MODULE - II

Multiple Choice Type Questions

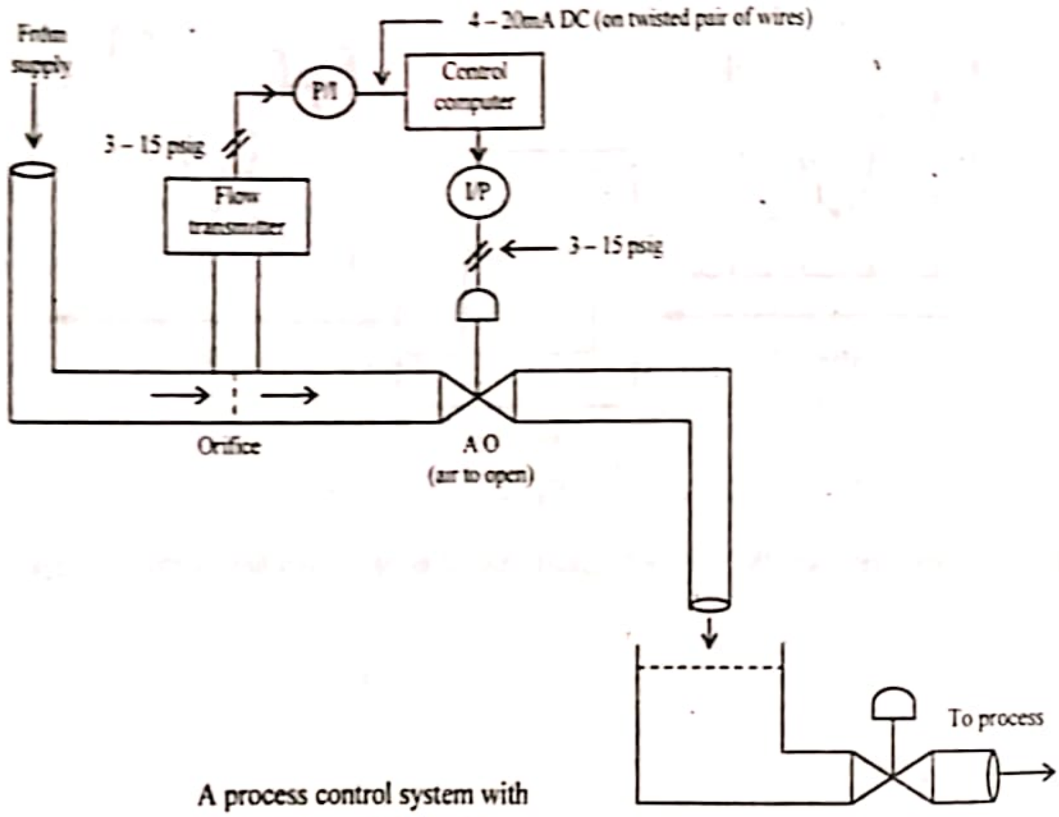
1. An example of an industrial control system (ICS) is [WBUT 2009, 2014]
   a) PLC
   b) DCS
   c) both PLC & DCS
   d) none of these

Answer: (c)

Short Answer Type Questions

1. Draw a block diagram showing different hardware elements in multi-loop control of process using digital computer. As compared to a general purpose computer what are the considerations to be made for a process control computer? [WBUT 2009]

Answer:



A process control system with computer as a controller

Computer system used for process control applications, differ from those used for general scientific and business purposes in that they contain special features that allow operation in a real-time environment. Some of the important features of computer-aided process control software are:

- It allows the process control computer hardware system to perform time-relative operations that are governed by a real-time clock.

- It helps the hardware in responding to other externally generated occurrences through an external or priority interrupt system.
- It helps the hardware top read the values of external variables and transmit signals to external devices, including human interpretable system such as an operator's console.

Personal Computer Controllers

Because of their high performance, low cost, and ease of use, personal computers (PCs) are a popular platform for process control. When configured to perform scan, control, alarm, and data acquisition (SCADA) functions, and when combined with a spreadsheet or database management application, the PC controller can be a low-cost, basic alternative to the DCS.

