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Real-time application of discrete second order sliding mode control to a chemical reactor

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ABSTRACT

Temperature control of processes that involve heating and cooling of semi-batch reactors can be a real problem for conventional controllers that do not put up with relatively large model uncertainty and external disturbances. The first order sliding mode control can be a solution for this problem; however, discrete-time implementation generates the chattering phenomenon. In order to reduce it, a second order discrete sliding mode control (2-DSMC) approach is proposed in this paper and used for the temperature control of a chemical reactor. As shown by the experimental results, this control law resolves the chattering problem while ensuring good robustness of the closed loop system behavior.

1. Introduction

The initial heat-up from ambient temperature and the subsequent temperature control of semi-batch reactors have always proved to be difficult control problems. In fact, in case of exothermic or endothermic reactions, the amount of heat released or absorbed depends on the temperature of the reaction's mixture and can exceed the cooling capacity of the reactor (Babu & Jyotsna, 1998; Shahraz & Bozorgmehry Boozarjomehry, 2009). This results in overshoots, harmful in most cases to the desired performances. Therefore, conventional controllers are often unable to handle these cases. A good robustness against plant-model mismatch is required. In this work, the sliding mode approach for the temperature control of a semi-batch reactor is implemented in discrete-time. To reduce the chattering phenomenon (Monsees, 2002), the second order discrete sliding mode control (2-DSMC) is used.

In fact, although the variable structure control is principally characterized by its robustness with respect to modeling uncertainties and external disturbances (Filippov, 1990; Lopez & Nouri, 2006; Utkin, 1992; Zlateva, 1996), the application of this control law is confronted to a serious problem; the chattering phenomenon. The sliding mode needs an infinite switching frequency which is impossible to realize in practice. For finite switching frequencies, oscillations appear on the state variables and on the switching function (Utkin, 1992). Many approaches have been suggested in order to reduce this phenomenon. Most of them allow a reduction of the oscillations' amplitude but at the cost of the robustness of the control law (Utkin, David Young, & Özguner, 1999). In the 1980s, a new control technique, called high order sliding mode control, has been investigated. Its main idea is to reduce to zero, not only the sliding function, but also its high order derivatives. In the case of the r-order sliding mode control, the discontinuity is applied on the $(r-1)$ derivatives of the control. The effective control is obtained by $(r-1)$ integrations and can, then, be considered as a continuous signal. In other words, the oscillations generated by the discontinuous control are transferred to the higher derivatives of the sliding function. This approach permits to reduce the oscillations amplitude, the notorious sliding mode systems' robustness remaining intact (Levant, 1993; Nollet, Floquet, & Perruquetti, 2008).

In the face of the many advantages of the digital control strategy (Ben Abdennour, Borne, Ksouri, & M'sahli, 2001), the discretization of the sliding mode control has become an interesting research field. Unfortunately discretized sliding mode control laws are confronted to the dilemma performance-robustness because they need a model of the system (Mihoub, Nouri, & Abdennour, 2007; Nouri, Mihoub, & Abdennour, 2008). The discontinuous term which guaranties robustness of the sliding mode control laws must not be of a large amplitude in discrete control laws, otherwise it generates oscillations on the sliding function and can even lead to instability because that the sampling rate is far from being infinite (Sira-Ramirez, 1991).

In this paper, a discrete sliding mode controller exploiting the high order approach is proposed and implemented for the

