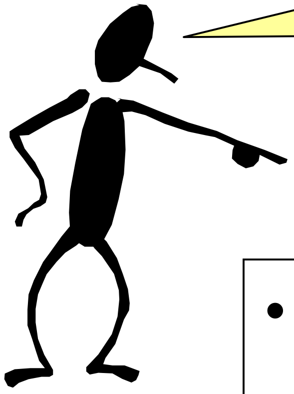
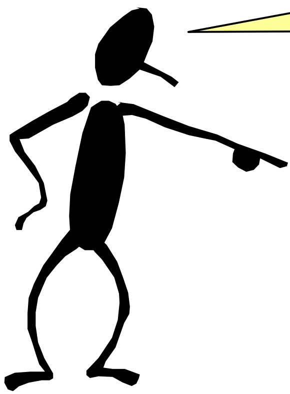
CHAPTER 21: Multiloop Control Performance



When I complete this chapter, I want to be able to do the following.

- Distinguish favorable and unfavorable interaction
- Balance controllability, integrity and dynamic performance
- Apply two methods for decoupling
- Properly select applications for decoupling

CHAPTER 21: Multiloop Control Performance



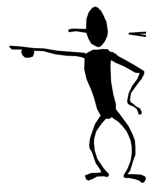
Outline of the lesson.

- Some observations on multiloop design performance
- The RDG, Relative Disturbance Gain
- Controllability and interaction
- Disturbance directionality
- Decoupling

MULTILOOP CONTROL PERFORMANCE

REQUIRED: **DOF, Controllability, Operating Window**

HIGHLY DESIRED



Let's learn how to achieve these good properties

- **Integrity** - **Performance is "acceptable after one or more controllers become inactive**

- **Control performance**

  - CVs achieve zero offset and low deviations from SP
  - MVs have acceptable dynamic variability

- **Robustness** - **Performance (not just stability) is achieved for a range of plant dynamics**

- **Range** - **Strong effect to compensate large disturbances**

MULTILOOP CONTROL PERFORMANCE

Motivating Example

No. 1 - Blending

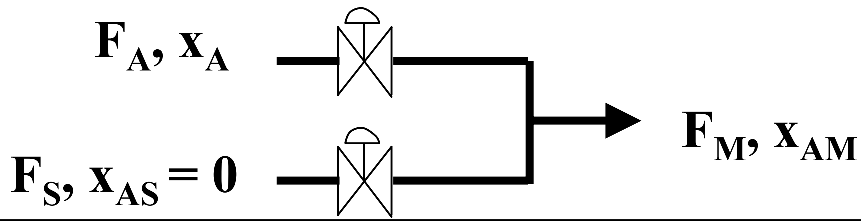


Table 20-4. Tuning for the blending system with dilute product (X_{xAM}=0.05, 8=0.95)

Tuning term	A_{xAM}-F_A controller (slow loop)		F_M-F_S controller (fast loop)	
	Single-loop	Multiloop	Single-loop	Multiloop
K_c (kg/min/wgt fraction)	105.	100	1.0	1.0
T_I (sec)	38.	38	2.6	2.6

Table 20-5. Tuning for the blending system with dilute product (X_{xAM}=0.05, 8=0.05)

Tuning term	A_{xAM}-F_S Pairing (slow loop)		F_M-F_A Pairing (fast loop)	
	Single-loop	Multiloop	Single-loop	Multiloop
K_c (kg/min/wgt fraction)	-2000.	-100	1.0	1.0
T_I (sec)	38.	38	2.6	2.6

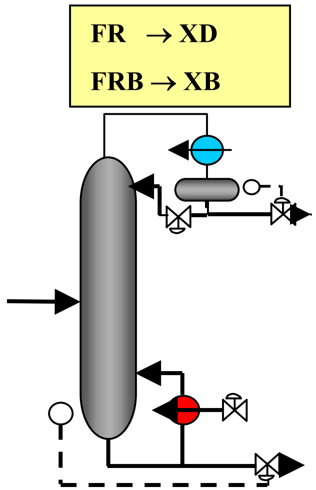
The design with RGA nearer 1.0 is better

Must retune when flow controller is in manual!

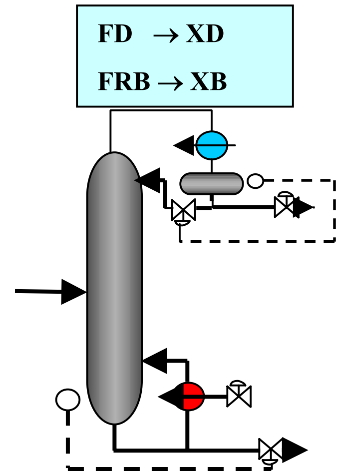
MULTILOOP CONTROL PERFORMANCE

Motivating Example No. 2 - Distillation SP Response

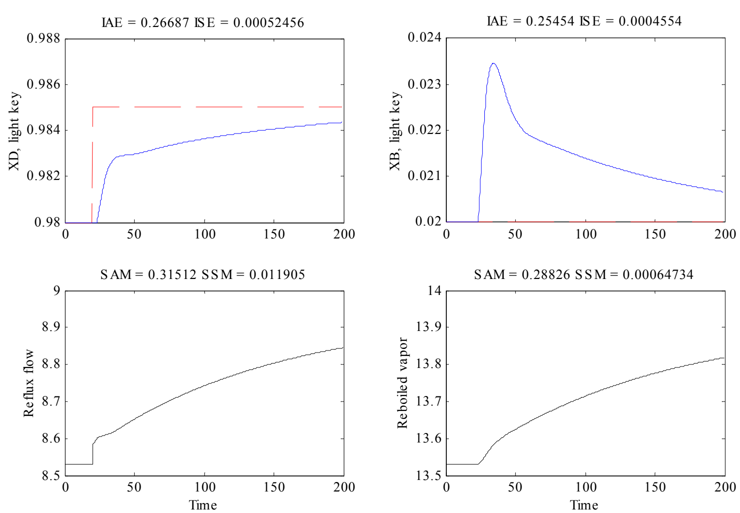
RGA = 6.09

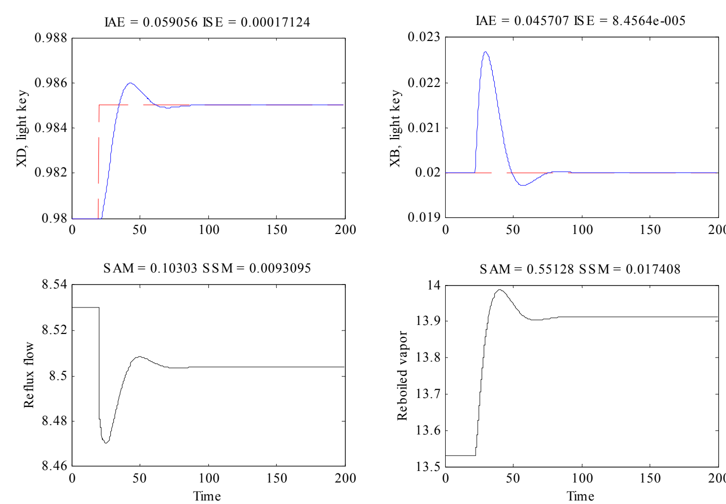


RGA = 0.39



For set point response, RGA closer to 1.0 is better



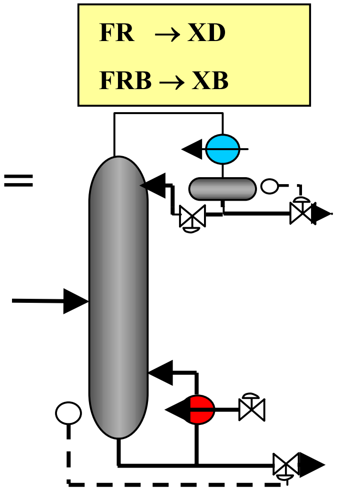


MULTILOOP CONTROL PERFORMANCE

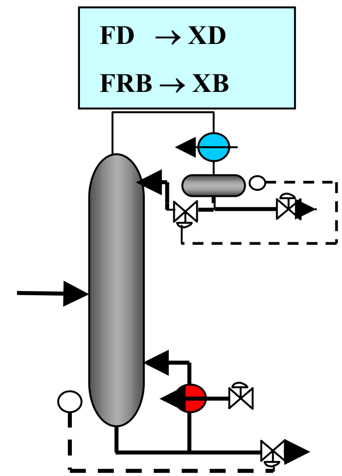
Motivating Example No. 3 - Distillation disturb. Response

