ARC '16

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http://dx.doi.org/10.5339/qfarc.2016.EEPP2278

Reduced LPV Modeling and Control of a Solution Copolymerization Reactor

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Controlling the operation of polymer reactors is a highly important task that aims at maximizing the production rate and the product quality and also minimizing the transition losses due to the high consumer demands, as well as the tight market competition for producing different grades of polymers. However, the control design task is nontrivial due to the nonlinear behavior of polymer reactor systems which exhibit strong dependence on multiple operating regimes, unstable modes at some operating points as well as time-varying parameters. In this work, linear parameter-varying (LPV) control techniques are considered to control a free radical solution copolymerization reactor. LPV systems describe a class of nonlinear/time-varying systems that can be represented in terms of parameterized linear dynamics in which the model coefficients depend on a number of measurable variables called scheduling variables. The LPV controller synthesis tools extend the well-known methods of controlling linear time-invariant (LTI) systems to control nonlinear systems with guaranteed stability and high performance over a wide range of operation. In this work, the LPV representation of the copolymerization reactor is obtained through a transformation capturing the system nonlinearities in 15 scheduling variables. With this high number of scheduling variables, the design of LPV controller involves two major problems. On one hand, for control synthesis design, the number of linear matrix inequalities (LMIs) to be solved increases exponentially with the number of scheduling variables, hence the problem becomes computationally intractable. On the other hand, overbounding the range of the scheduling variables often renders the LPV model to include some behaviors that are not exhibited by the original plant, which results in conservatism. In order to cope with the high number of scheduling variables, two approaches for reduced LPV model development for the copolymerization reactor are introduced. The aim of this work is to emphasize the capability of the LPV controllers, designed on the basis of reduced models, to provide high performance control of the polymerization reactor by enhancing the settling time of the output and reducing the control effort. In the first approach, the number of scheduling variables is reduced via the parameter set mapping (PSM) procedure based on

Cite this article as: Meskin N, Rahme S, Toth R, Mohammadpour J. (2016). Reduced LPV Modeling and Control of a Solution Copolymerization Reactor. Qatar Foundation Annual Research Conference Proceedings 2016: EEPP2278 http://dx.doi.org/10.5339/qfarc.2016.EEPP2278.

principal component analysis (PCA). PSM is an effective way to reduce the conservatism in LPV modeling by resizing the scheduling range such that the reduced model matches the original system behavior as closely as possible. With this method, the complexity of the LPV model of the copolymerization reactor is ideally reduced into one scheduling variable, which allows a minimal design complexity. However, the synthesized controllers may not guarantee the closed-loop stability and performance with the full nonlinear model of the copolymerization reactor since they are designed based on an approximation of the nonlinear model. The second method is based on an alternative conversion of the nonlinear model to an LPV form by truncating the state variables that have no significant role in the state evolution. This method is a specific model reduction approach aiming at reducing the complexity, as well as the number of scheduling variables of the model while the input-output behavior of the original system is preserved. The resulting reduced LPV model of the copolymerization reactor has 4 scheduling variables, which is a relatively large number. However, the stability and performance of the original plant are guaranteed with such controller. Once the operating region and the resulting LPV models are determined, a control design methodology is applied on each produced model. For the LPV-PSM approach, LPV H_infty control synthesis is used to synthesize an LPV controller for the reduced LPV model of the reactor. For the reduced order based model, a linear fractional transformation (LFT) based LPV controller synthesis approach is used since it is capable of handling plants with relatively large number of scheduling variables while maintaining low design complexity. However, the implementation of the designed LPV controllers requires the availability of all the scheduling variables, some of which are not measurable in the reactor model. Therefore, an extended Kalman filter (EKF) is designed for the nonlinear model of the copolymerization reactor in order to estimate its state vector. A comparative analysis of the closed-loop performance is done between the synthesized LPV controllers and the model predictive controller (MPC) developed in the literature. The PSM based LPV controller, based on one scheduling dimension LPV model, has shown a better disturbance rejection without either output oscillation or input saturation and a convergence time of 9 hours, which is lower than the reduced order based LPV controller and the MPC controller whose convergence times are 10 hours and 15 hours, respectively. This enhancement in the closed-loop performance is due to the low conservatism of the design by the PSM approach. However, the inability to guarantee the closed-loop stability with the nonlinear reactor model remains the main drawback of the PSM procedure, whereas the stability is guaranteed with the LPV controller based on reduced order LPV model. As a conclusion, a trade-off is illustrated by the low complexity and good performance on one hand, and the stability guarantee of the closed-loop system with the nonlinear model of the reactor on other hand.