Chemical process control an introduction to theory and practice

Science, Chemistry

The operating temperatures, pressures, concentrations, etc. should always be within allowable limits. Quality is also an important factor. A plant should be producing the desired amounts and quality of the final product. Moreover, the various types of equipment have constraints inherent to their operation. Such constraints should be satisfied throughout the operation of the plant. The plant must also conform to the market conditions that are the availability of raw materials and the demand for the final products. It should be as economical as possible in its utilization of raw materials, energy, capital, and human labor, hence, operating at minimum cost and maximum profit, striking a right balance between both to give optimal performance. Also, various federal and state laws may specify constraints on temperature, flow rates of effluents, etc. to be within certain limits, keeping environmental regulations in mind. (Stephanopoulos 3)

All these requirements dictate the need for a good design, which is accomplished through proper selection of controllers, plant design parameters, etc. Different controllers have different effects on the response of the controlled process. The type of feedback controller to control the given process hence forms the first step of controller design. The second design question is " How do we select the best values for the adjustable parameters of the feedback controller chosen?" This is known as the Controller Tuning Problem. Various performance characteristics such as Overshoot, Rise time, Settling time, Decay ratio and frequency of oscillation of the transient could be used as the basic criteria while designing. The designer must strike a subjective balance between the different conflicting characteristics through controller tuning. The various factors to be kept in mind while designing include minimization of integral square error, fast control, minimum wear and tear of control equipment, no overshoot at start-up and minimizing the effect of known disturbances. (Altmann 112) There are various approaches to deal with the controller tuning problem:

1. Process Reaction Curve Method: This method was developed by Cohen and Coon. In this method, a unit step change of magnitude A is applied to the final control element actuator of a control system, which has been opened by disconnecting the controller from the final control element. The value of the output is recorded with respect to time. The curve obtained is known as Process Reaction Curve. Cohen and Coon observed that the response of most processing units to an input change had a sigmoidal shape, which can be adequately approximated by a first-order system with dead time. Using this approximated first-order model, the expressions for the " best" controller settings using load changes and various performance criteria were derived, such as One Quarter Decay Ratio, Minimum Offset, minimum integral square error. (Stephanopoulos 310)

2. One Quarter Decay Ratio Criterion: One of the simplified approaches towards controller tuning, it uses decay ratio as its performance criterion. It has been seen that a decay ratio, given by the ratio of the amounts of ultimate values of two successive peaks,

C = 1

A 4

(Stephanopoulos 301)

is a reasonable trade-off between fast rise time and reasonable settling time. This criterion is known as One-Quarter Decay Ratio criterion. Usually, we select first the proportional gain Kc so that the controller has the necessary strength to push the response to the desired setpoint, and then we choose the corresponding value of the time constant so that the above criterion is satisfied.

3. Zieglar Nichols Tuning Technique or Continuous Cycling Method: The term " continuous cycling" refers to a sustained oscillation with constant amplitude. Unlike the Process Reaction Curve Method, the ZN tuning technique uses data from the closed-loop response of the system. The system is first brought to the desired operational level. Then, using proportional control only, and with a feedback loop closed, a setpoint change is introduced. The proportional gain is adjusted until continuous cycling is obtained. This frequency of continuous cycling is called crossover frequency, co. Let M the amplitude ratio of the system's response at this crossover frequency.

Using the values of Ku and Pu, Zieglar and Nichols recommended certain settings, using which Kc and the time constants for various controllers can be determined. (Stephanopoulos 352)

4. Tuning for no overshooting on startup (Pessin's Method): This method is a variation of the continuous cycling method and it is used whenever no overshoot is permitted, even in the extreme case of the start-up of the process. With a start-up, we mean the transition from manual to automatic control. An extreme start-up situation exists, if the setpoint and PV are very different when changing from manual to automatic control. In contrast to a change of setpoint, the change from manual to automatic control does not

cause a step-change in ERR. Therefore, the change does not directly affect P or D-control. Example of applying this tuning procedure, according to Pessin, is a closed tank that could burst or an open tank that could overflow. The steps of closed-loop tuning for no overshoot are the same as the ones for continuous cycling method. The formulae developed for

5. Tuning for some overshooting on startup: This method is a variation of the continuous cycling method. It is used whenever no overshoot during normal modulating control is desired, but some overshoot at start-up is acceptable. The steps of closed-loop tuning for some overshoot are the same as the ones for continuous cycling method. The formulae developed for PID control are as follows:

In conclusion, it can be seen that controller tuning forms an extremely important part of the design problem and is given the utmost importance in process control instrumentation. Basic methods like Process Reaction Curve Methods have been modified and have given way to more accurate methods of tuning such as Ziegler Nichols criteria. With the advent of digital control systems, it has been seen that Cohen Coon settings, Ziegler Nichols Settings and the time integral performance criterion methods are as relevant with these modern control systems, as they were with the basic control systems techniques, only much more advanced and even more accurate.