In order to use a PC for real-time control, it must be interfaced to the process instrumentation. The I/O interfaced to the process instrumentation. The I/O interface can be located on a board in an expansion slot, or the PC can be connected to an external I/O module using a standard communication port on the PC (e.g., RS-232, RS-422, or IEEE-488). The controller card/module supports 16-bit or 32-bit microprocessors, standardization and the high-volume PC market has resulted in a large selection of hardware and software tools for PC controllers.

In comparison with PLCs, PCs have the advantages of lower purchase cost, graphics output, large memory, large selection of software products (including databases and development tools), more programming options (use of C or Java vs. ladder logic), richer operating systems, and open networking. PLCs have the following advantages; lower maintenance cost, operating system and hardware optimized for control, fast boot times, ruggedness, low mean time between failures, longer support for product models, and self-contained units. PC-based control systems are predicted to continue to grow at a much faster rate than PLCs and DCSs during the next decade.

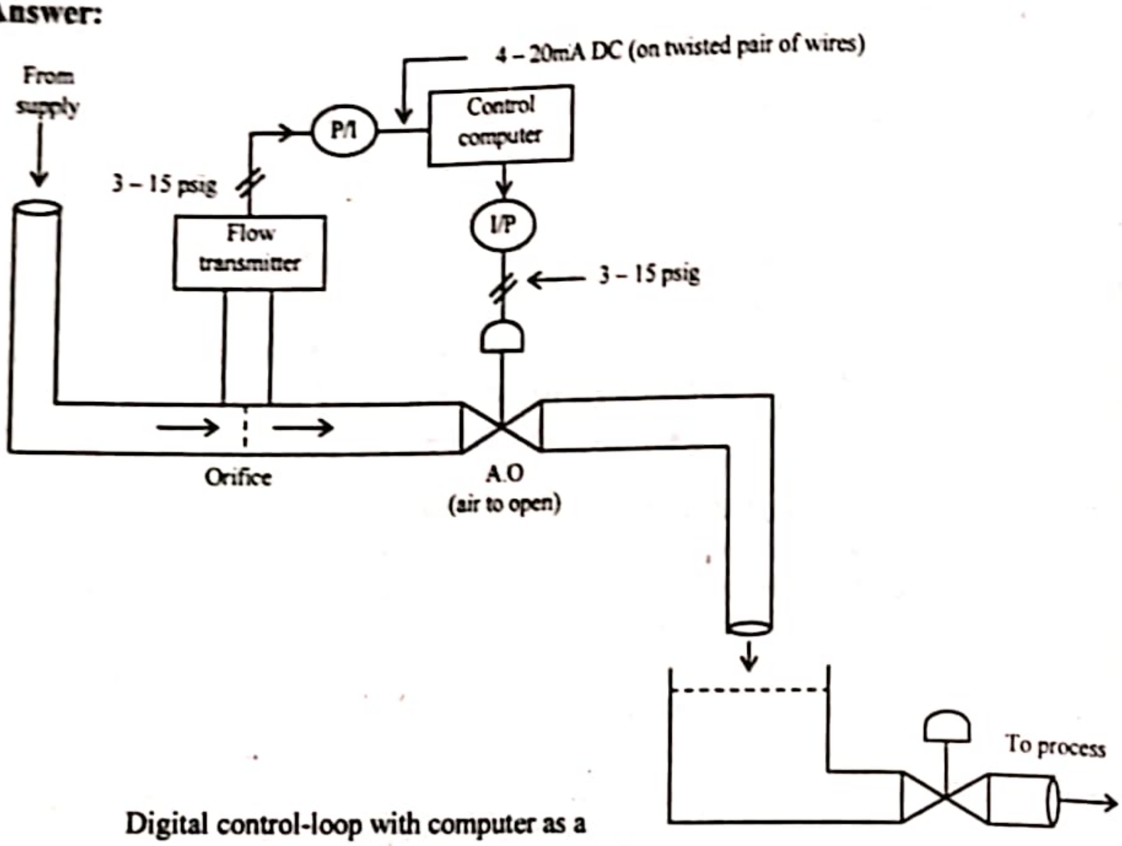
Process control systems should also be scalable, which means that the size of the control and instrumentation system is easily expanded by simply adding more devices. This feature is possible because of the availability of open systems (i.e., "plug-and-play" between devices), smaller size, lower cost, greater flexibility, and more off-the-shelf hardware and software in digital control systems. A typical system includes personal computers, an operating system, object-oriented database technology, modular field-mounted controllers, and plug-and-play integration of both system and intelligent field devices. New devices are automatically recognized and configured with the system. advanced control algorithms can be executed at the PC level.