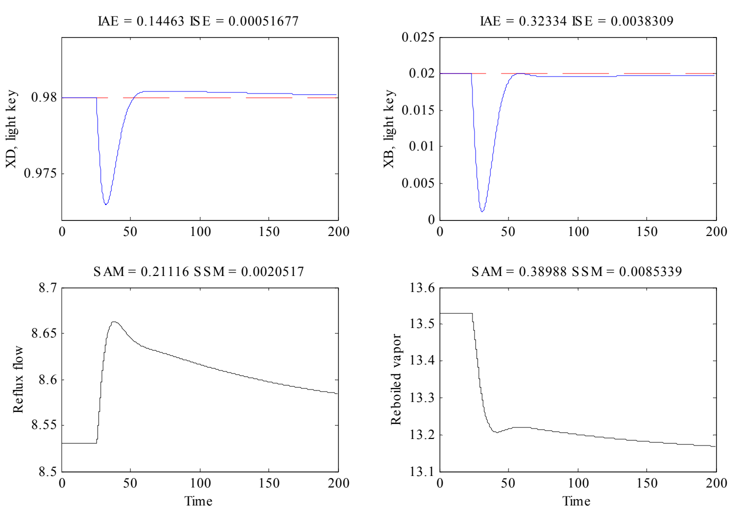
For set point response, RGA farther from 1.0 is better

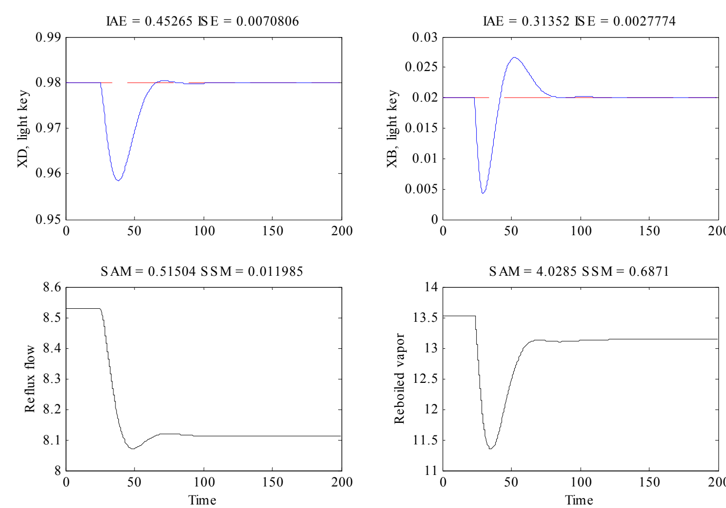
RGA = 6.09



RGA = 0.39

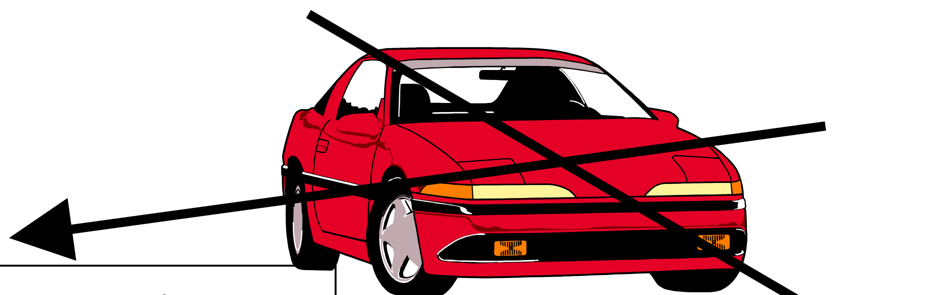






MULTILOOP CONTROL PERFORMANCE

- Conclusion from examples - RGA Alone does not provide sufficient information for control design
- Key missing information is disturbance type
- Key factor is the DISTURBANCE DIRECTION



Disturbances in this direction are difficult to correct.

Disturbances in this direction are easily corrected.

MULTILOOP CONTROL PERFORMANCE

Short-cut Measure of Multiloop Control Performance

- **We want to predict the performance using limited information and calculations**

- **We would like to have the following features**

  - Dimensionless

  - Based on process characteristics

  - Related to the disturbances type

MULTILOOP CONTROL PERFORMANCE

$$\int_0^\infty E_{ML}(t)dt = RDG \;\; f_{tune} \;\; \int_0^\infty E_{SL}(t)dt$$

<u>Relative Disturbance Gain</u>

- **dimensionless**
- **only s-s gains**
- **can be +/- and > or < 1.0**
- **different for each disturbance**
- **Usually the dominant term for interaction**

<u>Tune Factor</u>

Change in tuning for multi-loop

Single-loop performance (dead times, large disturbances, etc. are bad)

MULTILOOP CONTROL PERFORMANCE

$$\int_0^\infty E_{ML}(t)\,dt = RDG \;\; f_{tune} \;\; \int_0^\infty E_{SL}(t)\,dt$$

Relative disturbance gain

$$\left(\frac{1}{1-\left(K_{12}K_{21}/K_{11}K_{22}\right)}\right)\left(1-\frac{K_{d2}K_{12}}{K_{d1}K_{22}}\right)$$

$$\frac{\left(K_c/T_I\right)_{SL}}{\left(K_c/T_I\right)_{ML}}$$

$$\frac{K_D T_I}{K_p K_c}$$

What is the typical range?

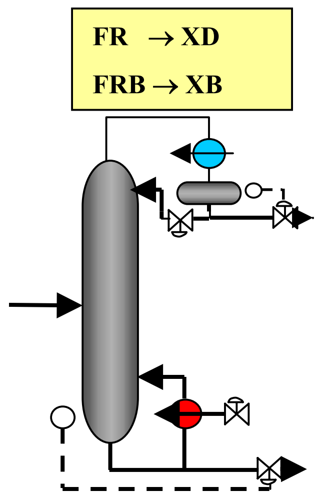
What unique information is here?

What is this term?

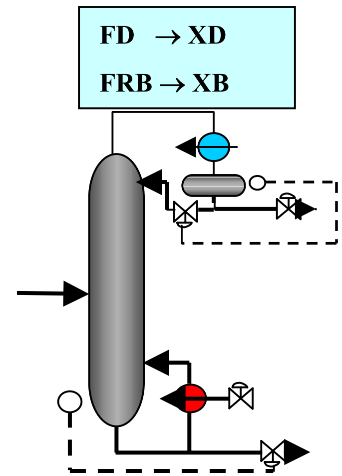
MULTILOOP CONTROL PERFORMANCE

Process Example: Binary Distillation with XD=.98, XB = 0.02

Energy Balance:



Material Balance:

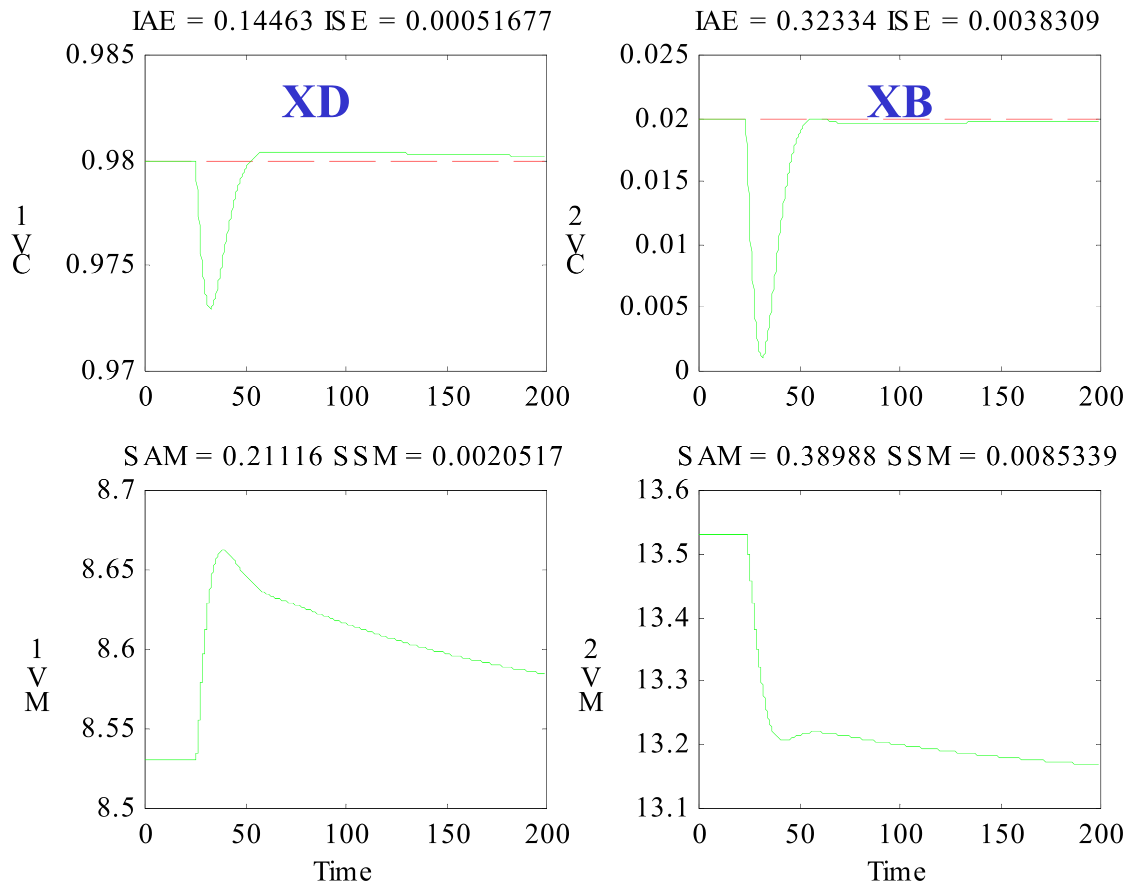


1. **Calculate the RGA, RDG, f_{tune}, and Ratio of integral errors for both loop pairings**
2. **Select best loop pairings**

