FTC STRATEGIES IN MODEL PREDICTIVE CONTROL OF A DEAROMATISATION PROCESS

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Abstract: The behaviour of an industrial dearomatisation process operated under model predictive control (MPC) is studied in the presence of incipient faults. Different automatic FTC strategies are studied utilising both a dynamic chemical engineering process simulator and the process MPC. The focus has been on FTC strategy directionality resulting from incipient faults like drifting, and in management of fault consequence risks like loss of production. The directionality, early detection, and detection reliability aspects in applying appropriate realtime FTC strategies are particularly pronounced in this process and economy environment. It is shown, that the inherent accommodation properties and model information in the studied MPC can readily be exploited as a vehicle to realise the types of FTC strategies required by the users.

Keywords: Fault detection, Fault isolation, Fault tolerance, Reliability, Predictive control, Simulators, Industrial control.

1. INTRODUCTION

Fault-tolerant control (FTC) introduces means for a plant to survive despite the presence of faults deteriorating process control while also taking into account plant safety and economic aspects. Several papers have been published on fault detection and isolation (FDI) and FTC as described in the following, but very few on the differences in the automatic realtime FTC-strategies depending on the fault failure direction, fault duration and detection reliability.

Kesavan and Lee (1997) have discussed monitoring and diagnosis of MPC systems and shown that due to the complexity of MPC the reasons behind a degraded control performance are hard to infer. Also according to Maciejowski (1999) FDI in MPC is a difficult task since in closed-loop the controller will try to compensate the effect of the fault, undermining the FDI-procedure. Pranatyasto and Qin (2001) have studied measurement validation and fault diagnosis for a simulated fluid catalytic cracker under MPC feedback. Principal component analysis (PCA) has been used for FDI. Experiments have been carried out to study gross error spikes, sensor failure and random noise by simulation.
Prakash *et al.* (2005) have proposed and tested an active on-line fault-tolerant MPC scheme with a model-based FDI. By monitoring the MPC prediction error on-line, the diagnosis yields both FDI and an estimate of fault magnitude. The proposed scheme accommodates the faults by explicitly modifying the prediction model and the constraints of the MPC control problem.

Liikala *et al.* (2005) have studied the effects of two different FDI method types in a dearomatisation process viz. the general-purpose FDI inbuilt to the MPC and the FDI type specially tailored to the process, such as proposed by Kinnunen (2004). Two types of faults, sudden and incipient (drift), in the on-line process analysers, used for feedback for the process MPC, were studied. The authors show that this type of process is highly sensitive to faults in the analysers. The undetected faults were shown to finally lead to off-spec production with very high economic sanctions or to quality giveaway depending on the failure direction. Consequently, there is a well founded justification for this process type to utilize a specialised and sensitive FDI, capable of supporting different FTC strategies.

In this paper the topic of utilising FDI results in an industrial MPC environment for realising appropriate FTC-strategies is studied. The effects of different failure directions for the incipient fault types have been examined. Also the use of the inherent properties of fault effect accommodation in MPC has been studied. Simulations have been carried out using an experimental platform consisting of a dynamic chemical engineering process simulator and an adaptive multivariable model predictive controller for pre-testing the strategies before the final industrial application tests. Basic concepts are presented for exploiting the different FDI results in determining the realtime evolution of the FTC-strategies as a function of incipient fault propagation and development to, or avoidance of, a possible full-blown failure.

2. NECST PROJECT DESCRIPTION

The work underlying this paper has been carried through as a part of the NeCST project. NeCST is an acronym for Networked Control Systems Tolerant to Faults, a European Union STREP-project under the 6th Framework Programme of Information Society Technologies for Embedded Systems.

The aim of the project is to explore research opportunities in the direction of distributed control systems, in order to enhance the performance of diagnostics and fault tolerant control systems. This is expected to lead to an improvement in the intensive use of NeCST technologies for the reactivity, autonomy, and monitoring of large scale systems. Algorithms and procedures are developed that are able to detect, at an early stage, anomalies and to switch to the fault tolerant control strategy and/or provide predictive and real-time maintenance.

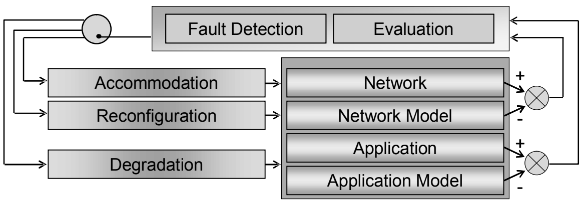

Fig. 1. NeCST conceptual model.

A toolkit of NeCST software modules is developed to provide the monitoring, diagnostic and action planning functions of a fault-tolerant system.

The project consists of a number of work packages. The work package for identifying the user requirements and specifying the corresponding functional requirements for the NeCST tools and software was carried through at an early stage of the project. This specification work forms the basis for the further development work in the NeCST project and was completed in March 2005. The NeCST project plan includes an implementation of the software prototype to an application within the Neste Oil Naantali Refinery dearomatisation process. The application is studied with the aim to test on-line the developed fault diagnostics and fault-tolerant control methods on a typical refinery process, with the objective of finding the method best suited for early detection of incipient faults and possibly avoiding or mitigating the effects of process faults in the refinery process case. The selected fault diagnosis and fault-tolerant control methods are first pre-tested using the process simulator. This paper mainly discusses the project pre-testing phase and the results obtained from the initial FTC strategy tests.

3. PROCESS DESCRIPTION

The solvent dearomatisation unit is a refinery process unit at Neste Oil Naantali Refinery, located at the south-western coast of Finland. Several product grades of low-aromatic solvents are produced with distillation curves ending in the range of 200-300 *°C*. Approximately 400 measurements are available from the process with about 200 of them being of particular interest for fault diagnosis purposes as reported (Kinnunen, 2004).

The process can be divided into two sections: the reactor section and the distillation section. The key elements of the reactor section are the two trickle-bed reactors with packed beds of catalyst where the hydrogenation reactions take place. The reaction product separation is mainly done in the distillation section in a sieve tray distillation column and in a side-draw stripper. Naturally, a large number of other equipment such as pipes, valves, filters, heat exchangers, pumps, compressors, separation vessels, and like, are part of the process. The process is operated through a DCS-system and has its own model predictive controller (MPC).

The reactor section is depicted in Figure 2. A more detailed process description is given by Liikala *et al.* (2005).

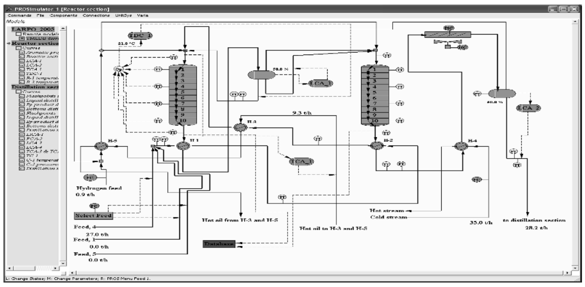

Fig. 2. PROSimulator flow diagram showing the reactor section of the solvent dearomatisation unit.

The distillation section is illustrated in Figure 3. Here, the specified flashpoint and the boiling range of two final solvent products (light and heavy) are attained. The light components are removed as overhead products. The stripping column is used for the lighter solvent product processing, its feed taken as a side-draw from the main column. The specialty solvents are the most valuable products from the unit. The heavy solvent product conforms to the strict specialty solvent product specifications with e.g. the flash point requirement over 100 *°C*. For solvents the distillation range is determined in terms of the initial boiling point, IBP (at ~0 %) and the final boiling point, FBP (at ~100 %) instead of the usual 10% and 90% points of the distillation curve. From operation