Stability Analysis Based Method for Inherently Safer Process Design at Conceptual Design Stage

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ABSTRACT

Recently, more and more attention has been paid to the chemical process safety, but how to design processes that are inherently safer—with the focus on disturbances having the potential for hazardous responses—is still a problem to be solved. This paper tries to propose a new method for designing such inherently safer processes at conceptual design stage.

First of all, analyze the chemical process and formulate it in the form of mathematic differential equations that properly describe the dynamic characteristics of the chemical process. Every variable’s behavior under time is described by the equations, based on which the key variables of the process could be identified, and then by changing these variables, we can get the safer design in further steps.

Secondly, determine the parameter values in the process differential equations during the conceptual design stage. These parameters are variables that can be easily changed by operator. Calculate the steady state variable values under every scenario, which is a difficult problem to be solved. Here the Homotopy continuation method is applied to solve this problem properly. These obtained steady state variable values compose a locus which gives a steady state image within the whole operable space.

Thirdly, analyze these steady state solutions in the locus, for that the bifurcation and singularity theory are introduced to test their stability. Some of these steady state solutions might not be stable when disturbances occur, so it is important to identify bifurcation points. Then the operable space can be divided into several subspaces that have different characteristics in terms of stability. There are 3 kinds of subspaces: the stable subspace, the unstable subspace and the mixed subspace. Within the stable subspace the system will run smoothly still, even if some variable disturbance is encountered, within the unstable subspace the system may change a lot or run away even under very little disturbance. This subspace is dangerous, so effort should be made to avoid selecting process steady state variable values in this subspace. The mixed subspace is the one within that the system may change a lot or not change at all when disturbance occurs. This situation is also should be avoided in order to guarantee the designed process is an inherently safer one.

Finally, determine suitable parameters’ values that make a chemical process design meeting the specified safety requirements. A metric is introduced to determine whether certain solution meets the demanded safety requirements. If the result not satisfied, repeat the above mentioned steps until these safety requirements are met. By this way, an inherently safer design can be obtained at the conceptual design stage.

In the paper, a case is studied to show how the method works step by step, and then a complicated industrial case study is shown to illustrate the effectiveness of the proposed method.

Keywords (3–6 words): Inherent safety; Steady state solutions; Stability analysis; Conceptual design