Chapter 5

Nonlinear Predictive PI Approach for a Class of Cascade Control Systems

5.1 Introduction

In any process, the load disturbance rejection is important. In process control system cascade control can be used in order to reduce the disturbance and improve the performance of the system. In a cascade control scheme the process has one input and two (or more) outputs. In process industry, this control approach is one of the most popular complex control structure, which has three advantages:

(1) It rejects disturbances produced in the inner loop.
(2) System response speed and accuracy gets improved.
(3) Reduce the effect of parameter variations in the inner loop [36].

Cascade control strategy does not give better performance for long delay time processes [31]. Therefore, predictive control theory has been introduced in control structure for compensating effect of time delay [24].

However, in long time delay processes the basic predictor control structure cannot reject load disturbances. In the literature, many researchers Kaya [24], Liu [26], Hang [27], Kwak [28], Matausek and Micic [29], Rao [30] have introduced various modified
forms of Smith predictor structures for delay time processes to increase the closed-loop performance. Related to this, Kaya [24] has introduced cascade control with Smith predictor for increased performance of stable systems and Liu [26], Uma [31], Garcia [32] has discussed for unstable systems. In the literature, there are only few applications based on the predictive control with cascade control configuration. Huber and Kermode [23] has introduced a predictive feedback system for continuous reactors that used two measurements (composition and temperature) in two parallel feedback loops. Krishnaswamy [33] developed a simplified model predictive control (SMPC) for control of higher order process with dead time and noise in single loop. Cascade model predictive control has been designed by Xu [34] for level control in boiler drum. Boiler drum level is maintained by implementing GPC structures on both inner and outer loops. In this, measured and unmeasured disturbances can be effectively rejected at constant load. Benyo [35] presented GPC in transfer function representation for power plant applications. For conventional cascade PI control scheme, Thirusak Thimirugan and Dananjayan [36] has introduced a multivariate based GPC law. In this, speed is good and torque track their desired target for matched and mismatched parameters.

The proposed cascade GPC (CGPC) uses one predictor and one cost function that produces many advantages in feature. The purpose of proposed controller is to explore the applications of cascade control with nonlinear PPI control schemes to increase the predictive feedback control performance. The design of controller is derived by departing from simple input/output (I/O) first order dynamic models obtained from step responses and using nonlinear PI structure for cascade controller design. A nonlinear PPI cascade control system is presented, in which according to error in cascade control configuration, the gain of master-slave controller varies.

5.2 Cascade Control

Cascade control can give a better response to a set point change by using a measurement point and two feedback controllers. However, the main concern is its performance when disturbance is present. The basic cascade control system is shown in Fig. 5.1. Here for simplicity, only two loops are considered but the approach can be generalized
more loops.

The transfer function of the process is,
\[ G(s) = G_2(s)G_1(s) \],

Where, \( Y_1 \) is the primary output, \( Y_2 \) is the secondary output, \( G_{c2} \) is the secondary (or slave) controller and \( G_{c1} \) is the primary (or master) controller. Analogously the inner loop is denoted as the secondary loop, and the outer loop is denominated as the primary loop. The disturbances in \( D_2 \) are compensated by feedback in the inner loop, the closed loop transfer function is obtained by block diagram.

\[
Y_1 = G_1Y_2 \tag{5.1}
\]

\[
Y_2 = Gd_2D_2 + G_2G_{c2}E_2 \tag{5.2}
\]

\[
E_2 = Y_{sp2} - Y_2 = G_{c1}E_1 - Y_2 \tag{5.3}
\]

\[
E_1 = Y_{sp1} - Y_1 = G_{c1}E_1 - Y_2 \tag{5.4}
\]

Eliminating all variables except \( Y_1 \) and \( D_2 \) gives,

\[
\frac{Y_1}{D_2} = \frac{G_1 - G_{d2}}{1 + G_{c2}G_2 + G_{c1}G_{c2}G_2G_1} \tag{5.5}
\]

By similar analysis, the set point transfer function for the outer and inner loops are:

\[
\frac{Y_1}{Y_{sp1}} = \frac{G_{c1}G_{c2}G_1G_2}{1 + G_{c2}G_2 + G_{c1}G_{c2}G_2G_1} \tag{5.6}
\]
\[
\frac{Y_2}{Y_{sp2}} = \frac{G_{c_2}G_2}{1 + G_{c_2}G_2} \tag{5.7}
\]