2. Explain a digital control loop with computer as a controller. Draw it's block diagram & explain each part briefly. Why is process part & measurement part different in the same loop? [WBUT 2010, 2012]

OR,

Draw a block diagram showing different hardware elements in a single process control loop with computer as controller. Explain in simple physical terms the necessity of converting a signal from analog to digital and vice-versa at the computer-process I/O interface. [WBUT 2011]

Answer:



Digital control-loop with computer as a controller

A typical digital controller is shown in the figure above.DDC is a method of process control in which computer is an integral part of the loop. Because of the nature of digital devices, signals from the plant have to be converted into a suitable form before they can be transferred for processing by the computer. Similarly, signals generated by the computer must be presented in a form compatible with the plant.

In the figure above, the output of the flow transmitter is converted into an electrical signal using P/I(pressure-to-Current) converter. This resulting 4-20 mA current signal is converted into a voltage signal and supplied to the computer. The ADC output is subsequently acted upon by the discretized version of controller stored in the computer. The discrete output from the computer is converted back into continuous signal (voltage) by using a DAC, which is further converted to 4-20 mA signal. The current signal is connected to I/P (Current-to-Pressure) converter, producing a pneumatic signal in 3-15 psig range, which operates the valve.

3. What are the advantages of digital control? **[WBUT 2012]**

Answer:

Improved Effectiveness

Since the control loop logic is now embedded with the software, this logic can be readily tweaked according to the requirements. DDC offers flexibility in the sense that set points and control logic can be changed easily. Based upon continuous monitoring of the process, more complex control schemes, energy and optimization strategies can be implemented.

Improved Operational Efficiency

The capabilities of DDC, like offering visualization and storage of data in various formats, trend analysis of data for fault diagnosis, and preventive maintenance schedules increase operational efficiency of the plant. Communication capabilities of DDC permits remote monitoring and control, polling of efforts by vendors, designers to visualize, diagnose and troubleshoot a problem.

Increased Energy Efficiency

Energy efficient routines can be programmed in DDC easily. Further, monitoring of energy consumption patterns by each unit permits change of various set points, resulting in effient utilization of energy.

4. Why is parameter identification required? Briefly describe the ARMAX model.
[WBUT 2014]

Answer:

1st Part:

Contrary to the process parameters that can be determined (at least in an approximation fashion) form physical vonsiderations, controller parameters are technological parameters that can be freely chosen by the designer. Hence, a tool is needed to determine optimal controller parameter values in the sense of minimizing (or maximizing) a performance index.

2nd Part:

ARMAX Model

The true process model is assumed to be

$$A^\circ(q)y(t) = B^\circ(q)u(t) + C^\circ(q)e(t)$$

or, $$y(t) = \frac{B^\circ(q)}{A^\circ(q)}u(t) + \frac{C^\circ(q)}{A^\circ(q)}e(t)$$

where

$$A^\circ(q) = 1 + a_1^o q^{-1} + \ldots + a_n^o q^{-n}$$

$$B^\circ(q) = \quad b_1^o q^{-1} + \ldots + b_n^o q^{-n}$$

$$C^\circ(q) = 1 + c_1^o q^{-1} + \ldots + c_n^o q^{-n}$$

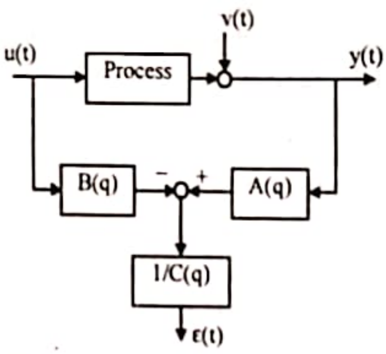


Fig: (i) Error generation of ARMAX model

and $e(t)$ is white noise with zero mean and variance R. So the equation disturbance is assumed to be an MA (moving-average) process; refer figure (i) for the block diagram of ARMAX model. This model was proposed by Astrom and Bohlin (1965) and has become a well known model.

