2.12 Interaction and Decoupling


INTRODUCTION

In this section, the interaction between loops, the measurement of interaction, and the design of the algorithms used are illustrated through a case study of level control on a chemical reactor and flasher system. The achievement of noninteracting control, or decoupling, is one of the goals of multivariable control. The decoupling algorithm is simple, and the physical meaning of the individual decoupling elements is clear to the designer and the plant operator.

During the last decade, advanced process control methods have been extensively used in processing industries. However, these methods have usually been applied to large processing systems because the cost of software and process model development is rather high.

In applications where the process is small or is only a small part of a larger process, the use of advanced process control may not be economically justified. When this is the case, process control engineers can develop and implement multivariable control on their own. Decoupling control is a tool that can be used to reach this goal.

INTERACTING PROCESS EXAMPLE

Figure 2.12a illustrates the conventional level controls of a process consisting of a chemical reactor and a flasher. Such systems are typical subprocesses in many petrochemical plants.

As shown in Figure 2.12a, feeds 1 and 2 enter the reactor, and the product from the reactor is sent to the flasher. The pressure in the flasher is much lower than that in the reactor, and therefore the low boilers contained in the product are vaporized and are sent from the flasher to a downstream distillation column for recovery.

The liquid from the flasher is returned to the reactor under level control ($m_1$). The product flow from the reactor to the flasher is manipulated to control the level in the reactor. Therefore, when the reactor level rises, the level controller increases the product flow, which in turn causes the flasher level to rise. Inversely, when the flasher level rises, the level controller on the flasher increases the recycle flow, which in turn raises the reactor level.

The left side of Figure 2.12b illustrates the oscillation, which is caused by the interaction between the two level control loops. On the right side of the figure, the response obtained by “partial decoupling” is shown. This technique will be described later, after developing some general equations and comments about noninteracting control.

Decoupling the Process

Figure 2.12c illustrates a noninteracting or decoupled version of the previously described process, in which the interaction between the level loops has been eliminated.

The reactor product flow is set as the sum of signals $m_1$ and $m_2$, which are the output signals of the level controllers on the reactor and the flasher. The recycle flow is set as $am_1 + m_2$, where “$a$” is the fraction of the product flow that stays in the flasher base as a liquid.

When the reactor level increases, causing the direct acting LC-1 controller output to also rise by $\Delta m_1$, the liquid flow to the flasher base will increase by $a\Delta m_1$. However, the recycle flow also increases by $a\Delta m_1$ if the adder #2 is correctly adjusted.

Therefore, the flasher level remains unchanged and the interaction has been “decoupled.” A similar sequence of events occurs when the flasher controller output changes by $\Delta m_2$.

![FIG. 2.12a](image)

Level controls for reactor and flasher process without decoupling the interaction of the loops.
In this example, the process dynamics were very simple, and a noninteracting control system could be configured by direct physical interpretation of the process. In the following discussion a generalized approach will be described.

**Generalizing the Solution**

Figure 2.12d represents a control system having two controlled variables (such as levels of the reactor and the flasher in the previous example), $c_1(s)$ and $c_2(s)$, where $s$ is a complex variable.

The transfer functions of the processes are represented by $G(s)$ symbols, and the transfer functions of the two controllers are denoted by $F_{11}(s)$ and $F_{22}(s)$. The controller outputs are respectively $m_1(s)$ and $m_2(s)$. The set points of the controllers are designated by $r_1(s)$ and $r_2(s)$.

In a noninteracting control system, the decoupler elements $F_{21}(s)$ and $F_{12}(s)$ are added so that they will compensate for and thereby eliminate the process interactions designated as $G_{21}(s)$ and $G_{12}(s)$.

In order to build a decoupled control system, one would first obtain $F_{21}(s)$. The effect of $m_1$ to $c_2$ is transmitted from point "$P$" to "$Q$" via two (heavily drawn) paths, one through $G_{21}(s)$, the other through $F_{21}(s)$ and $G_{22}(s)$, and the sum of the two should be zero:

$$G_{21}m_1 + F_{21}G_{22}m_1 = 0$$  \[2.12(1)\]

Therefore,

$$F_{21} = -\frac{G_{21}}{G_{22}}$$  \[2.12(2)\]

Similarly, considering the influence of $m_2$ on $c_1$,

$$F_{12} = -\frac{G_{12}}{G_{11}}$$  \[2.12(3)\]

For a general case with $n$ controlled variables and $n$ manipulated variables, see Reference 4.

For the reactor and flasher system:

$$\begin{bmatrix} G_{11} & G_{12} \\ G_{21} & G_{22} \end{bmatrix} = \begin{bmatrix} -l(A_1s) & 0 \\ 0 & a(A_2s) \end{bmatrix}$$  \[2.12(4)\]

where $A_1$ and $A_2$ are, respectively, the cross-sectional areas of the reactor and the flasher. Consequently, the decoupler settings are

$$F_{21}(s) = -\frac{G_{21}}{G_{22}} = -\left(\frac{a}{A_2s}\right)(-A_1s) = a$$  \[2.12(5)\]

$$F_{12}(s) = -\frac{G_{12}}{G_{11}} = -\left(\frac{1}{A_1s}\right)(-A_2s) = 1$$  \[2.12(6)\]

Note that the values of $A_1$ and $A_2$ in Equation 2.12(4) do not appear in Equations 2.12(5) and 2.12(6) because they...
cancel out. In general, it is easier to estimate the ratios than to estimate the individual transfer functions. This is particularly so when only crude estimates are available.