For disturbances in \( D_2 \), the closed loop transfer function is,

\[
\frac{Y_1}{D_1} = \frac{G_{d_1}(1 + G_{c_2}G_2)}{1 + G_{c_2}G_2 + G_{c_1}G_{c_2}G_1G_2} \tag{5.8}
\]

The characteristic equation is therefore

\[
1 + G_{c_2}G_2 + G_{c_1}G_{c_2}G_1G_2 = 0 \tag{5.9}
\]

while, if a conventional feedback control is employed, then characteristic equation is,

\[
1 + G_{c_1}G_1G_2 = 0 \tag{5.10}
\]

Stability of the cascade control system improves when the dynamics of the secondary loop is faster than the dynamics of the primary loop, so in primary loop a higher gain is produced [24]. This system is designed by tuning the secondary controller, when the primary loop is placed in manual mode. Then, the primary controller is tuned on the basis of the closed-loop transfer function of the secondary loop in series with the primary process transfer function (which contains the dominant dynamics, because of the tight tuning of the secondary loop) [24].

### 5.3 Nonlinear Predictive Cascade Control

A scheme based on nonlinear PPI based cascade control configuration has been proposed and it is shown in figure 5.2. It seems that in order to compensate the effect of the delay in the both loops, predictive scheme is applied. In the tuning procedure, a FOPDT transfer function is first estimated for the secondary process. The parameters of nonlinear PPI are selected consequently according to the tuning rules mentioned in Table 5.1. Inner loop control law is implemented for secondary process with time delay, which provides an effective disturbance rejection. Afterwards, inner loop is reduced in to the transfer function model as \( Gr(s) \) and secondary process is in series with reduced order model. Then, open loop identification procedure can be performed for estimating dynamics of overall process. The estimated transfer function is used for deriving
parameters of nonlinear PPI for compensating effect of delay time in output response. Here, nonlinear cascade control strategy is presented that replaces the conventional cascade control based on PI-PI configuration.

5.4 Identification Procedure

In general, model of process is represented in the form of First Order Plus Dead Time (FOPDT) model. The transfer function of the FOPDT model is represented as,

\[ G_{pm}(s) = \frac{K_m e^{-L_s}}{T_n s + 1} \]  \hspace{1cm} (5.11)

Where, \( n = 1 \) represents the outer loop process model and \( n = 2 \) represents the inner loop process model. It has three parameters, \( K \) the static gain, \( T \) the time constant and \( L \) is the dead time. The FOPDT model is used for \( G_2 \) because many industrial processes can be described well by this model and several tuning rules are based on this model [46].
5.5 Secondary Loop with Nonlinear PPI Control

By using open loop identification procedure, inner loop process model is obtained by applying a step signal to the process. A FOPDT transfer function of the fast dynamics of process can be calculated by estimating the step response. Then, the following transfer function is obtained,

\[ G_{p2}(s) = \frac{K_2 e^{-L_2 s}}{T_2 s + 1} \]  \hspace{1cm} (5.12)

Here, first will derive control law for inner loop as \( \hat{G}_{c2} \). The closed loop transfer function \( \hat{G}_{c2} \) is obtained with error feedback as,

\[ \hat{G}_{c2} = \frac{1}{G_{p2} \left( 1 - G_{o2} \right)} \]  \hspace{1cm} (5.13)

Solving this equation for \( G_{o2} \), we get

\[ G_{o2}(s) = \frac{G_{p2} G_{c2}}{1 + G_{p2} G_{c2}} \]  \hspace{1cm} (5.14)

If the closed-loop transfer function \( G_{o2} \) is specified and \( G_{p2} \) is known, then calculate \( \hat{G}_{c2} \). Assume that the desired closed-loop transfer function is identified as,

\[ G_{o2}(s) = \frac{e^{-Lms}}{1 + s\lambda_m T_m} \]

Where, \( \lambda_m \) is a tuning parameter. The time constants of the open and closed loop systems are the same when \( \lambda_m = 1 \). The closed-loop system responds faster than the open-loop system if \( \lambda_m > 1 \), and is slower when \( \lambda_m < 1 \). It follows from equation 5.13 that the controller transfer function becomes,

\[ \hat{G}_{c2} = \frac{U_2(s)}{E_2(s)} = \frac{1 + sT_2}{K_2(1 + s\lambda_m T_m - e^{-Lms})} \]  \hspace{1cm} (5.15)