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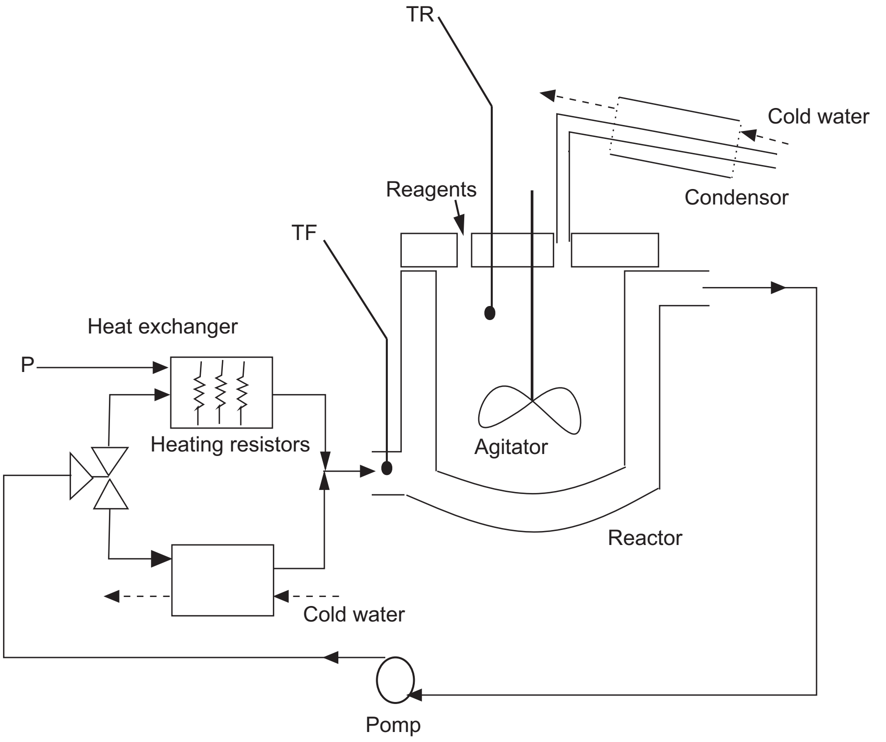

Fig. 1. Synoptic scheme of the reactor.

temperature control of a semi-batch reactor. The purpose is to reduce overshoots and chattering, which are harmful to the efficient progress of the reaction. In the second and third sections, respectively, a description and a modeling of the process is provided. In the fourth section, the second order discrete sliding mode control law is presented. The real-time application results of the 2-DSMC on the semi-batch reactor and a comparison study with the first order sliding mode control are given in the fifth section.

2. The semi-batch reactor

In this application, the chemical process is used to esterify olive oil. The produced ester is widely used for the manufacture of cosmetic products. A specific temperature profile sequence must be followed in order to guaranty an optimal exploitation of the reagents' quantities involved. The olive oil contains essentially a mono-unsaturated fatty acid that reacts with alcohol to give ester and water as shown by the following equation:

$$Acid + Alcohol \underset{2}{\overset{1}{\rightleftharpoons}} Ester + Water \tag{1}$$

The final solution contains all the reagents and products in certain proportions. To drive the reaction equilibrium in direction 1 and increase the ester's proportion, water should be removed from the solution. This is achieved by vaporization. The fatty acid (oleic acid) and the ester ebullition temperatures are approximately 300 °C. The chosen alcohol (1-butanol) is characterized by an ebullition temperature of 118 °C. Consequently, heating the reactor to a temperature slightly over 100 °C will result in the vaporization of water only.

The reactor is heated by circulating a coolant fluid through the reactor jacket. This fluid is, in turn, heated by three resistors located in the heat exchanger (Fig. 1). The reactor's temperature control loop monitors temperature inside the reactor and manipulates the power delivered to the resistors. It is also possible to cool the coolant fluid by circulating cold water through a coil located in the heat exchanger. Cooling is normally done when the reaction is over to accelerate the reach of ambient temperature.

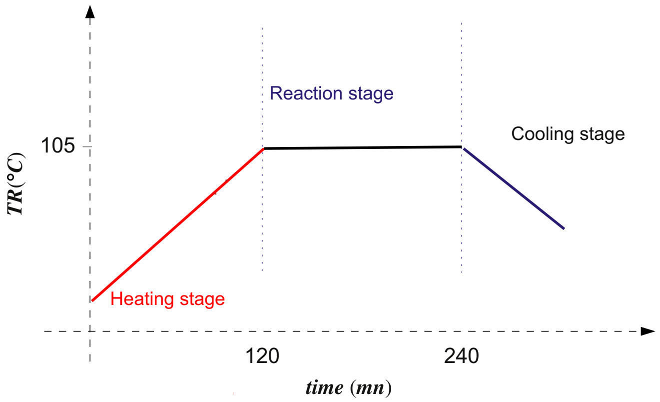

Fig. 2. Reactor's temperature set point.

The control law must, consequently, carry out the following three stages:

- bring the reactor's temperature TR to 105 °C,
- keep the reactor's temperature to this value until the reaction is over (the end of the reaction is deduced when no more water is dripping out of the condenser),
- lower the reactor's temperature.

Therefore, the set point given by Fig. 2 is chosen.