**Measuring the Interactions**

Before an effort is made to design a noninteracting control system, it is desirable to have an idea of the amount of interaction that is present. A relative gain calculation, described in Section 2.25, serves this purpose.

Relative gain is defined as the open-loop gain when all the other loops are in manual, divided by the open-loop gain when all the other loops are in automatic.

\[
\lambda_{11} = \frac{\frac{\partial c_1}{\partial m_1}}{\frac{\partial c_1}{\partial m_2}}
\]  

2.12(7)

It can be seen from the block diagram in Figure 2.12d that if both \( F_{12}(s) \) and \( F_{21}(s) \) were nonexistent (i.e., if the single-variable control system of Figure 2.12a were implemented), the numerator in the relative gain calculation would be \( G_{11}(s) \) and the denominator would be

\[
\left( G_{11}G_{22} - G_{12}G_{21} \right) / G_{22}
\]

2.12(8)

because the control loop for \( c_2 \) would force \( m_2 \) to take on the value which would cause

\[
G_{22}m_1 + G_{21}m_2 = 0
\]

2.12(9)

If the value of \( a \) is 0.5, then from Equations 2.12(5) to 2.12(8):

\[
\lambda_{11} = 1/(1 - a) = 2.0
\]

2.12(10)

This means that when the recycle flow \( m_2 \) is manually fixed at a constant value (which is the numerator in Equation 2.12(7)), the effect of manipulating the reactor product flow \( m_1 \) to control the reactor level is twice as much as it is in the case when \( m_1 \) is automatically manipulated (the denominator in Equation 2.12(7)).

When the decoupler of Equation 2.12(5) is inserted into the loop (Figure 2.12d), \( c_2 \) does not vary when \( m_1 \) is changed. Therefore, output \( m_2 \) of controller \( F_{22} \) does not vary either, i.e., the denominator in Equation 2.12(7) is equal to the numerator and therefore the relative gain is 1.0. (As is shown in Section 2.25, \( \lambda_{22} = \lambda_{11} \).)

Therefore, the effect of manipulating the recycle flow \( m_2 \) can be treated similarly. Interaction between the two loops is significant.

**MERITS, DRAWBACKS, AND COMPROMISES**

Decoupling algorithms such as Equations 2.12(5) and 2.12(6) can be simple, and therefore their physical meanings can be easily understood by the designer and by the plant operators. After noninteracting control is implemented, the control loops can be easily tuned based on single-variable control theory (Section 2.35).

**Drawbacks**

When noninteracting control is implemented, a set point change applied to one controlled variable will have no effect on the other controlled variable(s).

In some other industrial process control systems interaction between control loops can be exploited to achieve overall
control. In other words, a noninteracting control system can be slower in recovery from an upset than an interacting one.

A more obvious drawback of decoupling can occur in the case when one of the $G_i$'s in Figure 2.12d has a positive zero, that is, for example,

$$G_{11} = \frac{(s - b)}{(s + c)}$$  \hspace{1cm} 2.12(11)

where $b$ and $c$ are positive constants. Such a process characteristic is called inverse response.\(^1\) In this case decoupler $F_{12}(s)$ in Equation 2.12(3) will have a term $(s - b)$ in the denominator, and the control system will provide poor performance and could become unstable.

**Partial and Static Decoupling**

Because of these potential drawbacks, it is recommended to give consideration to partial decoupling, i.e., to implement only some of the available decouplers. Likewise, it may be an advantage to use a smaller gain than complete decoupling would allow. Partial decoupling can be more robust and less sensitive to modeling errors,\(^5\) and in some cases it can achieve better control than complete decoupling does.

Another method of obtaining noninteracting control is through static decoupling.\(^6\) Here the objective is to eliminate only the steady-state interactions between loops. The static decouplers are obtained by $\lim_{s \to 0} F_{21}(s)$ and $\lim_{s \to 0} F_{11}(s)$ in Equations 2.12(2) and 2.12(3). In case of the reactor and flasher systems, the decouplers used are static decouplers.

**The Reactor–Flasher Example**

The right half of Figure 2.12b was obtained by setting the decoupler $F_{12}$ to 0.5 instead of using the 1.0 setting, which Equation 2.12(6) would have called for. The gain in the decoupler was halved to reduce the flow variation in the flasher overhead to the subsequent distillation column. In addition, decoupler $F_{21}(s)$ was not implemented at all. It was left out because the response of the flasher level is much faster (the cross-sectional area of the tank is smaller) than that of the reactor, and therefore variation in the flasher level, within reasonable limits, is not detrimental to the operation, while changes in the reactor level are.

As can be seen in Figure 2.12b, even with only partial decoupling, the variation in the reactor level is much reduced in comparison to the case without decoupling. It should be noted that this improvement occurred even though a drastic change in reactor feed #1 did substantially upset the flasher level.

**References**

2. Ibid, p.111.

**Bibliography**

