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Applications of an IMC based PID Controller tuning strategy in atmospheric and vacuum distillation units

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ABSTRACT

Applications of internal model control (IMC) based single loop controller tuning in atmospheric and vacuum distillation units were investigated. The robust IMC-PID controller not only inherits the virtues that the IMC controller has, but also has a simple and general structure such as that of a PID controller. Tuning and optimization of controllers becomes more convenient using the IMC-PID controller. It can also become easier to achieve in a distributed control system (DCS) via control module configuration. In order to make it easier to apply in industrial processes, the modeling problem of the industrial process should be resolved. In this paper, a convenient closed-loop system identification strategy based on new Luus-Jaakola (NLJ) algorithm was presented, meanwhile, the principle of IMC-PID was interpreted. A software package was developed, capable of collecting actual data on-line, obtaining the process model and optimizing the parameters of the controllers. It was applied in an atmospheric and vacuum distillation unit of a refinery to tune the PID parameters of all controllers. The application results demonstrate the validity of the proposed method.

1. Introduction

The idea of IMC may have originated from the time delay compensator proposed by Smith. But as a general conception involved in a design control system, it was proposed by Garcia et al. [1]. In a single-variable and multi-variable continuous system, it has attracted a variety of researches and applications [2,3], and has been extended into discrete systems [4]. Morari had given a complete design procedure of IMC, and analyzed the stability and robustness of linear IMC in theory [2, 5]. Thereafter, an extension of the method to nonlinear systems was also studied [6]. Development of IMC can be divided into three periods as follows [1–3,7]:

(1) From the end of 1950s to 1982: germination of IMC. At the time, the conception of IMC had not been formally presented. Whereas, both the traditional feedback control structure and Smith control structure had further development. Dynamic Matrix Control, Model Algorithm Control and other heuristic Predictive Control Algorithms had been put forward, which formed the foundation for IMC.
(2) From 1982 to 1989: the rapid development stage of the conventional internal model control structure. It was marked by the published literature of C.E. Garcia and M. Morari. On the basis of the control frame presented, various kinds of studies on IMC were quickly developed. In 1989, Morari and Zafirious published the literature on "Robust Process Control", in which the IMC was analyzed more completely. Thus, the conventional Internal Model Control methods gradually became mature.

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(3) From 1990s, intelligent IMC, multivariable constraint IMC, nonlinear control and other algorithms have been most widely studied. In 1990s, with the development of neural network, fuzzy logic reasoning and nonlinear control theories, many novel ideas were introduced for studies of IMC. Developments still persist up to date. Effective applications of IMC in industrial production processes and how to make it more practical are therefore of significant interest.

The main characteristic of IMC is that it has a simple structure and fewer parameters to be tuned on-line and is easy for tuning. Especially, it has significant effectiveness in improving robustness and control performance of systems with a long time delay. The idea of IMC has also been extended to uncertain nonlinear systems through feedback compensation to further improve the robustness of IMC under model mismatch and disturbances [8]. Furthermore, it can be also combined with many other control methods such as adaptive control, fuzzy decision, neural networks, model predictive control and so on [3]. As one kind of model based control method, the internal model control has the advantage of good control performance and provides a suitable framework for PID controller design. The IMC-PID controller not only has all the virtues that the IMC has, but also has a simple structure such as that of the PID controller [9]. And besides this, tuning and optimization of the controller parameters become more convenient, which is easier to achieve in DCS systems via module configuration. Therefore, generalizing the application of the IMC control system in industry processes and displaying the control performance in DCS are of great importance. As a particular control system structure, Internal Model Control was employed in process control and obtained successful applications [7]. In more than twenty years, IMC has greatly advanced and formed the basis for its wide applications either in design of the controller itself, in combination with other control methods or in expansion towards nonlinear and multivariable systems [3,7]. The major idea of IMC is to connect the plant model with the actual plant in parallel, and the controller approaches the dynamic inverse of the model. For a single input-single output(SISO) system, the Internal Model Controller was chosen from the inverse of the minimum phase part of the model, and to strengthen the system's robustness by adding a low-pass filter. Compared with traditional feedback control, IMC can obviously indicate the relationship between tuning parameters, closed-loop response and robustness to guarantee control performance.

Nowadays, a variety of controllers used in process industries are still of the PID type, and how to combine IMC with PID has been investigated by many researchers. Ibrahim Kaya presented an IMC based automatic tuning method for PID controllers in a Smith predictor configuration [10]. R. Vilanova proposed tuning guidelines and automatic tuning of an IMC based robust PID design [11]. Also Wang et al. proposed a higher order controller tuning method by IMC-PID [12]. The key factor for the successful application of IMC is the accuracy of the model. In order to make it easier to apply for process control, the modeling problem of the industrial process should be resolved. In this paper, an IMC based robust IMC-PID control was introduced, which not only has all the virtues that the IMC controller has, but also has a simple structure such as that of the PID controller. Tuning and optimization of the designed parameters become more convenient which can be achieved in a DCS system via module configuration. For a successful application of IMC-PID, a simple and convenient closed-loop system identification algorithm was suggested. A software package was developed, combining the algorithm mentioned above in designing IMC-PID controllers. The proposed method was applied in the atmospheric and vacuum distillation unit of a refinery. Robustness and performance of the control system are improved significantly. This paper is organized as follows: Section 2 gives an account of the IMC-PID principle; the closed-loop identification method based on NLJ algorithm and its implementation are introduced in Section 3; Section 4 gives a brief description about the process flow of atmospheric and vacuum distillation unit; Section 5 shows some examples of actual applications; and finally some concluding remarks are summed up in Section 6.

2. Principles of IMC-PID

A control system design is expected to provide a fast and accurate set-point tracking, that is, the output of the system should follow the input signal as closely as possible. Also, any external disturbances must be corrected by the control system as efficiently as possible [10]. In practice, an open-loop control system is sensitive to modeling errors and inability to deal with external disturbances entering the system. To deal with disturbances and modeling error, control systems are always of closed-loop type.

With the theory of IMC and its feature for designing, an IMC-PID based advanced process control is studied for tuning parameters of a traditional PID controller. By means of such a method, a general PID controller can also realize good robustness and excellent control performance.

2.1. Brief introduction of IMC technology

IMC (Internal Model Control) is a kind of control strategy based on the process mathematic model to design the controller. Actually, it belongs to a robust control. Fig. 1 shows the structure of the control system. In this control structure, besides the controller $G_{IMC}(s)$, the process model $G_m(s)$ is also included. The design idea of IMC is that the plant model should be parallel with the actual plant, and as the controller approaches a dynamic inverse of the model, the inverse of the model's minimum phase is taken as the IMC controller and a low-pass filter is introduced and designed for physical realization of the controller.