After rearranging the above equation becomes,

\[ U_2(s) = \frac{1 + sT_2}{sK_2\lambda_m T_m} E_2(s) - \frac{1}{s\lambda_m T_m} (1 - e^{-Lms}) U_2(s) \]  \hspace{1cm} (5.16)

For simplification, consider \( T_2 = T_m \) and \( L_2 = L_m \)

\[ U_2(s) = \frac{1}{\lambda_m K_2} (1 + \frac{1}{sT_2}) E_2(s) - \frac{1}{s\lambda_m T_m} (1 - e^{-Lms}) U_2(s) \]  \hspace{1cm} (5.17)
Linear PPI controller with gain $K_{p2} = \frac{1}{\lambda_m T_m}$ and integral gain $T_{i2} = T_2$. Secondary controller in time domain form,

$$u_2(t) = K_{p2} e_2(t) + \frac{K_{p2}}{T_{i2}} \int_0^t e_2(t) - \frac{1}{\lambda_m T_{i2}} \int_0^t (1 - e^{-L_2t}) u_2(t)$$  

(5.18)

Here, linear PPI controller is replaced by nonlinear PI controller

$$u_2(t) = K_{p2}(1 + \beta_2 |e_2(t)|) + \frac{K_{p2}}{T_{i2}} \int_0^t e_2(t) - \frac{1}{\lambda_m T_{i2}} \int_0^t (1 - e^{-L_2t}) u_2(t)$$  

(5.19)

Here, error square type of nonlinear PI with predictive structure is employed for reducing effect of noises. As compare to linear controller, nonlinear PPI controller is more appropriate as the nonlinear PPI controller allow us to use a low value of gain. so that the system is stable near the set point over a broad range of operating levels. In this way, secondary controller is developed and its tuning parameters are determined from their process model.

### 5.6 Model Reduction

After completion of the designing of the secondary controller, the model of the process of the primary controller has to be determined. It is practical to determine a FOPDT transfer function as,

$$G_r(s) = \frac{K_r}{T_r(s) + 1} e^{-L_2s}$$  

(5.20)

Using this model we can apply a tuning rule for the primary controller. For this, the transfer function is given in the series of the inner loop and $G_m(s)$,

$$G_m(s) = \frac{\dot{G}_c G_2(s)}{1 + \dot{G}_c G_2(s)} G_1(s)$$  

(5.21)

To get rational transfer function the delay term $e^{-L_2s}$ is estimated by a first order approximation. Then, according to the method introduced by Sung (1998) determine the reduce order model i.e. identify the three parameters $K_r$, $T_r$ and $L_r$.

$$K_r = G_m(0)$$  

(5.22)

$$T_r = \frac{\sqrt{K_r^2 - |G_m(j\omega)|^2}}{|G_m(j\omega)|\omega l}$$  

(5.23)
Finally, dead time $L_r$ is determined as,

$$L_r = -\frac{\arg G_m(j\omega_c) + \arctan(\omega_c T_r)}{\omega_c}$$  \hspace{1cm} (5.24)

Where,

$\omega_c$ represent the critical frequency of the system.

$\omega_i$s represent the sufficient number of frequencies located with equal intervals between $0$ and $\omega_c$.

$\arg G_m(j\omega_c)$ is the set point of given argument for which the given function attains its maximum value.

$\arctan(\omega_c T_r)$ represent the inverse of the tangent $\omega_c T_r$.

The basis of this model reduction method is that, it provides a sufficiently good approximation.

### 5.7 Outer Loop with Nonlinear PPI Control

Above FOPDT transfer function $G_r(s)$ has been obtained, the primary controller can be developed by following same design procedure used in inner loop.

