Slovak University of Technology in Bratislava
Institute of Information Engineering, Automation, and Mathematics

PROCEEDINGS

17^{th} International Conference on Process Control 2009
Hotel Baník, Štrbské Pleso, Slovakia, June 9 – 12, 2009
ISBN 978-80-227-3081-5
http://www.kirp.chtf.stuba.sk/pc09

Editors: M. Fikar and M. Kvasnica

Osuský, J., Veselý, V.: Decentralized Controller Design with Interaction Rejection, Editors: Fikar, M., Kvasnica, M., In *Proceedings of the 17th International Conference on Process Control '09*, Štrbské Pleso, Slovakia, 125–128, 2009.

Full paper online: http://www.kirp.chtf.stuba.sk/pc09/data/abstracts/021.html

DECENTRALIZED CONTROLLER DESIGN WITH INTERACTION REJECTION

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Abstract: The paper presents independent decentralized controller design approach with interaction rejection for MIMO systems. Presented method can be used for decentralized control design or for tuning of multivariable systems. Controller gains are as small as possible what decrease noise sensitivity of the system. The approach is demonstrated on example.

Keywords: decentralized control, independent design, interaction rejection, PID controller.

1 INTRODUCTION

Two main approaches to SISO controller tuning are as follows: 1) Tight control: Fastest possible control subject to achieving acceptable robustness (Astrom and Hagglund 1995, Skogstad 2003, Ziegler and Nichols, 1942); and 2) Smooth control: Slowest possible control subject to achieving acceptable disturbance rejection (Skogestad, 2006). Although “smooth” control is probably the more common objective in industrial practice, almost all published proportional-integral-derivative (PID) tuning rules aim at tight control and similar is it with tuning of MIMO systems (Hovd and Skogestad, 1994, Hovd and Skogestad, 1993, Kozakova 1998, Viswanadham and Taylor, 1988).

In this paper method for decentralized control with interaction rejection of system is proposed. This method is based on smooth PID control tuning with acceptable disturbance rejection proposed by (Skogestad 2006). Rules for disturbance rejection in SISO systems are used for interaction rejection in multivariable systems. Design procedure is illustrated on example of multivariable system with two inputs and two outputs.

2 PRELIMINARIES AND PROBLEM FORMULATION

Consider that the input-output pairing was done and diagonal pairing is preferred. Effect of interactions in multivariable system can be considered similar as disturbance in SISO systems. Assume feedback control system with disturbance Fig. 1.

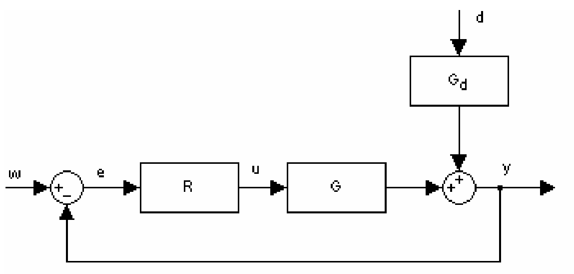

Fig. 1 Block diagram of feedback control system

In multivariable plant it is possible in each subsystem instead of disturbance transfer function $G_d(s)$ connect transfer functions which represent interactions from other subsystems. If interactions are not too large that can cause instability, it can be handling by subsystem controller design as a disturbance in SISO system.

Problem formulation:

Design decentralized controller using independent design method where interactions will be considered as disturbance in subsystem and local controllers gain will be as small as possible. Small gains of local controllers will have positive effect noise sensitivity of system.

3 THEORETICAL RESULTS

3.1 *Disturbance rejection for SISO system*

Smooth PID control with acceptable disturbance rejection was proposed by [Skogestad, 2006]. The author derived lower limit on the frequency-dependent controller gain for first order plus delay $G(s)=\frac{k}{s\tau+1}e^{-\theta s}$ processes as

$$|R(j\omega)|\geq|R_{\min}(j\omega)|=\frac{|G_d(j\omega)|}{|G(j\omega)|}\cdot\frac{|d_0|}{|y_{\max}|} \quad (1)$$

where

$G_d(j\omega)$ - Disturbance transfer function

$G(j\omega)$ - System transfer function

$|d_0|$ - Magnitude for any sinusoidal disturbance ($d(t)=d_0\sin\omega t$)

$|y_{\max}|$ - Upper limit for deviation of resulting output y

For first order plus time delay processes PI controller structure is sufficient, moreover derivative part increase noise sensitivity of closed-loop what is undesirable.