MULTILOOP CONTROL PERFORMANCE

Distillation tower (R,V) with <u>both controllers in automatic</u> for feed composition disturbance

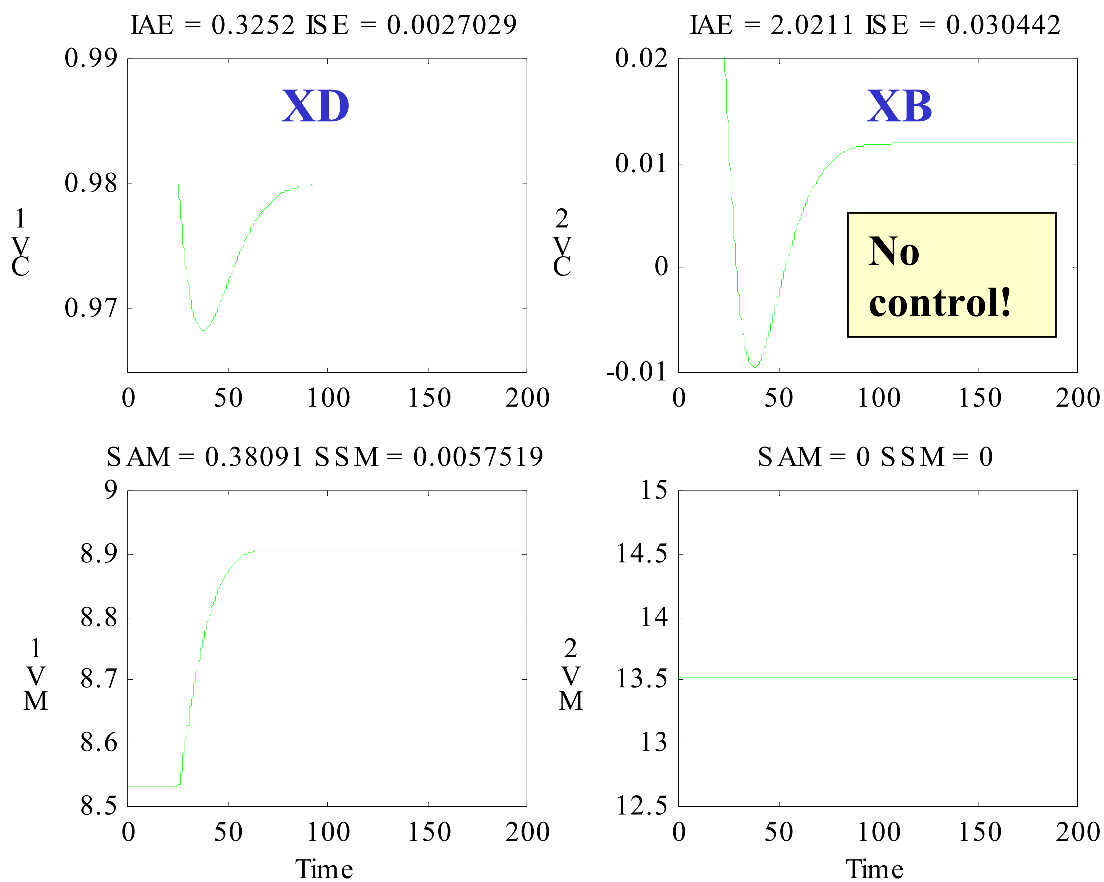
Good performance in spite of the large RGA



MULTILOOP CONTROL PERFORMANCE

Distillation tower (R,V) with <u>only XD</u> <u>controller in automatic</u> for feed composition disturbance

Favorable interaction results in small XB deviation although it is not controlled!

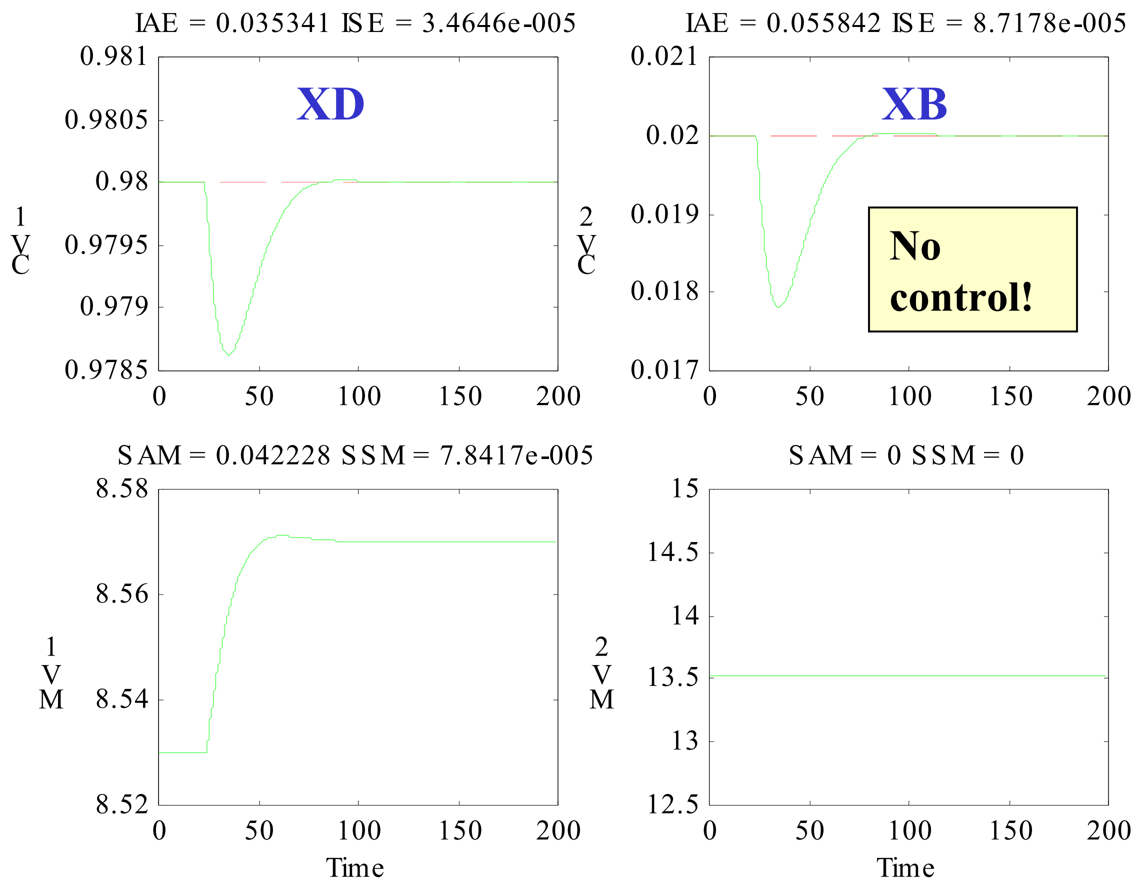


MULTILOOP CONTROL PERFORMANCE

Distillation Tower (R,V) with <u>only XD controller in automatic</u> and disturbance through FR model

Example is change in reflux subcooling.

