387e Explicit Parametric Controller for a Batch Polymerization System

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Model Predictive Control (Morari and Lee, 1999) has been widely adopted by industry to address multivariable problems with input and output constraints. Model Predictive Control (MPC) is based on a receding horizon philosophy – a sequence of future control actions is computed according to a prediction of the system's future evolution and applied to the plant until new measurements are available. Then, a new sequence is determined, based on output feedback updates that replace the previous one. MPC exhibits performance benefits over a wide class of complex processes because it handles efficiently the presence of operating constraints, captures the system's unique characteristics and orchestrates optimally the multivariable system components.

It is a challenging and complicated task to obtain the desired product quality due to the nonlinear behaviour of the polymerization reactors (Ray and Villa, 1999). The molecular structure of the polymer is particularly sensitive to the operating conditions and the critical molecular properties can be highly affected by disturbances. Furthermore, in the particular case of batch operation, polymerization reactors are usually controlled by pre-programmed recipe implementation and temperature controls that are far from being a trivial problem due to the high process nonlinearity and varying operating conditions which are amplified by the batch nature of the process. These reasons as well as the absence of steady state and the unavoidable uncertainties, which are common in most chemical processes, make the applications of model based controllers difficult (Rho et al., 1998). It is clear that polymerization processes are ideal candidates for advanced process control applications such as Model Predictive Control (MPC).

The benefits of MPC have been shown by several authors (Rho et al., 1998; Özkan et al., 1998; BenAmor et al., 1996) and some of them are optimal performance, constraint satisfaction and robustness to changes of operating conditions. However, the implementation of MPC as an on-line optimization method raises some serious implementation issues. Implementation of MPC for high order and fast processes could be prohibitive due to demanding computational burden which dictates the need for expensive and complicated hardware and software (Qin and Badgwell, 2000). Furthermore, there is currently no specific commercial software for the design of MPC controllers for batch polymerization processes.

A solution to the implementation problem of MPC is given by using novel Parametric Programming techniques. Parametric Programming is an advanced mathematical programming method for solving optimization problems – MPC controllers obtained via Parametric Programming are usually referred to as Parametric Controllers or Explicit Controllers. Their main feature is its ability to perform all the MPC computations off-line, while preserving all its other characteristics (Pistikopoulos et al., 2002; Bemporad et al., 2002). The optimization problem of the MPC is solved off-line and the optimization variables (the plant manipulated inputs) are obtained as functions of the parameters of the process such as the output, states and set points. The feasible region of the parameters space is also obtained. The on-line implementation of MPC is then reduced to a simple function evaluation at each sampling time instant. Hence, parametric controllers can be implemented on inexpensive hardware with inexpensive and less complicated software. This has been successfully demonstrated on several continuous processes (Panga et al., 2005), however it has never been applied to a batch process.

This work attempts for the first time to design a parametric controller for the temperature control of a batch styrene polymerization reactor. First, a nonlinear model is built for the process. Then, an optimal temperature profile (set point) was designed that minimizes the batch time and ensures satisfaction of a number of constraints on the reactor and inlet jacket temperature, the product's molecular weight and the coolants flow rate. A PI controller is then designed for set point tracking which is used for comparing with the parametric controller. The parametric controller is developed by first obtaining a linear input/output ARX representation of the non-linear system. The specifications of the parametric controller are to reduce the tracking error between the output and the optimal temperature profile and satisfy the constraints imposed on the parameters of the polymerization. The simulations of the batch process for nominal operating conditions with both the PI and parametric controller are compared and show that the parametric controller can achieve similar performance to classical PI controller. It manages to force the output of the system to follow the optimal temperature profile and the desired polymer properties and conversion are achieved. However, it is shown that the parametric controller outperforms the PI when small variations of the operating conditions are applied. This is mainly due to the fact that the parametric controller is designed to minimize the tracking error over a range of values of the current and future values of the output and input.

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