Long Answer Type Questions

1. Explain difference between Dahlin's Algorithm controller and a Dead beat controller in process control. **[WBUT 2015, 2016]**

Answer:

Dahlins algorithm specifies that the closed loop sampled data control system behave as though it were a first order process with dead time. Dead beat algorithm requires the closed loop response to have finite setting time, minimum rise time and zero steady state error is referred to as a dead beat algorithm.

Performance of Dahlin control algorithm is better than that of deadbeat.

Specification of Dead beat algorithm is $\frac{C(z)}{R(z)} = Z^{-n}$. If the process were to contain a time delay that is greater than the sampling period, the $D(z)$ will require future values of the errors to determine the current value of the controller output which is physically impossible.

The possible existence of ringing is dominant in dead beat relative to Dahlin algorithm.

2. a) Draw and Explain the block diagram of a process control loop with computer as a controller. **[WBUT 2017]**

Answer:

Refer to Question No. 2 of Short Answer Type Questions.

b) State the advantages of digital control system over analog control system. **[WBUT 2017]**

Answer:

1. Digital circuits and systems are usually much more robust to noise and interference than analog circuits.
2. The digital controller is versatile. It can be reprogrammed. Very complex control algorithms (adaptive, optimal, non-linear, stochastic, etc.) which are virtually impossible of being implemented with analog electronics can be implemented.
3. The hardware for implementing digital controllers is very cheap.
4. Digital control systems are easily realisable using logic programs and use limited storage space.
5. Digital can be encrypted so that only the intended receiver can decode it
6. Enables transmission of signals over a long distance.
7. Transmission is at a higher rate and with a wider broadband width.
8. Minimal electromagnetic interference in digital technology.

3. Define ARMA and ARX. **[WBUT 2017]**

Answer:

Refer to Question No. 4(c) of Long Answer Type Questions.

4. Write short notes on the following:

a) Dahlin's algorithm **[WBUT 2009, 2012, 2014, 2017, 2018]**
b) Dead-beat controller design method **[WBUT 2015, 2016]**
c) ARMA & ARX **[WBUT 2016]**
d) Ringing and how its eliminate **[WBUT 2016]**
e) ARMAX model for system identification **[WBUT 2018]**

Answer:

a) Dahlin's Control Algorithm

Dahlin suggested to design the feedback controller such that the closed loop response has a first order plus dead time transfer function (Fig. (1)). In many modern control approaches this idea is still used today.

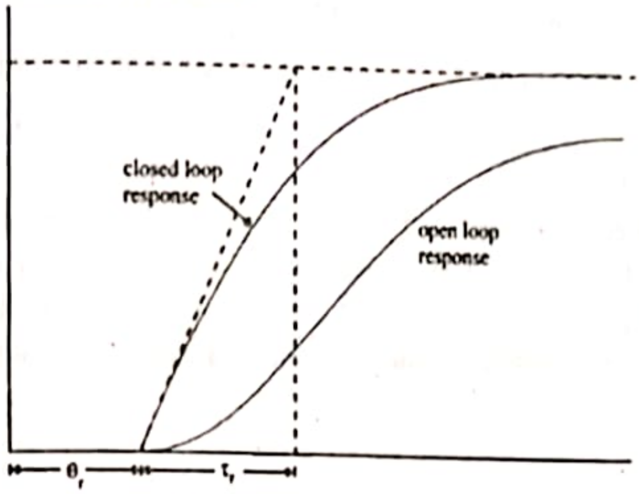


Fig: (1) Desired closed loop system response

The approach is different from tuning a PI(D) controller to yield a specific closed loop response because the Dahlin approach does not restrict the structure of the controller. By choosing a PI(D) controller one has fixed the structure, leaving only the parameters free to be adjusted in order to achieve the desired response. The Dahlin approach determines both the structure and the parameters necessary to achieve a first order plus dead time response.