Good performance in spite of the large RGA



MULTILOOP CONTROL PERFORMANCE

PRELIMINARY LOOP PAIRING GUIDELINE

Pair loops with good single-loop performance and favorable interaction, as indicated by a small |RDG|.

$$\int_0^\infty E_{ML}(t)dt = \underline{RDG} \; f_{tune} \; \underline{\int_0^\infty E_{SL}(t)dt}$$

Small = good SL performance

Small = favorable interaction

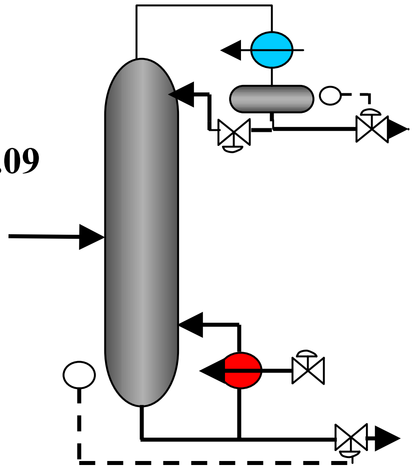
MULTILOOP CONTROL PERFORMANCE

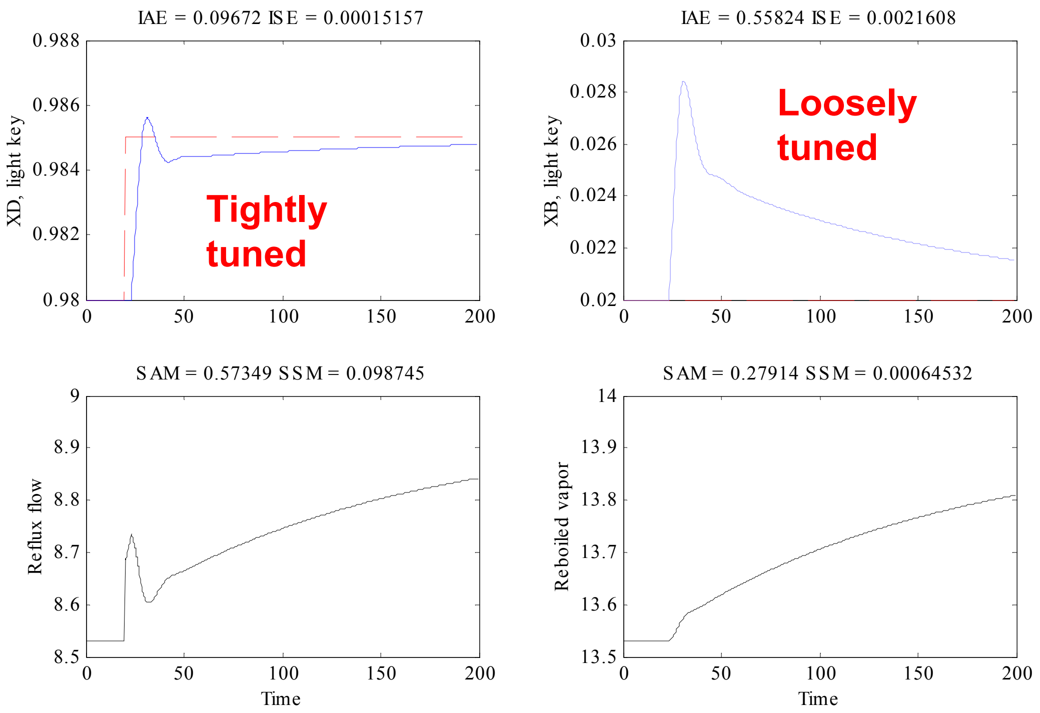
TAKING ADVANTAGE OF THE DYNAMICS

If unfavorable interaction exists in the best loop pairing, the effects of interaction can be reduced by tight tuning of the important loop and loose tuning of the less important loops.

FR → XD
FRB → XB

RGA = 6.09



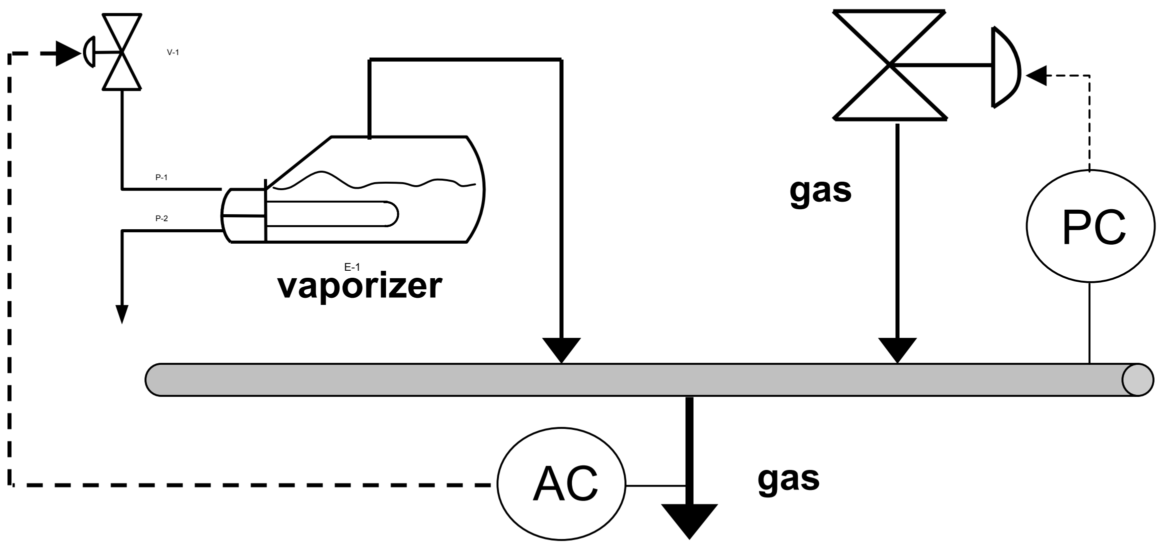


MULTILOOP CONTROL PERFORMANCE

TAKING ADVANTAGE OF THE DYNAMICS

Seek MV-CV pairings that provide fast feedback control for the more important loops. This tends to match the dynamic performance with the control objectives.

Evaluate the loop pairing for this process example, which supplies gas to a consumer from two sources.



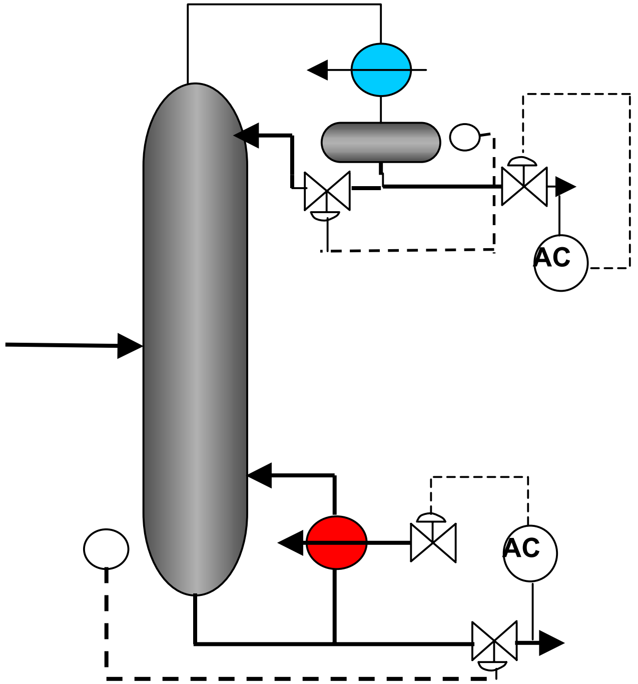
A = composition

MULTILOOP CONTROL PERFORMANCE

PROVIDING LARGE RANGE (OPERATING WINDOW)

- **For most important CVs, select an MV with large range.**
  - If other loops are in manual, the important loop retains large operating window.

- **Provide "extra" MV using split range capabilities.**



Discuss the range available when

1. **Both loops are in automatic.**
2. **Only one loop is in automatic.**

MULTILOOP CONTROL PERFORMANCE

PROVIDING INTEGRITY

- **Favor loop pairings with positive relative gains.**

  - Only use negative RGA if very advantageous dynamics
  - Use zero RGA very carefully for dynamic advantage

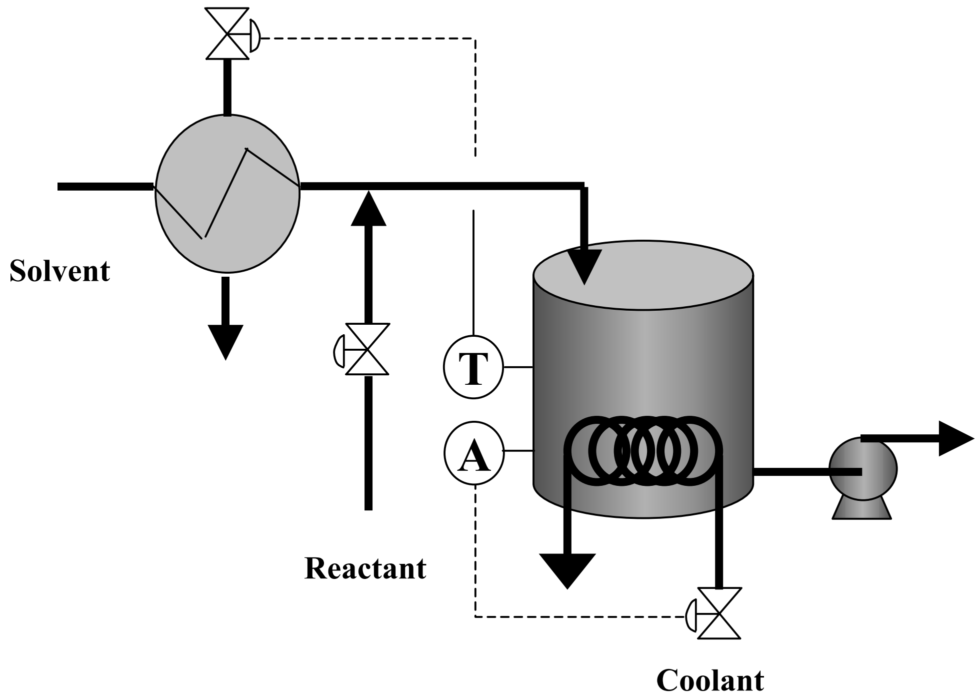
- **If non-positive RGA used, add monitor to alarm operator when other loop is inactive**

- **Consider the effects of RGA on tuning. Avoid high multiloop gains that lead to unstable single-loop systems.**

MULTILOOP CONTROL PERFORMANCE

RETAINING CONTROLLABILITY

Do not implement a loop that eliminates the causal relationship of another loop.