By using open loop identification procedure, outer loop process model is obtained by applying a step signal to the process. A FOPDT transfer function of the fast dynamics of process can be calculated by estimating the step response. Then, the following transfer function is obtained,

$$G_{p1}(s) = \frac{K_1 e^{-L_{1s}}}{T_{1s} + 1}$$  \hspace{1cm} (5.25)

Here, the main objective is to derive control law for outer loop as $\hat{G}_{c1}$. The closed loop transfer function $\hat{G}_{c1}$ is obtained with error feedback as,

$$\hat{G}_{c1} = \frac{1}{G_{p1}} \frac{G_{o1}}{1 - G_{o1}}$$  \hspace{1cm} (5.26)

Solving this equation for $G_{o1}$, we get

$$G_{o1}(s) = \frac{G_{p1} G_{c1}}{1 + G_{p1} G_{c1}}$$  \hspace{1cm} (5.27)
If the closed-loop transfer function \( G_{o1} \) is specified and \( G_{p1} \) is known, then calculate \( \tilde{G}_{c1} \). Assume that the desired closed-loop transfer function is identified as,

\[
G_{o1}(s) = \frac{e^{-Lms}}{1 + s\lambda_m T_m}
\]

Where, \( \lambda_m \) is a tuning parameter. The time constants of the open and closed loop systems are the same when \( \lambda_m = 1 \). The closed-loop system responds faster than the open-loop system if \( \lambda_m > 1 \), and is slower when \( \lambda_m < 1 \). It follows from equation 5.33 that the controller transfer function becomes,

\[
\tilde{G}_{c1} = \frac{U_1(s)}{E_1(s)} = \frac{1 + sT_1}{K_1(1 + s\lambda_m T_m - e^{-Lms})}
\]  

(5.28)

Rearrange the above equation

\[
U_1(s) = \frac{1 + sT_1}{sK_1\lambda_m T_m}E_1(s) - \frac{1}{s\lambda_m T_m}(1 - e^{-Lms})U_1(s)
\]  

(5.29)

For simplification, consider \( T_1 = T_m \) and \( L_1 = L_m \)

\[
U_1(s) = \frac{1}{\lambda_m K_1}(1 + \frac{1}{sT_1})E_1(s) - \frac{1}{s\lambda_m T_m}(1 - e^{-Lms})U_1(s)
\]  

(5.30)

Linear PPI controller with gain \( K_{p1} = \frac{1}{\lambda_m T_m} \) and integral gain \( T_{i1} = T_1 \). Secondary controller in time domain form,

\[
u_1(t) = K_{p1} e_2(t) + \frac{K_{p1}}{T_{i1}} \int_0^t e_1(t) dt - \frac{1}{\lambda_m T_{i1}} \int_0^t (1 - e^{-L_{i1}t})u_1(t)
\]  

(5.31)

Here, linear PPI controller is replaced by nonlinear PI controller

\[
u_1(t) = K_{p1}(1 + \beta_1|e_1(t)|) + \frac{K_{p1}}{T_{i1}} \int_0^t e_1(t) dt - \frac{1}{\lambda_m T_{i1}} \int_0^t (1 - e^{-L_{i1}t})u_1(t)
\]  

(5.32)

In this way primary controller is developed, afterwards tuning parameters of nonlinear cascade control is determined from formulae proposed by Koo [52]. However, the tuning and analysis of nonlinear PI/PID controllers is much more difficult than that of conventional linear PI/PID controllers. So that, optimal tuning procedure is applied to time delay systems for getting desired response.
5.8 Tuning of Controllers

Two nonlinear PPI control laws are applied to both process model to deal with disturbances, delay and noise effect occurred in control configuration. In nonlinear cascade control, error squared controller (nonlinear quadratic) (ESC) is also termed as nonlinear PI is employed in both loop, which is proposed by Shinskey [12]. It is usually used in averaging level and surge level control systems and some other applications. ESC acting as nonlinear PI controller with changeable proportional gain \( K_{pm} \). From control law, it can be seen that with increasing of error signal, proportional gain of controller is increased which has result decreasing of overshoot. In the case of small error signal, proportional gain \( K_p \) of ESC is decreasing which can lead to sluggish response and steady state error so that an integral part of control algorithm is added. A systematic tuning procedure for cascade control loops is described in this section. In this procedure, optimal tuning formulae obtains by using linear reversion of the dimensionless groups \( K_n K_p n, T_n T_n, \beta_n Y_{sp} \) and \( \beta_n D_{max} \). Here, \( n = 1 \) represents the primary process and \( n = 1 \) represents the secondary process model. This model has three parameters, the process gain \( K \), the time constant \( T \) and the dead time \( L \), Controller parameters are \( K_p \) as proportional gain and \( T_i \) as integral time constant. Nonlinear control methods are mostly used for linear processes to give better control performance than linear controllers. The tuning parameters of nonlinear PI are obtained by using the following formulae for the load changes [34],

