CHAPTER 1

INTRODUCTION

1.1 PROBLEM STATEMENT

Model-based Predictive Control (MPC) constitutes a class of control algorithms that make direct use of a process model [1]. In recent times, MPC has become one of the dominant methods of advanced industrial process control.

Central to the success of the MPC technique is the derivation of accurate process models. It has also been found that model accuracy degrades with time after the MPC controller has been commissioned. Consequently, controller performance is adversely affected. Therefore, periodic re-identification of the process models and subsequent controller redesign is necessary to ensure optimal long-term controller performance [2].

Industrial project experience has shown that the most difficult and time-consuming work in an MPC project is modeling and identification [3]. In practice, during controller design, the process models are obtained by conducting open-loop step testing on the relevant process unit [4]. Widespread applications of MPC technology call for a more effective and efficient method of multivariable process identification.

The open-loop step testing approach works for stable processes, but the cost is very high. Stepping the manipulated variables may disturb the product quality and the test time is also very long, which occupies much manpower and makes production planning difficult. Furthermore, the tests are done manually, which dictates extremely high commitment of engineers and operators [4]. When the process is nonlinear, ill-conditioned or sensitive then it is also very difficult to carry out open-loop tests. When a process is unstable in open-loop, an open-loop test is also undesirable [5].

Closed-loop System Identification (SID) of the process models may well address some of these issues. This identification technique is less intrusive and may reduce re-identification time considerably [6]. Plant models identified while under closed-loop control also provide better models for controller design than models identified in open-loop [7].

Sasol Chemical Industries (SCI) currently utilise two MPC techniques: Dynamic Matrix Control (DMC) and Robust Model Predictive Control (RMPCT), supplied by AspenTech [8] and Honeywell [9] respectively. A DMC controller is used to control the industrial chemical process, namely the Methyl Iso Butyl Ketone (MIBK) plant in Sasolburg, South Africa. For the above-mentioned reasons it was considered necessary to develop a closed-loop system identification methodology for this plant.

The ability to identify the process model while the existing MPC controller is operating will ensure that safety, product quality and optimality concerns are met [10].

In Section 1.2 an overview of the current activities in the closed-loop SID field is provided. Then, in Section 1.3 the objectives are given and in Section 1.4 the approach to solving this problem is discussed. The contribution of this work is discussed in Section 1.5 and, lastly, in Section 1.6, the organization of the dissertation is explained.

1.2 Literature Review

Closed-loop SID refers to the process in which plant models are identified using data collected from closed-loop experiments, where the underlying process is fully or partly under feedback control [11].

In this section the available literature on closed-loop SID is discussed in terms of the advantages of closed-loop SID, the identifiability and correlation problems of closed-loop SID, and special-purpose software for closed-loop SID.

1.2.1 Advantages of Closed-Loop Identification

It is sometimes necessary to perform identification experiments in closed-loop as the plant may be unstable, or has to be controlled for production, economic, or safety reasons, or contains inherent feedback mechanisms [11]. Also, according to Landau [7], the problem of identifying systems operating under output feedback appears in practice to be one of the most convenient methods to provide good controller design models.

It is, therefore, not surprising that this problem has generated significant interest in the identification literature over the years [6]. The problem offers many possibilities and also some fallacies, and a wide variety of approaches have been suggested, many quite recently.

In the past identification in closed-loop was considered difficult, but it is now considered a very feasible approach that offers a number of practical advantages over open-loop identification [7]:

- validation of the designed controller and on-site re-tuning,
- obtaining better models for controller design,
- controller maintenance,
- iterative identification in closed-loop and controller redesign, and
- controller order reduction.

Controller maintenance involves validation of a controller, and re-tuning of the controller on the basis of a newly identified model. Since closed-loop SID makes it possible to do the validation and identification with the same set of data, it has an advantage over open-loop SID. Also, the model obtained from closed-loop data gives a more accurate image of the current closed-loop behaviour [7].

By identifying a reduced order plant model, which captures characteristics at the critical frequencies for control, the order of a controller can be reduced. A reduced model identified in closed-loop captures these characteristics and this makes closed-loop SID advantageous [7].