The key to the Dahlin approach is the explicit use of a process model in the design equations. The controller is designed to achieve the following objectives:

i) reduce the process dynamics as far as possible

ii) add dynamics to the loop so that the closed loop response is first order plus dead time

iii) the closed loop gain should be equal to one so that setpoint changes are followed.

These objectives can be achieved by including an inversion of the process transfer function in the controller design. Consider a control system as shown in figure (2).

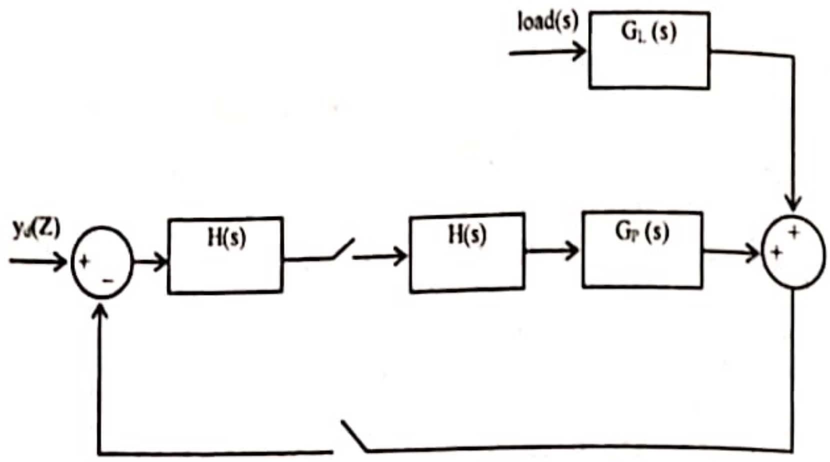


Fig: 2 Discrete time control system with the Dahlin controller D(z)

Dahlin states that the desirable closed loop transfer function is first order plus dead time:

$$K(s) = \frac{y(s)}{y_d(s)} = \frac{e^{-\theta_r s}}{\tau_r s + 1} \qquad ...(1)$$

where θ_r is the closed loop dead time and τ_r the first order time constant that can be chosen by the user. For discrete controller design, the pulse transfer function equivalent to $K(s)$ must be determined. A zero-order hold is included because the output $y(s)$ is a continuous variable. The Laplace transfer function of a zero-order hold is:

$$H(s) = \frac{1 - e^{-Ts}}{s} \qquad ...(2)$$

Hence, $$K\,H(z) = Z\left[\frac{1 - e^{-Ts}}{s} \frac{e^{-\theta_r s}}{\tau_r s + 1}\right] \qquad ...(3)$$

Assume that the dead time θ_r is an integer multiple of the control interval T, thus one can write:

$$KH(z) = \frac{(1 - e^{-T/\tau_r})z^{-n}}{1 - e^{-T/\tau_r} z^{-1}} \qquad ...(4)$$

where $nT = \theta_r$. The block diagram for setpoint changes in the z-domain where the process is represented by its pulse transfer function $G_p H(z)$. The closed loop pulse transfer function is:

$$K\,H(z) = \frac{y(z)}{y_d(z)} = \frac{D(z)G_p H(z)}{1 + D(z)G_p H(z)} \qquad ...(5)$$

This can be rewritten as the design equation for the discrete controller $D(z)$:

$$D(z) = \frac{K\,H(z)}{1 - K\,H(z)} \frac{1}{G_p H(z)} \qquad ...(6)$$

The controller consists of two terms:

- the term $1/G_p H(z)$, which is an inversion of the process dynamics and thus it cancels the process dynamics

- the term $KH(z)/(1-KH(z))$ which accounts for the way in which the dynamics of the controller affect the closed loop response.