Thus, once the tuning parameter is assigned to primary and secondary process then

<table>
<thead>
<tr>
<th>Table 5.1: Tuning Rules</th>
</tr>
</thead>
<tbody>
<tr>
<td>For Load Change</td>
</tr>
<tr>
<td>( K_n K_p n = 0.1682 \left( \frac{T_n}{T_n} \right)^{-1.164} )</td>
</tr>
<tr>
<td>( \frac{T_n}{T_n} = 1.49 \left( \frac{T_n}{T_n} \right)^{1.308} )</td>
</tr>
<tr>
<td>( \beta_n D_{max} = 10.61 - 6.164 \left( \frac{T_n}{T_n} \right) )</td>
</tr>
<tr>
<td>For set point change</td>
</tr>
<tr>
<td>( K_n K_p n = 0.1245 \left( \frac{T_n}{T_n} \right)^{-0.965} )</td>
</tr>
<tr>
<td>( \frac{T_n}{T_n} = 0.09 + 1.57 \left( \frac{T_n}{T_n} \right) )</td>
</tr>
<tr>
<td>( \beta_n D_{max} = 4.12 + 1.05 \left( \frac{T_n}{T_n} \right)^{0.763} )</td>
</tr>
</tbody>
</table>

desired output response is obtained.
5.9 Simulation Results

Example (1): The given example discussed by Hang and Tan [42] with plant models of

\[ G_{p1} = \frac{e^{-s}}{(1 + s)^2}; \quad G_{p2} = \frac{e^{-\alpha s}}{1 + \alpha s} \]  \hspace{1cm} (5.33)

Where, \( \alpha = 0.1 \) after identification procedure, the parameter for the inner loop process model is obtained as,

\[ G_{p2} = \frac{0.9563e^{-0.115s}}{(1 + 0.0947s)} \]  \hspace{1cm} (5.34)

The outer loop process model is estimated as,

\[ G_r \ast G_{p1} = \frac{0.9653e^{-1.63s}}{(1 + 1.908s)} \]  \hspace{1cm} (5.35)

The parameter calculated for the inner loop PI controller \( G_{c2} \) are, \( K_{p2} = 0.603, K_{i2} = 2.277 \) and outer loop controller parameters are, \( K_{p1} = 0.6592, K_{i1} = \frac{1}{T_{i1}} = 0.3536 \). In the proposed nonlinear predictive cascade control, parameters of slave controller are, \( K_{p2} = 0.1403, K_{i2} = \frac{1}{T_{i2}} = 5.4971, \beta_2 = 15.6234 \) Master controller parameters are, \( K_{p1} = 0.2094, K_{i1} = 0.4322, \beta_1 = 26.7205 \). In figure 5.3 step response of example (1) shows the closed loop performance from \( t = 0 \)sec to \( t = 500 \)sec a large step load disturbance sees in to the process for this case at \( t = 250 \) sec.

Example (2): In second example, the process model is,

\[ G_{p1} = \frac{e^{-4s}}{(1 + 5s)^2}; \quad G_{p2} = \frac{e^{-0.2s}}{1 + s} \]  \hspace{1cm} (5.36)

Using identification procedure, the parameters for inner and outer process models are assessed as,

\[ G_{p2} = \frac{1.213e^{-4.45s}}{(1 + 6.421s)}; \quad G_r \ast G_{p2} = \frac{1.105e^{-0.25s}}{(1 + 0.8s)} \]  \hspace{1cm} (5.37)

Initially, the tuning of the two controllers is, primary controller: \( K_{p1} = 1 \) and \( K_{i1} = 0.0833 \)
Secondary controller: \( K_{p2} = 0.5 \) and \( K_{i2} = 0.25 \) In suggested control method, parameters calculated for inner loop nonlinear PPI controller are,
$K_{p2} = 0.5895; K_{i2} = 3.8411$ and $\beta_2 = 18.4234$

While, control parameters for outer loop are,

$K_{p1} = 0.2125; K_{i1} = 0.1688$ and $\beta_1 = 25.1278$. The performance comparison study is carried out from $t = 0sec$ to $t = 100sec$. A large step load disturbance is added in to the process at time $t = 50sec$