Controller gain can be calculated as follows

$$K_R=\max_{\omega}\left(\frac{|G_d(j\omega)|}{|G(j\omega)|}\cdot\frac{|d_0|}{|y_{\max}|}\right) \quad (2)$$

Integral part of PI controller $R_{PI}=K_R(1+\frac{1}{T_i s})$ is than calculated as

$$T_i=\min(\tau,4(\tau_c+\theta)) \quad (3)$$

where

$$\tau_c=\frac{\tau}{K_R k}-\theta \quad (4)$$

Controller designed with this approach ensures output value deviation $y(t)<|y_{\max}|$ for any sinusoidal disturbance d of magnitude $|d|$. However controllability condition

$$\theta<0.5\frac{|\tau|}{|k|}\frac{|y_{\max}|}{|d_0|} \quad (5)$$

has to be satisfied because otherwise the process is not controllable with any controller.

3.2 *Interaction rejection in multivariable system*

If in (1) for each subsystem, disturbance transfer function is replaced by transfer functions of interaction and magnitude of disturbance is replaced by average value of controller output, than for $k-th$ subsystem $G(s)\in R^{mxm}$ we obtain:

$$|R_k(j\omega)|\geq|R_{\min k}(j\omega)|=\frac{\sum_{j=1;j\neq k}^{m}|G_{kj}(j\omega)||u_j|}{|G_{kk}(j\omega)|}\cdot\frac{1}{|y_{\max k}|} \quad (6)$$

For simplicity consider only system with two inputs and two outputs.

$$|R_1(j\omega)|\geq|R_{\min 1}(j\omega)|=\frac{|G_{12}(j\omega)|}{|G_{11}(j\omega)|}\cdot\frac{|u_2|}{|y_{\max 1}|} \quad (7)$$

$$|R_2(j\omega)|\geq|R_{\min 2}(j\omega)|=\frac{|G_{21}(j\omega)|}{|G_{22}(j\omega)|}\cdot\frac{|u_1|}{|y_{\max 2}|} \quad (8)$$

Similar equation (2) can be changed into form

$$K_{R1}=\max_{\omega}\frac{|G_{12}(j\omega)|}{|G_{11}(j\omega)|}\cdot\frac{|u_2|}{|y_{\max 1}|} \quad (9)$$

$$K_{R2}=\max_{\omega}\frac{|G_{21}(j\omega)|}{|G_{22}(j\omega)|}\cdot\frac{|u_1|}{|y_{\max 2}|} \quad (10)$$

(1) and (2) were derived for sinusoidal signal d but by interaction rejection this signal is replaced by controller output u_i. $|u_i|$ can be obtain from controller output settling value by system retuning or can be estimate from transfer function.

Controller output signal is “better” than sinusoidal signal what can express as reserve between $|y_{\max}|$ and $y(t)$.

After controller gain, from (3), (4) integral part of controller is calculated. $|y_{\max i}|$ is used to quality determination and minimal values of $|y_{\max i}|$ can be calculate from (5)

$$|y_{\min i}| > \frac{\theta_i |k| \sum_{j=1, j\neq i}^{m} |u_j|}{0.5|\tau_i|} \qquad (11)$$

Respectively for system with two inputs and two outputs

$$|y_{\min 1}| > \frac{\theta_1 |k_1| |u_2|}{0.5|\tau_1|}$$

and

$$|y_{\min 2}| > \frac{\theta_2 |k_2| |u_1|}{0.5|\tau_2|} \qquad (12)$$

4 EXAMPLE

Example: System with two inputs and outputs

$$G(s) = \begin{bmatrix} \frac{4e^{-0.5s}}{6s+1} & \frac{2e^{-s}}{6s+1} \\ \frac{3e^{-3s}}{10s+1} & \frac{5e^{-2s}}{10s+1} \end{bmatrix}$$