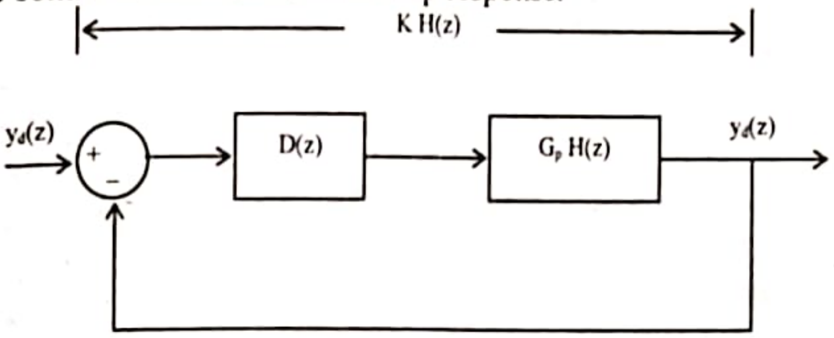


Fig: Control system analogy in the z-domain

Equation (6) is a general design equation for discrete controllers. The closed loop specification, $KH(z)$, can be used to design the controller.

The Dahlin closed loop specification is given in equation (4). Upon substitution into equation (6) the Dahlin controller equation becomes:

$$D(z)=\frac{\left(1-e^{-T/\tau_r}\right)z^{-n-1}}{\left(1-e^{-T/\tau_r}z^{-1}\right)-\left(1-e^{-T/\tau_r}\right)z^{-n-1}}\frac{1}{G_pH(z)} \qquad ...(7)$$

The following should be observed:

- the closed loop dead time θ_r, should be equal to or greater than the actual process dead time
- the closed loop time constant τ_r can be used as a tuning parameter.

Equation (7) can also be written in the following form:

$$D(z)=\frac{(-e^{-T/\tau_r})z^{-n-1}}{(1-z^{-1})(1+(1-e^{-T/\tau_r})z^{-1}+(1-e^{-T/\tau_r})z^{-2}+...+(1-e^{-T/\tau_r})z^{-n})G_pH(z)} \qquad ...(8)$$

The factor $(1-z^{-1})$ in the denominator indicates that the Dahlin controller algorithm contains integral action. The factor z^{-n} in the numerator cancels the process dead time.

b) Design criteria:

1. The system must have a zero steady state error at sampling instants.
2. The time to reach final output must be finite and minimum.
3. The controller should be causal.

From Fig. 1,

$$M(z)=\frac{C(z)}{R(z)}=\frac{D_c(z)G_p(z)}{1+D_c(z)G_p(z)}$$

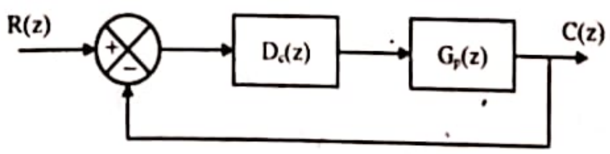


Fig: 1 An all digital control system

Thus, after rearrangement,

$$D_c(z) = \frac{1}{G_p(z)} \frac{M(z)}{1-M(z)}$$

The error signal $E(z) = R(z) - C(z) = \dfrac{R(z)}{1+D_c(z)G_p(z)}$

Where, R(z) may be step, ramp or any other input.

Physical realizability of $D_c(z)$:

Physical realizability condition of $D_c(z)$ imposes constraints on the form of $M(z)$. Let

$$G_p(z) = g_n z^{-n} + g_{n+1} z^{-n-1} + \ldots\ldots$$

and, $M(z) = m_k z^{-k} + m_{k+1} z^{-k-1} + \ldots\ldots$

where, n and k are the excess poles over zeros of $G_p(z)$ and $M(z)$ respectively. Thi implies

$$D_c(z) = d_{k-n} z^{-(k-n)} + d_{k-n+1} z^{-(k-n+1)} + \ldots\ldots$$

For $D_c(z)$ to be realizable, $k \ge n$,

Thus, if $G_p(z)$ does not have poles or zeros outside the unit circle, then $M(z)$ shoul have the following forms,

