledit algorithme (14) dans le domaine de Laplace est kk_p , où k_p est le gain proportionnel (unités de sortie/unités d'erreur), et k est un multiplicateur par une constante.
4. Dispositif selon la revendication 1, la revendication 2, ou la revendication 3, dans lequel ledit moyen de conversion de signal de variable de processus pour produire ledit deuxième signal comprend un algorithme (50, 52) dans le domaine de Laplace.
5. Dispositif selon la revendication 4, dans lequel ledit algorithme (50, 52) dans le domaine de Laplace est :

$$kd$$

$$60 kk_d S + 1/(60 \frac{k_d}{k_a} S + 1)$$
 où
 - k_d est le gain de dérivée (unités de sortie/minutes - unités d'erreur);
 - k est un multiplicateur par une constante ;
 - k_a est le signal d'erreur de variable de processus ;
 - S est l'opérateur de Laplace.
6. Dispositif selon l'une quelconque des revendications précédentes, dans lequel ledit moyen de conversion de signal de variable de processus pour produire ledit troisième signal comprend un algorithme (54 ; 70) dans le domaine de Laplace.
7. Dispositif selon la revendication 6, dans lequel ledit algorithme (54) dans le domaine de Laplace est $60 k_i/S$, où K_i est le gain d'intégrale (unités de sortie/minutes - unités d'erreur) et S est l'opérateur de Laplace.
8. Dispositif selon la revendication 6, dans lequel ledit algorithme (70) dans le domaine de Laplace est kk_i/S , où K_i est le gain d'intégrale (unités de sortie/minutes - unités d'erreur) et S est l'opérateur de Laplace.