Estimation of u_1 and u_2 will we done from transfer function matrix. For the step change from 0 to 1, the settling value for subsystems without interactions will be $u_1 = 0.25$ and $u_2 = 0.2$ (final value divided by subsystem gain). But both interactions has positive sign, so u_1 and u_2 estimations can be little bit lower. For controller design we choose average value of $u_1 = 0.2$ and $u_2 = 0.15$. Than from (12) minimal value for output deviation is $|y_{\min 1}| = 0.133$ and $|y_{\min 2}| = 0.3$. Let $|y_{\max 1}| = 0.3$ and $|y_{\max 2}| = 0.5$, local controllers are than

$$R_1 = 0.25(1 + \frac{1}{6s}) \text{ and } R_2 = 0.24(1 + \frac{1}{10s})$$

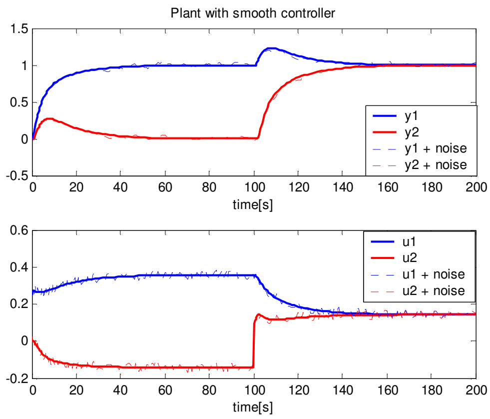

Fig.2 System with designed controller with and without noise

System with controller was simulated with and without noise of magnitude 0.1. We can see that both output deviation requirements were satisfied.

For comparison controllers designed with decentralized technique proposed by (Kozakova, et. al. 2008)

$$R_1 = 0.755(1 + \frac{1}{2.8s}) \text{ and } R_2 = 0.164(1 + \frac{1}{3.44s})$$

System with this controller has shorter settling time but the noise sensitivity is higher mostly in first subsystem and output deviation is higher in second one Fig 3.

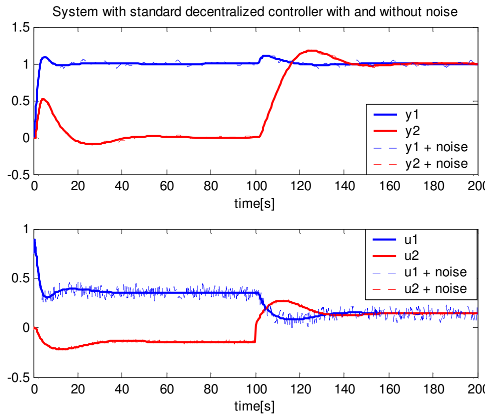

Fig. 3 System with standard decentralized controller with and without noise

Consider now that we are more interesting in first output and our aim is to have deviation of this output small as possible. So we choose $|y_{\max 1}| = 0.134$ (close to $|y_{\min 1}| = 0.133$) and $|y_{\max 2}| = 0.7$, local controllers are than

$$R_1 = 0.56(1 + \frac{1}{6s}) \text{ and } R_2 = 0.17(1 + \frac{1}{10s})$$

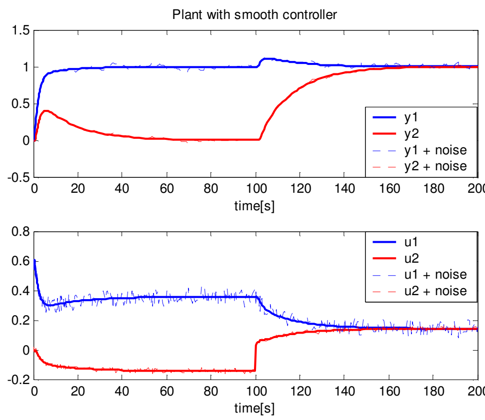

Fig. 4 System with controller aimed on first output

Simulation in Figure 4 show that conditions are satisfied thus deviation for first output is less than 0.134.

5 CONCLUSION

In this paper independent decentralized controller design approach with interaction rejection for MIMO systems was proposed. Presented method ensure controller gains as small as possible, but still fulfilling quality requirements. Small controller gain decrease noise sensitivity of the system what is desirable for industrial practice.

ACKNOWLEDGMENTS

The work has been supported by the VEGA grant 1/0544/09 and ESF Project no. 13120200115.

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