The effect of feedback will have an additional advantage if the process is ill-conditioned, meaning that several Controlled Variables (CVs) are strongly correlated. High purity distillation columns, typically controlled by MPC, are often ill-conditioned as the top and bottom compositions are strongly correlated. For the control of ill-conditioned processes, it is important to identify a good estimate of the low-gain direction. In an open-loop test where Manipulated Variables (MVs) are moved independently, the low gain direction has very low power and cannot be estimated accurately from noisy data. In order to amplify the power in the low-gain direction, correlation between MVs are needed. This correlation can be created naturally by feedback control [3].

Closed-loop identification also reduces the disturbances to process operation and eliminate the production of off-specification product. This is because in closed-loop one can specify the amplitude of the set-point movement and the controller will help to keep the CVs within their operation limits. This in turn means that closed-loop tests are less demanding of operators and control engineers [3].

1.2.2 Correlation Problems in Closed-Loop

Unfortunately most of the standard open-loop estimation methods fail when applied directly

Different ways of satisfying the identifiability condition have been analysed and tested. In many traditional methods, identifiability is ensured by adding a Persistently Exciting (PE) test signal into the closed-loop. For this reason many papers on closed-loop SID discuss the topic of experiment design. Many different types of test signals have been designed and tested to ensure PE signals [2, 4, 10, 11, 16, 17]. Some of these will be discussed in Section 4.3.

A novel approach to direct closed-loop identification, called output inter-sampling, has been introduced recently. It is claimed that by using the inter-sampled plant input-output data, traditional restrictive identifiability conditions are removed [18].

1.2.4 Special-Purpose Closed-Loop Identification Software

Special-purpose closed-loop SID software packages exist: Adaptech, for example, developed closed-loop identification software named, WinPIM-CL: Plant Model Identification in Closed-loop Operation [19]. This software uses modified closed-loop Output Error (OE) identification methods and modified IV methods. Furthermore, a closed-loop SID toolbox, called Closed-loop SID (CLOSID), has been developed by Van den Hof *et al.* [20] for the identification of Single-Input-Single-Output (SISO) systems. This toolbox is designed as an add-on to the MathWork's System Identification Toolbox (SITB). It compromises of several closed-loop SID methods.

Closed-loop SID software applicable to plants, controlled by MPC controllers, has also been developed: Butoyi and Zhu [21], who have studied closed-loop identification of large-scale industrial processes for use in MPC, developed closed-loop SID software for model based process control, named Tai-Ji ID: Automatic Closed-Loop Identification. This software uses the Asymptotic Method (ASYM) and is programmemed using MATLAB and the Control System Toolbox. The ASYM method of identification was developed by Zhu [4] to solve industrial identification problems systematically.

In practice, however, most of the industrial control engineers, including those at Sasol, still conduct the standard open-loop step tests on the relevant process units [4] and do not use these closed-loop SID software to obtain the process models.

1.3 Research Objectives

The objectives of this research project are to:

- do a literature review of closed-loop identification techniques,
- develop a closed-loop system identification methodology,
- develop closed-loop system identification software, if necessary, and
- apply the methodology and software to the industrial Methyl Iso Butyl Ketone plant, controlled by a Dynamic Matrix Controller.

1.4 Research Approach

The approach to the research project is to:

- review all the relevant closed-loop identification techniques,
- choose the most appropriate closed-loop identification methodology for plants, controlled by MPC controllers,
- use simulations to validate this methodology,
- use the methodology to identify a part of the MIBK plant from real process data,
- compare the identified model with the open-loop identified process model, and
- evaluate the implemented methodology.

1.5 Research Contribution

Closed-loop SID is a very interesting topic of great practical relevance. Although it has been studied for at least four decades, there are still many open problems to address.

Although identification in closed-loop appears in practice to be one of the most convenient methods to provide good design models and although there is an urgent need for efficient and effective identification methods in control engineering, many industrial control engineers do not even use most of the open-loop identification techniques developed over the last thirty years [4, 22].

Substitution of the open-loop identification technique with the closed-loop identification methodology could save Sasol, as well as other companies in the same field, valuable time and production cost. This will in turn ensure the success of the MPC technique.

A complete discussion of a closed-loop methodology that solves industrial identification problems systematically will encourage and help industrial control engineers to implement

Chapter 6 then discusses the implementation of the methodology proposed in Chapter 4 on the MIBK process data, the validation process that is followed and the results that are obtained. The implemented methodology is thoroughly evaluated and further recommendations are made.

Chapter 7 concludes the dissertation and also discusses the direction of possible future research.