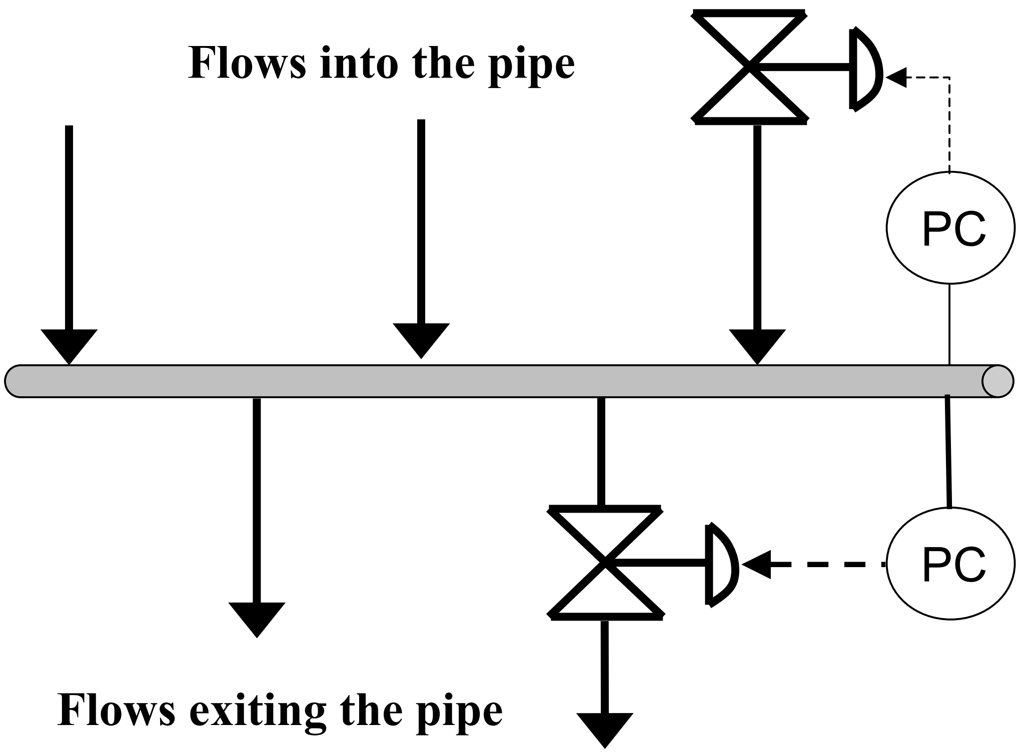


- **Evaluate the design, specifically the control of the concentration in the reactor**
- **Suggest an alternative design**

MULTILOOP CONTROL PERFORMANCE

RETAINING CONTROLLABILITY

Do not control the same variable with two loops with the same set point.

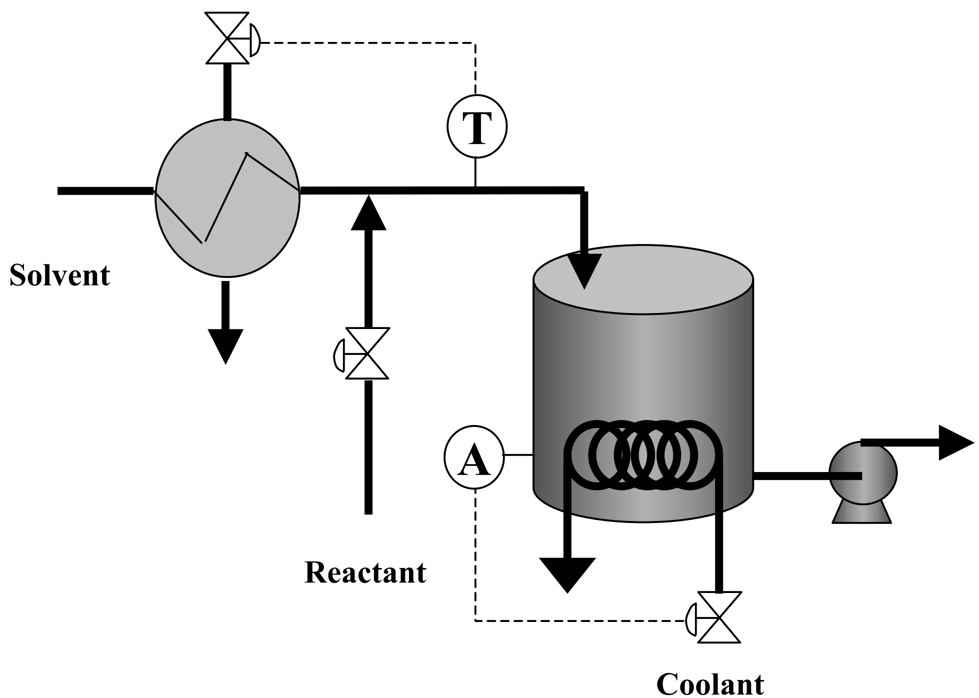


- **What problems could occur if the two PCs had the same set point?**
- **Why would we use different set points?**
- **Would the system function with different set points?**

MULTILOOP CONTROL PERFORMANCE

REDUCING EFFECTS OF DISTURBANCES

Implement loops that reduce the effects of disturbances before they affect the key controlled variables.



- How does this design satisfy the rule above.
- Suggest additional methods for reducing the effects of disturbances

MULTILOOP CONTROL PERFORMANCE

REDUCING THE EFFECTS OF UNFAVORABLE INTERACTION USING DECOUPLING

- **Retains the single-loop control algorithms**
- **Reduces (eliminates) the effects of interaction**
- **Three approaches**

  - Implicit decoupling: Calculated MVs

  - Implicit decoupling: Calculated CVs

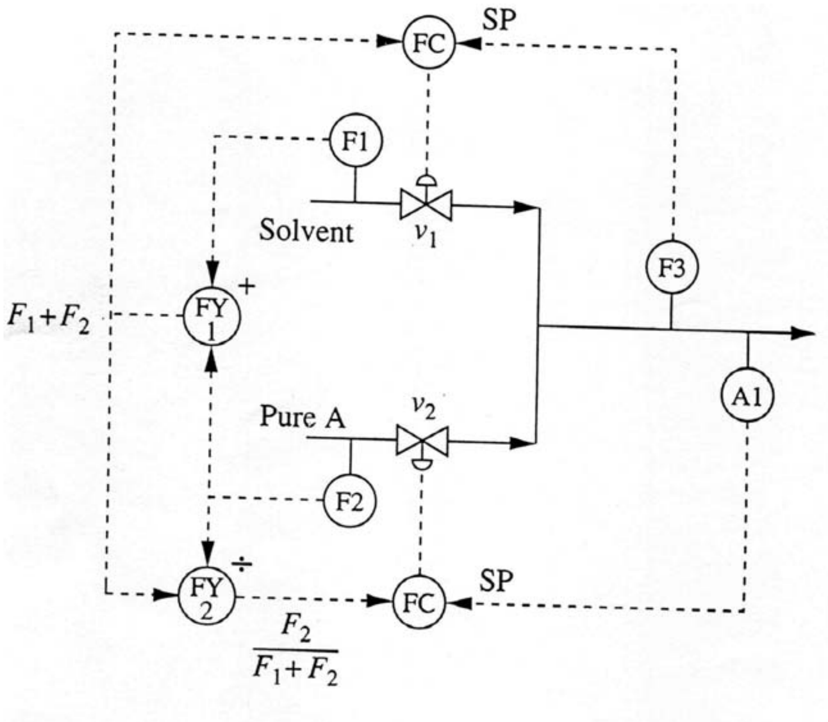
  - Explicit decoupling: Controller compensation

MULTILOOP CONTROL PERFORMANCE

IMPLICIT DECOUPLING: CALCULATED MVs

$$\tau_A \frac{dA_1}{dt} = \frac{F_2}{F_1 + F_2} - A_1 = MV_1 - A_1$$

$$\tau_F \frac{dF_3}{dt} = (F_1 + F_2) - F_3 = MV_2 - F_3$$



- How can we adjust these calculated variables?
- Are there any special tuning guidelines?