1. Step input:

$$R(z) = \frac{z}{z-1}$$

$$M(z) = \frac{1}{z^n}$$

2. Ramp input:

$$M(z) = \frac{(n+1)z - n}{z^{n+1}}$$

c) ARMA & ARX

ARMA: ***Refer to Question No. 4 of Short Answer Type Questions.***

ARX Models:

The Structure

The most used model structure is the simple linear difference equation

$$y(t) + a_1 y(t-1) + \ldots + a_{na} y(t-na) =$$

$$b_1 u(t-nk) + \ldots + b_{nb} u(t-nk-nb+1)$$

which relates the current output $y(t)$ to a finite number of past outputs $y(t-k)$ an inputs $u(t-k)$.

The structure is thus entirely defined by the three integers na, nb, and nk. na is equal to the number of poles and nb-1 is the number of zeros, while nk is the pure time-delay (the dead-time) in the system. For a system under sampled-data control, typically nk is equal to 1 if there is no dead-time.
For multi-input systems nb and nk are row vectors, where the i-th element gives the order/delay associated with the i-th input.

d) Ringing and how its eliminate:
The phenomenon of controller ringing was noted in conjunction with digital feedback control of a first or second-order process. Such behaviour is unique to discrete-time direct synthesis methods and produces excessive actuator movement and wear. It is also unsettling to plant operators. To examine why ringing occurs, suppose D contains a stable pole p_1 that is located near $z=-1$ in the complex z plane. D can be factored as

$$D(z)=\frac{1}{1-p_1z^{-1}}D'(z) \qquad \text{.... (1)}$$

The controller output based on an error signal E is therefore

$$P(z)=\left[\frac{1}{1-p_1z^{-1}}D'(z)\right]E(z) \qquad \text{.... (2)}$$

If partial fraction expansion of P is carrier out, we can isolate the effect of the pole p_1, assuming $D(z)$ and $E(z)$ are specified:

$$P(z)=\frac{r_1}{1-p_1z^{-1}}+[\text{other terms}] \qquad \text{.... (3)}$$

When Eqn. (3) is inverted to the time domain, the first term becomes $r_1(p_1)^n$, where n is the time step. A negative pole near the unit circle has a pronounced effect on the response, causing the controller to oscillate or ring. On the other hand, negative poles near the origin are heavily damped and their results are not so noticeable. Positive poles do not cause the controller output to change in sign. Any digital control algorithm should contain some procedure for eliminating ringing pole(s) when they occur.
The most direct way to evaluate ringing with Dahlin's controller is to calculate P/R, since C/R may not exhibit oscillation at the sampling instants for the ringing case.

$$\frac{P}{R}=\frac{D}{1+HGD} \qquad \text{.... (4)}$$

For Direct Synthesis algorithms with no model error, the formula for D in

$$D=\frac{1}{HG}\frac{\left(\frac{C}{R}\right)_d}{1-\left(\frac{C}{R}\right)_d}$$

can be substituted into Eqn. (4) yielding the following equation for P/R:

$$\frac{P}{R}=\frac{1}{HG}\left(\frac{C}{R}\right)_d \qquad \text{.... (5)}$$

For the special case of Dahlin's controller ($D=G_{DC}$; no ringing pole removed) and the second-order plus time-delay process model,

$$\frac{P}{R}=\frac{\left(1+a_1z^{-1}+a_2z^{-2}\right)}{b_1z^{-1}+b_2z^{-2}}\frac{(1-A)z^{-1}}{1-Az^{-1}} \qquad \text{.... (6)}$$

In Eqn. (6), for any input R, the term $b_1+b_2z^{-1}$ will cause ringing if b_1 and b_2 have the same sign, although the severity of ringing will depend on the relative sizes of b_1 and b_2.

Two special cases of Eqn. (6) can be considered:

1. $a_2=b_2=0$ (first-order model): There can be no ringing pole for any value of A.
2. $A=0$ (minimal prototype): $b_1+b_2z^{-1}$ may yield a ringing pole, depending on the signs of b_1 and b_2.

