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Robust decentralized controller design for stable plants

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The paper deals with the robust decentralized controller design in the frequency domain for stable plants. Nominal and robust stability conditions under a decentralized IMC controller are developed. An illustrative example is included.

1 INTRODUCTION

PID controllers are standard and well-proven solution for the majority of industrial applications. Over the years, a plenty of PID tuning rules were developed see e.g. (Šulc and Vítečková, 2005).

In this paper decentralized PID controller design approaches are developed for stable systems and further extended to satisfy robust stability conditions in terms of unstructured uncertainty developed in (Kozáková A., Veselý, 2005; Kozáková and Veselý, 2009). The approach is IMC structure-based and applicable just for stable plants; an innovation brought about by its development is derivation of robust stability conditions in terms of a decentralized IMC controller.

The paper is organized as follows: preliminaries and problem formulation are given in Section 2, robust decentralized IMC controller for stable plants is addressed in Section 3. In Section 4, a detailed robust decentralized PID controller design procedure is illustrated on an example in Section 5. Conclusions are drawn at the end of the paper.

2 PRELIMINARIES AND PROBLEM FORMULATION

The Internal Model Control (IMC) structure was introduced as an alternative to the classic feedback structure. Its main advantage is that closed-loop stability is guaranteed simply by choosing a stable IMC controller.

Consider the simplified block diagram of the IMC structure (Morari and Zafiriou, 1989) depicted in Fig. 1

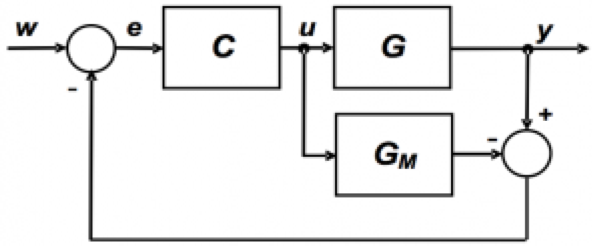

Fig. 1 – IMC structure

where $C(s) \in R^{m \times m}$ denotes the controller, $G(s) \in R^{m \times m}$ is the plant and $G_M(s) \in R^{m \times m}$ is the plant model. Exact knowledge of the output y is assumed. If the model is exact, i.e. if $G(s) = G_M(s)$ then

$$y(s) = G(s)C(s)w(s), \quad (1)$$

Relationship with the standard feedback structure in Fig. 2 is obtained simply by comparing outputs from both structures

$$[G(s)R(s) + I]^{-1}G(s)R(s) = G(s)R(s), \quad (2)$$

where $R(s) \in R^{m \times m}$ is the controller

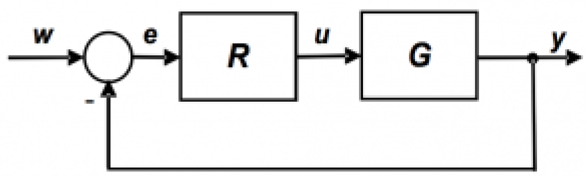

Fig. 2 – Standard feedback configuration

The standard controller $R(s)$ and the IMC controller $C(s)$ are related through

$$R(s) = [I - C(s)G(s)]^{-1}C(s), \quad (3)$$

If $G(s)$ is stable and $G(s) = G_M(s)$, the standard feedback system with controller (3) is internally stable if and only if $G(s)$ is stable. In such a case (3) is a simple parameterization of all stabilizing controllers $R(s)$ in terms of stable $C(s)$. Thus, instead of searching for $R(s)$ it is possible and simpler to search for $C(s)$ (Morari and Zafiriou, 1989).

When designing a controller a major source of difficulty is plant model inaccuracy; hence uncertainty models are to be used which means that instead of a single model a class Π of perturbed models is to be considered. Denote $\tilde{G}(s) \in \Pi$ any perturbed plant model and $G(s) \in \Pi$ the nominal plant model. A simple uncertainty model is obtained using unstructured uncertainty $\Delta(s)$. Three uncertainty forms are commonly used: additive (a), multiplicative input (i) and multiplicative output (o) uncertainties.

Standard feedback configuration with unstructured uncertainty of any type can be rearranged to obtain the general $M - \Delta$ structure in Fig. 3 where $M(s)$ represents the nominal model and $\Delta(s) : \sigma_{max}[\Delta(j\omega)] \leq 1$ the normalized perturbation.

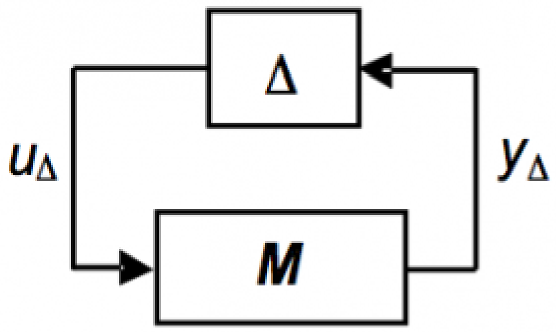

Fig. 3 – $M-\Delta$ structure

Robust stability condition for unstructured perturbations is formulated in terms of stability of the $M-\Delta$ system: if both the nominal system $M(s)$ is stable (nominal stability) and the normalized perturbation $\Delta(s)$ is stable, closed-loop stability is guaranteed for