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Modelling for the effective control of the electric flow heaters – Simulation validation

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Abstract

This paper suggests the possibility of improving the performance of the control system for electric flow heaters by applying the balance-based adaptive control (B-BAC) methodology, in which the synthesis of the control law is always preceded by the nonstationary balance-based modelling according to the general but also strictly defined rules. The resulting simplified model of a heater is derived assuming a large uncertainty on the process nonlinearities and it has the form of the first-order dynamic equation with the only one time-varying parameter that represents the unknown nonlinearities and modelling inaccuracies. The value of this parameter is unknown so we suggest its on-line estimation by the weighted recursive least-squares (WRLS) method. The modelling accuracy is investigated by the simulation in the application to the example nonlinear electric flow heater. It is also shown how to derive the B-BAController on the basis of the suggested model. The generality of the simplified model ensures that the B-BAC methodology can be applied to control a wide variety of electric flow heaters and its application results in more effective control system, which is also verified by simulation in the comparison to the conventional PI controller.

Keywords: Nonlinear modelling; Time-variant model; Adaptive model-based control; Simulation validation

1. Introduction

Nowadays, the electric flow heaters are widely used in small-scale water distribution networks and they allow for heating the flowing water by the electric power supply. In the majority of cases, these domestic or industrial networks are supplied by the municipal water and thus we can expect large variations of the temperature and of the pressure of the supplying water. These phenomena, combined with the variations in the water consumption, result in the significant disturbances influencing the system, such as the variations of the inlet temperature and of the flow rate of the water incoming to the unit. If the variations of the disturbances are large, which, in fact, takes place very frequently, the outlet temperature of the water outgoing from the electric flow heater varies in a wide range. Moreover, the dynamics of the system varies as well, which can

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result in the potential instability of the control loop or, at least, in a shortfall in control performance. The control loop should be able to reject the disturbances and to ensure possibly small power consumption combined with a high efficiency. Therefore, even small improvement of the control performance gives the significant economical benefits over the long operation period.

In the practice, we have two possibilities of the successful control of electric flow heaters. One is the application of the conventional PI controller. This approach is very general, it almost does not require any preliminary modelling and it can provide quite good control performance when the system is operated in one region of the gain of a system and when the disturbances vary in a narrow range. For such a case, the PI controller can be tuned more aggressively, which usually provides small overshoots and short regulation time. If the control performance falls due to frequent and wide variations of the disturbances or of the set point, there is a need to apply the gain-scheduling technique, which allows for the automatic retuning of the PI controller according to the varying dynamics of the system. However, this approach requires preliminary off-line identification of the system properties in order to determine the variations of the optimal tuning parameters for different operating points [1].

The other possibility is to take advantage of the nonlinearities of the process and to apply one of the advanced nonlinear model-based techniques (e.g. [23,13,25]). They usually allow for the significant improvement of the control performance but there is always one limitation: at least a part of the complete nonlinear description of a system, including nonlinearities and the values of some model parameters, must be known. If this requirement is met, it is possible to apply the linearization technique based on the cancellation of the process nonlinearities [12] but this approach is very sensitive to modelling uncertainties and practically there is always a need to include integral action to the control law to eliminate the regulation error [14,15,22]. The other solution is to apply the observer-based control synthesis, which leads to the adaptive control law but, generally speaking, this approach usually needs very sophisticated calculations and computation on one hand and some questionable assumptions and simplifications on the other [2]. Especially, there is a need to apply additional excitation signals to ensure the persistence of excitation and consequently the estimation convergence in the case of the multiparameter on-line estimation [11]. Another very interesting attempt to the problem of the model-based control is the predictive functional control (PFC) methodology [24]. This approach requires the preliminary identification of the dynamical model of a system in the form of the Laplace transfer function and then, on its basis, the final form of the predictive controller is derived. The nonlinearities of the process are compensated by the identified variations of the parameters of the transfer function. The application of PFC methodology to the control of the electric flow heater can be found in [20,18]. However, let us state once again that all these techniques are based on the nonlinear or time-variant description of the process. If this description is unknown or if it has nonlinear and complex form, which frequently takes place in the practice, the model-based approach cannot be applied.

The complete nonlinear physical model of an electric flow heater is very difficult to derive, especially if we really want to match up the process and the model with a possibly high accuracy. In the practice, there are a large number of different physical phenomena, which influence the dynamics of the system and for which there is a large uncertainty both on the form of their description and on the values of the model parameters. Thus, if we want to benefit from any of the model-based control methodology, we must suggest how to derive the simplified model of an electric flow heater. This model should combine high modelling accuracy for possibly wide range of the input variations with simple and affine form. Additionally, the synthesis of this model should be easy without any time-consuming identification experiments. In the paper, we suggest such a simple and general first-order dynamical model for the electric flow heater. This model is derived only on the basis of the general energy conservation law. Consequently, its balance-based origin implicates the strictly defined but also general form, in which all unknown nonlinearities and modelling uncertainties are replaced by a single time-varying parameter. The value of this parameter is non measurable on-line and though it varies continuously, it must be estimated on-line by the recursive least-squares procedure, which can be derived on the basis of the same simplified model. Thus, the suggested model must be updated on-line on the basis of the measurement data collected by the sensors and, consequently, it is not suitable for any quantitative considerations of the process behaviour because it cannot work without continuous feedback from the process. In fact, this model can be only applied as a basis for a model-based control approach and in the paper its modelling accuracy is investigated by simulation in comparison with the complete nonlinear description of the electric flow heater.