OPTIMAL DESIGN OF STABLE PROCESSES

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Abstract - **Open loop dynamic stability is a major feature of operability. An optimization approach for open loop stable process design is presented. It is based on Lyapunov's stability theory and formulated as an eigenvalue optimization problem. The resultant non-linear semi-definite programming problem is reformulated into an interior-point / logarithmic-barrier- transformation programming problem. The proposed methodology is applied to the design of a three states stirred tank reactor.**

Keywords - **Optimization, Process Design and Stable Design**

I. INTRODUCTION

The interaction between process design and process operability is an active research area. Design for operability is necessary because the sought of steady state economic optimality only, may lead to designs with poor operational features. Several approaches have been proposed to carry out such an interaction. In terms of philosophies it can be mentioned (Lewin, 1999) the use of heuristics, the operability measures approach and the complete integration of design and operability. The first approach is mostly based on experience and is widely applied in conceptual design (Douglas, 1988).

Operability measures describe particular operability features and are applied as screening tools to evaluate alternative designs. Controllability and resiliency measures (Barton *et al.*, 1991), relative gain array, singular value indices, etc., are the most relevant within this category. Finally, integration between design and operability stands for the explicit inclusion of operability elements within the process design formulation. This is clearly the most ambitious approach both from a modeling and resolution point of view. Luyben and Floudas (1994), for example, proposed a multi objective optimization approach between economics and some controllability index. Mohideen et al. (1996) posed and solved a design plus a control system (feedback PI) superstructure. Besides its inherent difficulties, the trend of design is in the sense of integration.

Operability is a wide concept, which involves optimality, dynamics, flexibility in the face of uncertainty, risk, environmental concern, etc. As pointed out by Wolff *et al.* (1994), open loop stability and optimality are major properties of operability, and should be considered simultaneously at the design stage. Economic optimality is a natural objective in chemical process design. Open loop dynamic stability is an issue of paramount importance, which should be ensured by proper design. It is the purpose of this contribution to present an integrated approach to design / operability, which explicitly considers economic optimality and open loop dynamic stability. Within the framework of Lyapunov's stability analysis, the design formulation with dynamic stability constraint on the steady state operating point is posed as an eigenvalue optimization problem. The proposed approach is first introduced with a simple motivating example and then applied to the meaningful jacketed exothermic stirred tank reactor (CSTR). A considerable effort has been devoted to the study of the dynamics, in particular the stability issue, of the CSTR (Russo and Bequette, 1995). Lyapunov's stability theory has been applied mostly as an analysis tool in such studies. Kokossis and Floudas (1994) presented a systematic methodology applicable to the optimal design of stable process systems focused on complex reaction networks synthesis. They propose an iterative matrix measure relaxation algorithm in order to ensure that the system jacobian matrix is Hurwitz and hence local stability of the resulting design. Within the same philosophy, an alternative approach, based on Lyapunov direct method from a design point of view, is proposed in this work.

II. LYAPUNOV´S STABILITY THEORY

In the present section, most relevant issues of Lyapunov´s Stability Theory are outlined. See, for example, Vidyasagar (1993) for a complete analysis.

For the general non-linear system $\dot{\mathbf{x}} = \mathbf{f}(\mathbf{x})$, stability of the equilibrium point $\mathbf{x}_{ss}$ has local meaning. For asymptotic local dynamic stability we understand the existence of a certain neighborhood around the equilibrium point within which asymptotically stable trajectories originate. This means that any trajectory starting inside this "domain of attraction" (Fig. 1) approaches the equilibrium point as time increases. We are not interested at the moment in the shape or size of such a region but just on its existence. Consider the free, autonomous system:

$$\dot{\mathbf{x}} = \mathbf{f}(\mathbf{x}), \quad \mathbf{f}(\mathbf{0}) = \mathbf{0} \tag{1}$$

By linearizing around the origin we have, $\mathbf{f}(\mathbf{x}) = \mathbf{A}\mathbf{x} + \mathbf{f}_1(\mathbf{x})$, where $\mathbf{A} = \left[\dfrac{\partial \mathbf{f}}{\partial \mathbf{x}}\right]_{\mathbf{x}=\mathbf{0}}$. Then, it can be