From the above, we conclude that increasing the order of the assumed process model has a major influence on the occurrence of ringing. Therefore, care must be taken when a higher-order model is chosen to represent the process. On the other hand, it can be shown that a controller designed using an inaccurate first-order model can also lead to ringing behaviour.

Now consider the non-ringing version of Dahlin's controller $\overline{G}_{DC}$. In this case, Eqn. (5) cannot be used because $\frac{C}{R}\neq\left(\frac{C}{R}\right)_d$ (no longer an exponential approach to set point).

Hence we must analyze Eqn. (4). After developing a non-ringing version of Dehlin's controller ($\overline{G}_{DC}$) for a second-order plus time-delay model, and substituting it into Eqn. (4), the resulting transfer function is

$$\frac{P}{R}=\frac{(1-A)\left(1+a_1z^{-1}+a_2z^{-2}\right)}{(b_1+b_2)\left[1-Az^{-1}-(1-A)z^{-N-1}\right]+\left(b_1+b_2z^{-1}\right)(1-A)z^{-N-1}} \qquad \text{.... (7)}$$

Recall that the controller $\overline{G}_{DC}$ should eliminate ringing. However, analysis of the roots of the denominator polynomial in Eqn. (7) (left to the reader) indicates that an additional ringing pole could appear for $N=1$. For $N\geq 2$ several new ringing poles can appear, although they may not be severe, depending on the tuning parameter A. If $A=0$ (minimal prototype), the possibility of severe ringing exists even for $N=1$. If there are errors in the model parameters (a_1, a_2, b_1, b_2), the extent of ringing may also increase depending on their specific values and the size of A.

e) ARMAX Model:

In principle, an ARMAX model is a linear regression model that uses an ARMA type process {which provides a parsimonious description of a (weakly) stationary stochastic process in terms of two polynomials, one for the autoregression (AR) and the second for moving average (MA)} i.e., ω_t to model residuals:-

$$y_t = \alpha_0 + \beta_1 x_1,t + \beta_2 x_2,t + \ldots\ldots + \beta_b x_b t + \omega_t$$

$$\left(1 - \phi_1 L - \phi_2 L^2 - \cdots\cdots\cdots - \phi_p L^p\right)\left(y_t - \alpha_0 - \beta_1 x_1,t - \beta_2 x_2,t\right)$$

$$= \left(1 + \theta_1 L + \theta_2 L^2 + \cdots\cdots\cdots + \theta_q L^q\right) a_t$$

$$\left(1 - \phi_1 L - \phi_2 L^2 - \cdots\cdots\cdots - \phi_p L^p\right)\omega_t = \left(1 + \theta_1 L + \theta_2 L^2 + \cdots\cdots\cdots + \theta_q L^q\right) a_t$$

$$a_t \sim \$_i.i.d\$ \sim \Phi\left(0,\ \sigma^2\right)$$

where,

L is the lag (or, back shift) operator

y_t is the observed output at time t

x_k, t is the k-th exogenous input variable at time t

β_k is the coefficient value for the k-th exogenous input variable.

b is the number of exogenous input variables.

ω_t is the auto correlated regression residuals.

p is the order of the last lagged variables.

q is the order of the last lagged innovation or shock.

a_t is the innovation, shock at time t.

a_t time series observations are independent and identically distributed and follow a Gaussian distribution (i.e., $\Phi(0,\ \sigma^2)$)

Assume y_t and all exogenous input variables are stationary, then taking the expectation from both the sides, we can express α_0 as follows:

$$\alpha_0 = \mu - \sum_{i=1}^{b} \beta_i E\left[x_i\right] = \mu - \sum_{i=1}^{b} \beta_i \bar{x}_i \bar{x}_k$$

is the long- run average of the i-th exogenous input variable.

Some important points:

a) The variance of the shocks is constant or time-invariant.

b) The order of an AR component process is solely determined by the order of the last lagged auto-repressive variable with a non-zero coefficient (i.e., ω_{t-p}).

c) The order of an MA component process is solely determined by the order of the last moving average variable with a non-zero coefficient (i.e., a_{t-q}).