MULTILOOP CONTROL PERFORMANCE

IMPLICIT DECOUPLING: CALCULATED CVs

$$A\frac{d(L_1' + L_2')}{dt} = (F_{1in}' + F_{2in}') - (F_1' + F_2')$$

$$A\frac{d(L_1' - L_2')}{dt} = (F_{1in}' - F_{2in}') + 2K(L_1' - L_2') - (F_1' - F_2')$$

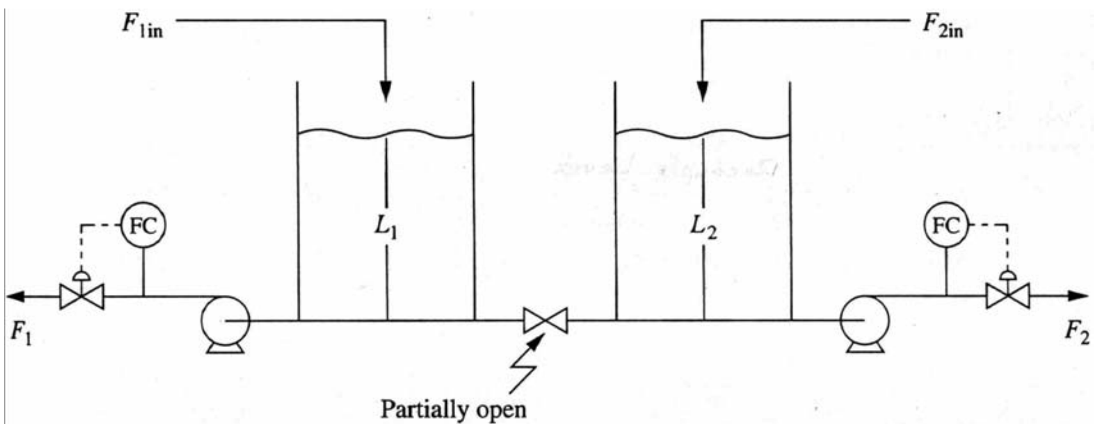


FIGURE 21.10

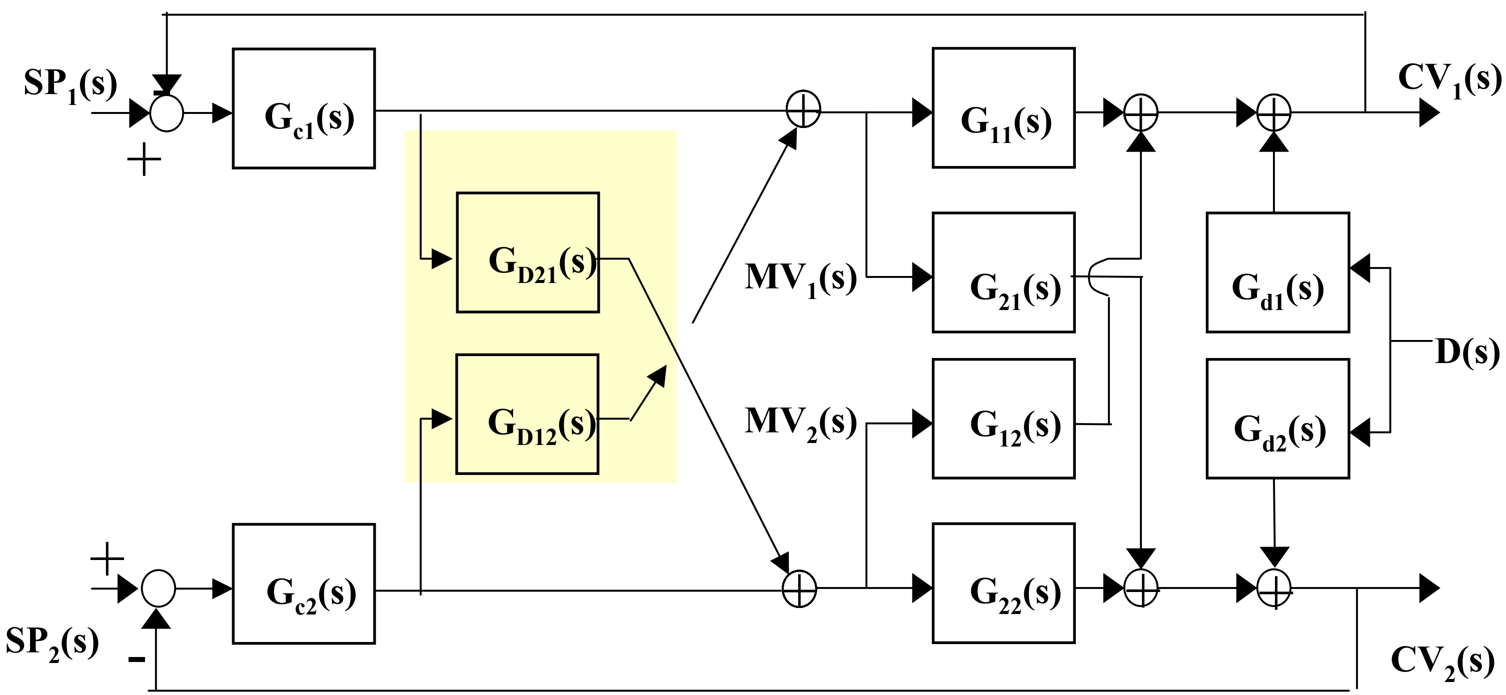
Level process.

- **How can we control these calculated variables?**
- **Are there any special tuning guidelines?**

MULTILOOP CONTROL PERFORMANCE

REDUCING THE EFFECTS OF UNFAVORABLE INTERACTION USING EXPLICIT DECOUPLING

- Compensates for the effects of interaction

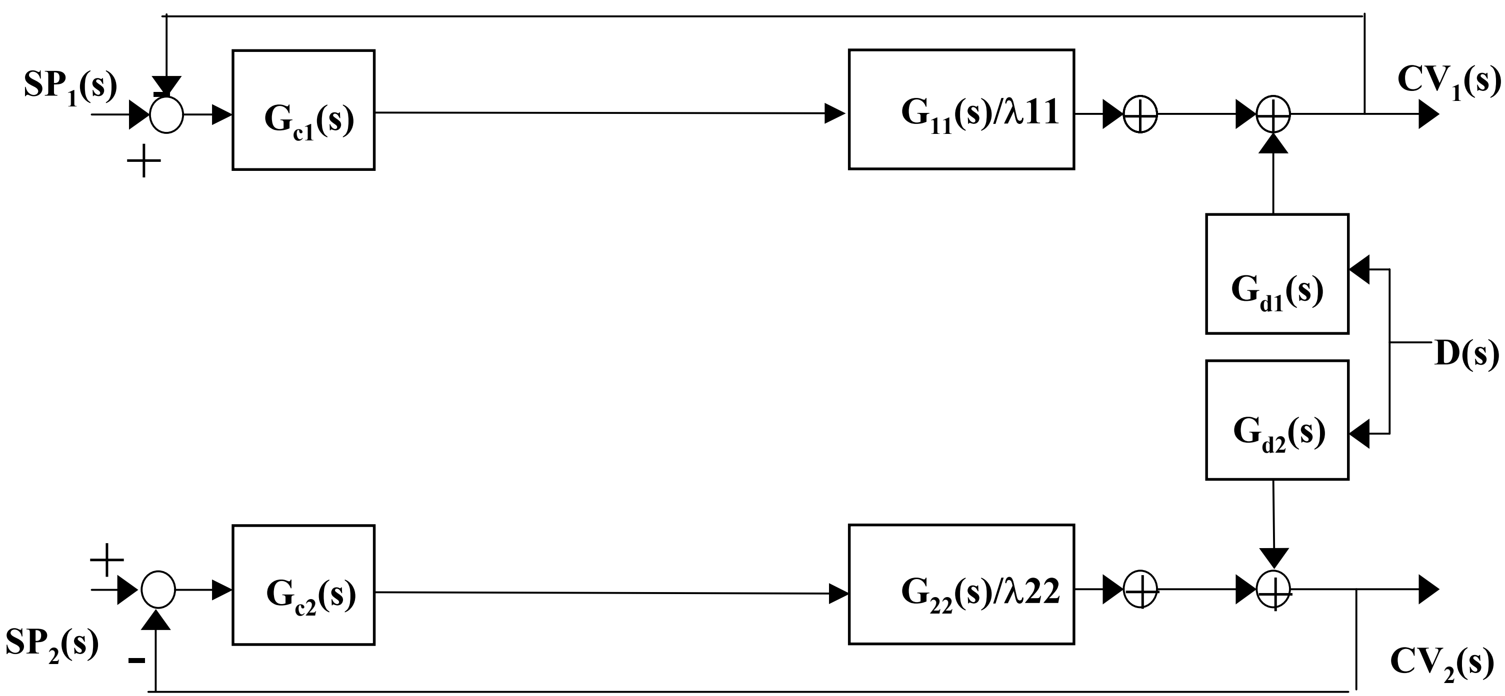


MULTILOOP CONTROL PERFORMANCE

Decoupling - Perfect decoupling compensates for interactions

One design approach:

$$G_{Dij}(s) = -\frac{G_{ij}(s)}{G_{ii}(s)}$$



Decoupling - Deciding when to decouple

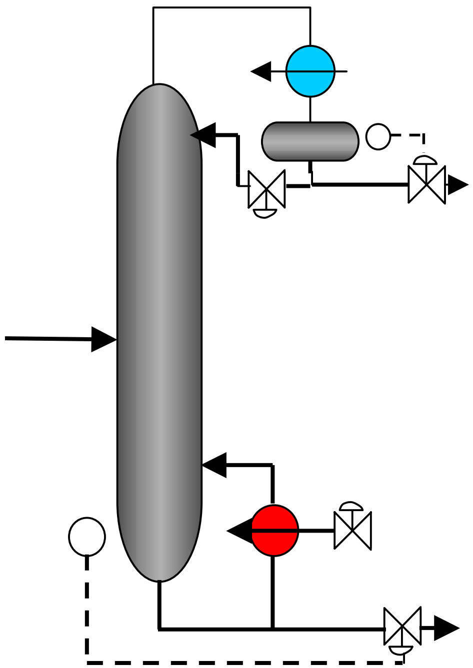
Interpretation	Decision
Favorable interaction	Do not decouple
No significant difference	Do not decouple
Unfavorable interaction	Decouple (see next item)

MULTILOOP CONTROL PERFORMANCE

Which decoupling do you recommend?

FR $\rightarrow$ XD

FRB $\rightarrow$ XB

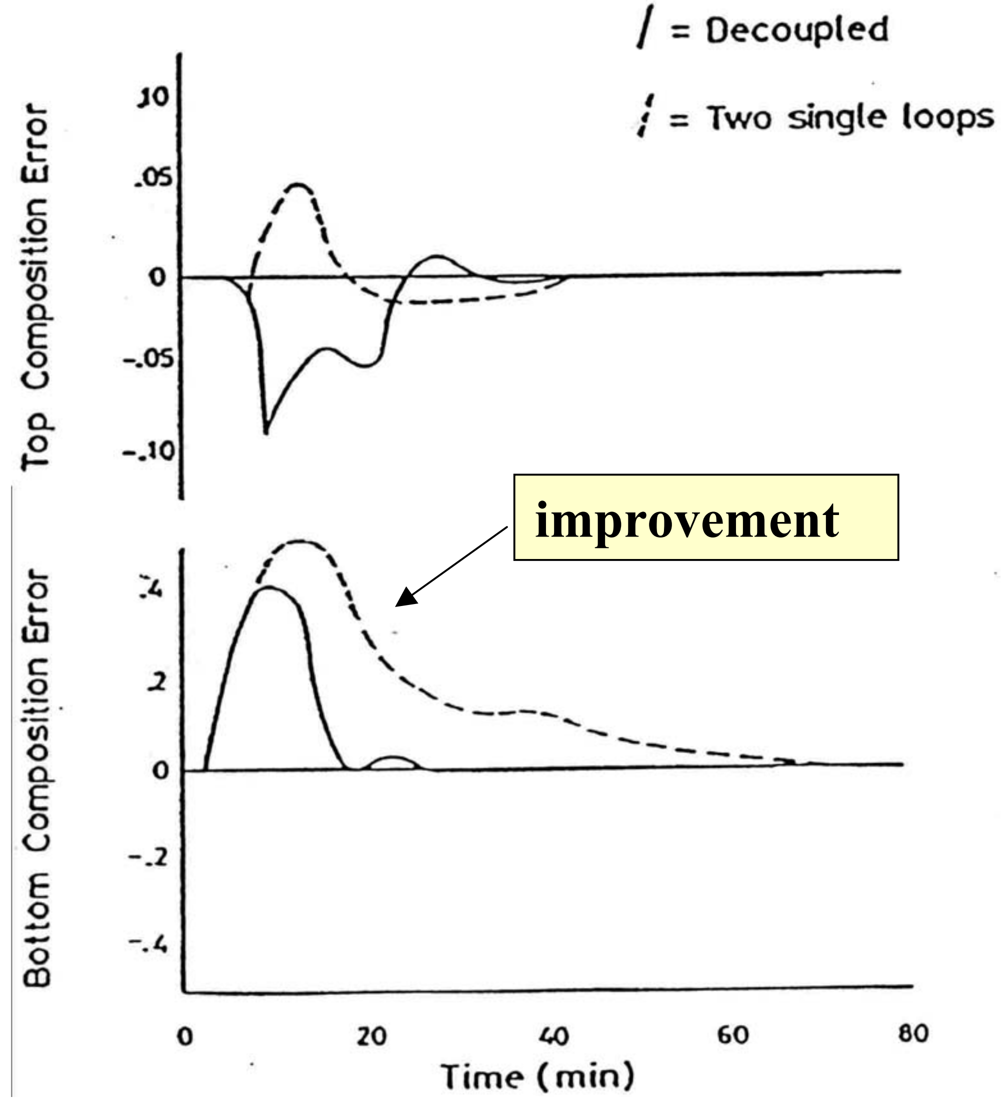


	RDG	Tuning factor (with Kc_{ML} =$(Kc)_{SL}/\lambda$)	$\dfrac{\int E_{ML}}{\int E_{Dec}} = \dfrac{\int E_{ML}}{\int E_{SL}}$
XD	-0.50	1.55	-0.77
XB	1.2	1.55	1.85

MULTILOOP CONTROL PERFORMANCE

Simulation confirms that top-to-bottom decoupling improves XB control performance.

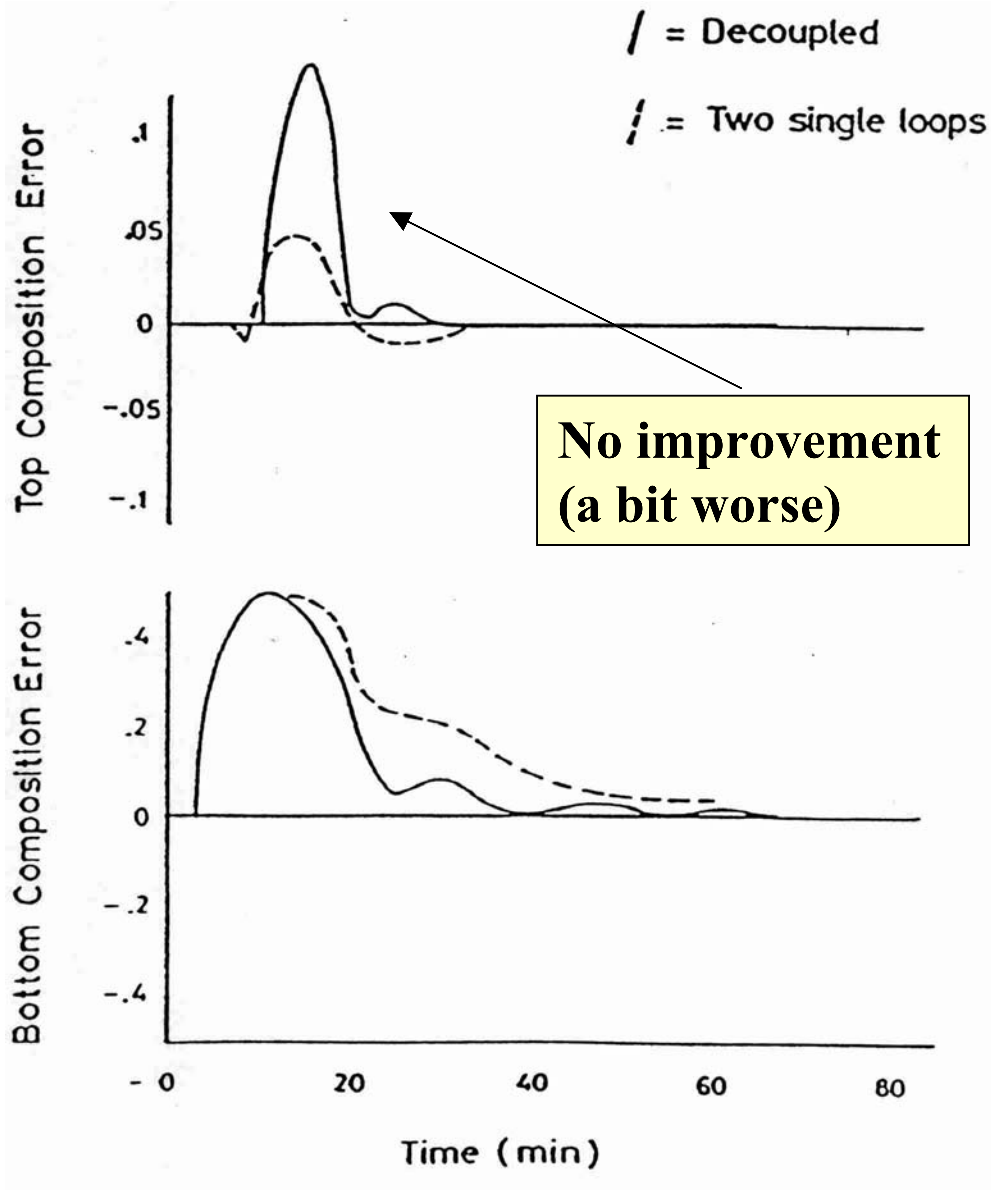
$|RDG^* f_{tune}| > 1.0$



MULTILOOP CONTROL PERFORMANCE

Simulation confirms that bottom-to-top decoupling does not improve XD control performance.