**Example(3):** Consider a process model of boiler drum level system provided by Xu [34]. The goal is to control the exit temperature and the most significant disturbance is reduced. The inner and outer loop process models are given by,

$$G_{p1} = \frac{1.23467e^{-20s}}{(1 + 68s)^2}; G_{p2} = \frac{-0.064}{1 + 80s}$$

(5.38)

Here, cascade PI control parameters are formulated from identified model as,

$K_{p2} = 700$, $K_{i2} = 1$ and $K_{p1} = 30$, $K_{i1} = 12$. We can find the controller settings of nonlinear PPI in both loops.

Slave controller parameters are:

$K_{p2} = -0.00196$, $K_{i2} = \frac{1}{712} = 23.258$ and $\beta_2 = 35.123$

Master controller parameters are:
$K_{p1} = 2.5103, \ K_{i1} = 0.0645$ and $\beta_1 = 31.425$

Figure 5.4: Step Response of Example (2)

Figure 5.5: Step Response of Example (3) Boiler drum level system

Performance to the variations is analyzed in terms of ISE as shown in table. It proves the robust performance of proposed method. In order to compensate the effect of the delay in the both loops of cascade control, predictive scheme is applied. The
Table 5.2: Time domain specifications in simulation results at S.P=1, ts: Settling time in seconds.

<table>
<thead>
<tr>
<th>Type</th>
<th>NonlinearPPI</th>
<th>cascade</th>
<th>Cascadecontrol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example1</td>
<td>25</td>
<td></td>
<td>160</td>
</tr>
<tr>
<td>Example2</td>
<td>5</td>
<td></td>
<td>17</td>
</tr>
<tr>
<td>Example3</td>
<td>1000</td>
<td></td>
<td>1002</td>
</tr>
</tbody>
</table>

Table 5.3: Error performance indices in simulation results, ISE: Integral Square Error

<table>
<thead>
<tr>
<th>Type</th>
<th>Nonlinearpredictive</th>
<th>cascade</th>
<th>Cascadecontrol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example1</td>
<td>1.22</td>
<td></td>
<td>2.25</td>
</tr>
<tr>
<td>Example2</td>
<td>1.27</td>
<td></td>
<td>2.07</td>
</tr>
<tr>
<td>Example3</td>
<td>1.20</td>
<td></td>
<td>2.23</td>
</tr>
</tbody>
</table>

parameters of nonlinear PPI are selected according to tuning rules given in Table 5.1. Control law is implemented for disturbance rejection. Fig. 5.3 and Table 5.2 shows that if disturbance is added at t= 250 sec then also it gives better performance than cascade control system as it uses the control law. It shows that, nonlinear PPI with cascade has settling time 25 sec and cascade control has 160 second. Nonlinear PPI with cascade has reduced settling time than cascade control as it uses predictive scheme. Nonlinear PPI with cascade has reduced settling time 135 sec than cascade control in example 1, reduces 12 sec in example 2 and 2 sec in example 3. Table 5.3 shows that in example 1, proposed controller has ISE vale 1.22 and cascade control has 2.25, it proves the robust performance of proposed method. Similarly, in example 2 and example 3, if disturbance is added at t= 50 sec and t= 1500 sec respectively, then also nonlinear PPI with cascade gives better performance than cascade controller.
5.10 Conclusion

This chapter represented a modified nonlinear PPI method for the cascade control system. As the inner loop process acts much faster than outer loop in cascade control system, both inner loop and outer loop process model parameters can be obtained using well recognized method. In order to reject the disturbance and for better performance control law is used. Nonlinear PPI cascade control is well suited for time delay systems available in cascade control configuration. In order to compensate the effect of the delay, predictive scheme is applied. Table 5.2 shows that nonlinear PPI with cascade has reduced settling time than cascade control. In nonlinear cascade control, gain of both controller are varied by their respective error signal is illustrated for better performance than standard linear control. Finally, by using different examples like boiler drum level control, usefulness of the proposed method has been shown. Figure 5.3-5.5 shows that if disturbance is added in the process then also it gives better performance than cascade control. This method is very straight forward to minimize the effect of disturbance and for long delay time occurred in process.