$$|RDG^*f_{tune}| < 1.0$$

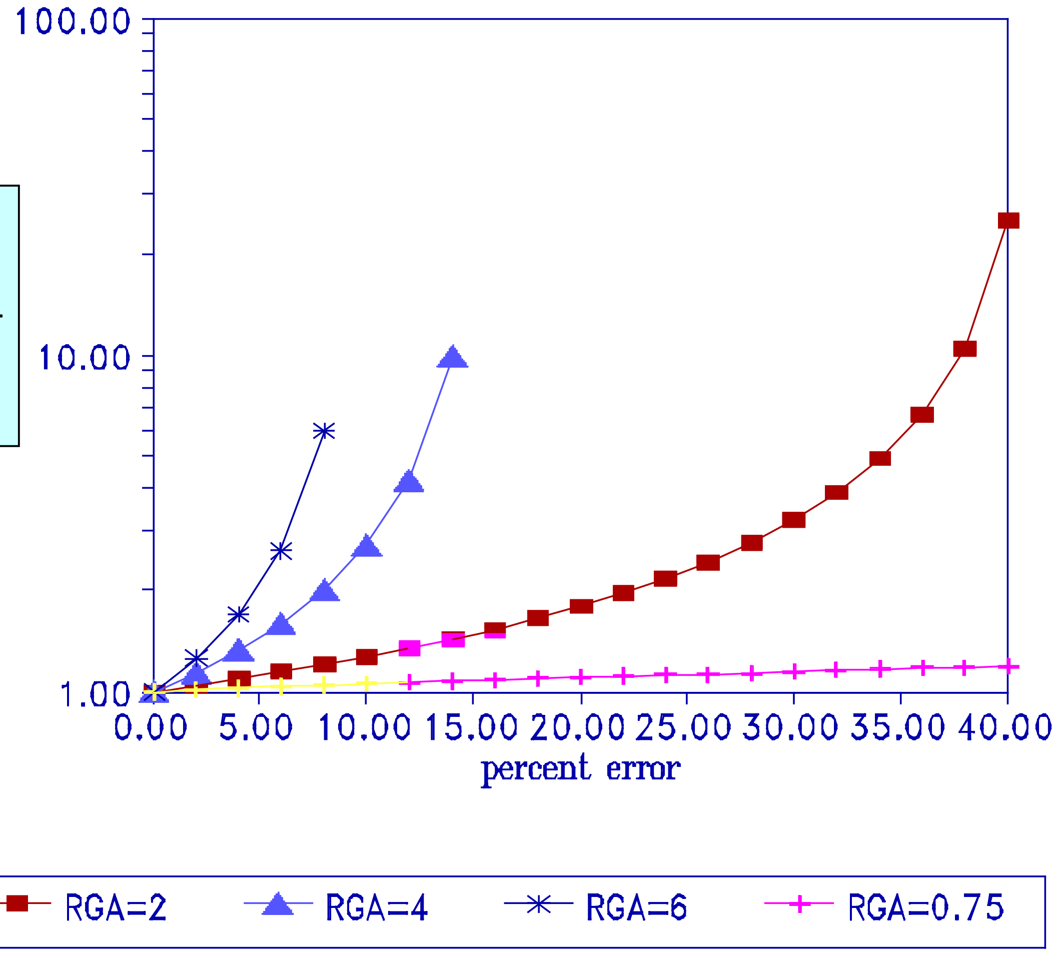


MULTILOOP CONTROL PERFORMANCE

Decoupling - A large relative gain indicates extreme sensitivity to modelling errors can occur

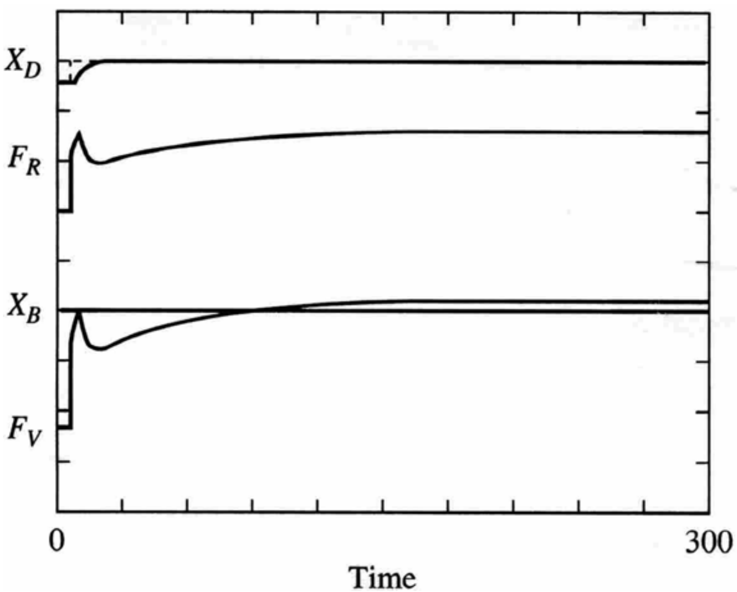
$$\frac{\int |E_{2-wayDecouple}|\,dt}{\int |E_{1-wayDecouple}|\,dt}$$

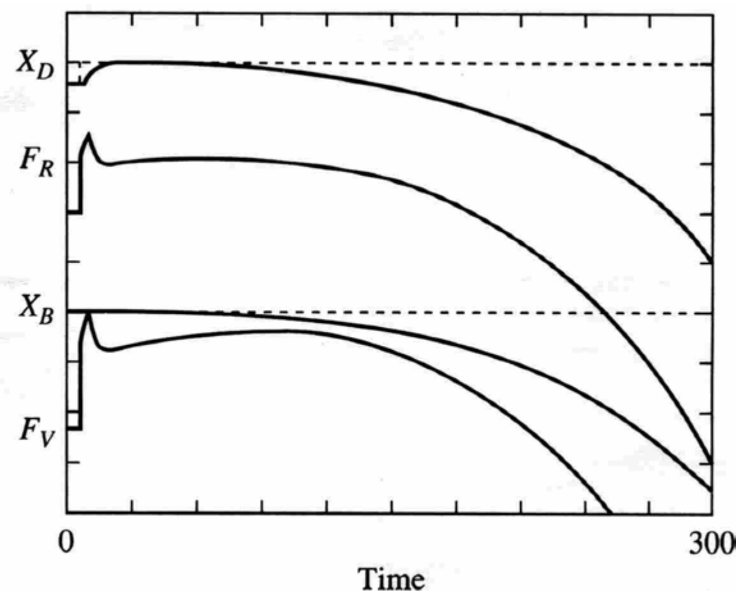
(Worst case mismatch)



MULTILOOP CONTROL PERFORMANCE

Decoupler performance can be <u>very sensitive</u> to gain errors. If possible, use process knowledge in determining plant gains, K_{ij}.





Decoupler with no errors; excellent performance!

Decoupler with 15% gain errors, unstable!

MULTILOOP CONTROL PERFORMANCE

Decoupling

- Because the closed-loop system changes, the controller must be retuned by approximately the relative gain, $(Kc)_{dec} \approx \lambda\ (Kc)_{SL}$.
- When a valve saturates, the "other" loops need to be retuned again!
- The behavior with integral windup is complex.
- Why not use MPC?

MULTILOOP CONTROL PERFORMANCE

CONCLUSIONS

- **CONTROL PERFORMANCE DEPENDS STRONGLY ON THE DISTURBANCE**

  - Multiloop systems have directions that are easy/difficult to achieve

  - Multiloop performance can be worse or better than SL

- **SHORT-CUT METHOD IS AVAILABLE TO EVALUATE MULTILOOP PERFORMANCE**

  - RDG uses steady-state gains

  - Large value is BAD; small value might be good (careful of +/- cancellation)

MULTILOOP CONTROL PERFORMANCE

Complete the following table with recommendations for control design

	Small RGA	Large RGA
Small RDG Favorable interaction		
Large RDG Unfavorable interaction		