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Real-time implementation of fault diagnosis to a heat exchanger

Stojan Persin[a,*], Boris Tovornik[b]

[a]Faculty for Electrical Engineering and Computer Science, University of Maribor, Smetanova 17, 2000 Maribor, SI, Slovenia
[b]ELTI, Panonska 23, 9250 Gornja Radgona, SI, Slovenia

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Abstract

The detection and isolation of faults in engineering systems has lately become of great significance. This paper is concerned with application of analytical fault detection techniques to a heat exchanger. The system is nonlinear and a velocity-based linearization is proposed before the residual generation, which is then realized using an observer, and parity relations. The problem of reasoning is treated by an approximate reasoning approach, called the transferable belief model. Its important feature is the ability to treat inconsistency in data by using more general belief functions. The system under consideration is controlled by programmable logic controller and supervised by supervisory control and data acquisition system. The procedure for implementation is designed with particular emphasis on industrial practice and the Ole for process control data access client/server technology is used for communication between sub-systems.

Keywords: Fault detection; Fault isolation; Heat exchangers; Linearization; Reasoning; Real-time systems; OPC

1. Introduction

State and operational capability of elements of controlled systems must be observed by automated monitoring. This procedure begins with monitoring the status of each element of the process, actuators, sensors, control equipment including their behaviour in open- and closed-loop operation. The increasing demand for safer and more reliable systems leads us to take into account fault detection and isolation (FDI) issues. Fault detection procedures are intended to be on the basis of real-time observations, to decide whether the system is in normal operating conditions or in faulty ones (Isermann, 1984). FDI aims at the identification of the kind of fault (if present) among a given fault set (Patton, Frank, & Clark, 2000). The reader is also referred to a survey paper by Frank (1996) and books by Basseville and Nikiforov (1993) and Gertler (1998). Heat exchangers are the subject under discussion in this paper which deals especially with the diagnosis and implementation issues. An interested reader is also referred to (Ballé, Fischer, Füssel, Nelles, & Isermann, 1998).

This paper is arranged in the following manner. Section 2 describes the system under consideration. Sections 3 and 4 describe the diagnostic system and the experiments conducted (in real-time) to demonstrate the used algorithms. An implementation issue is addressed in Section 5 and finally, in Section 6, conclusions are drawn from the work.

2. System description

Fault diagnosis will be presented and applied on a pilot heat exchanger depicted in Fig. 1. In the primary circuit, the electric heater produces hot water in the vessel at a pressure of 1 bar (system is open to the atmosphere). The temperature of the outgoing water in the secondary circuit ($\vartheta_{c\,out}$) is a controlled variable and the control is achieved through the change of mass flow

*Corresponding author. Tel.: +386 2 220 7170;
fax: +386 2 251 1178.
E-mail address: stojan.persin@uni-mb.si (S. Persin).

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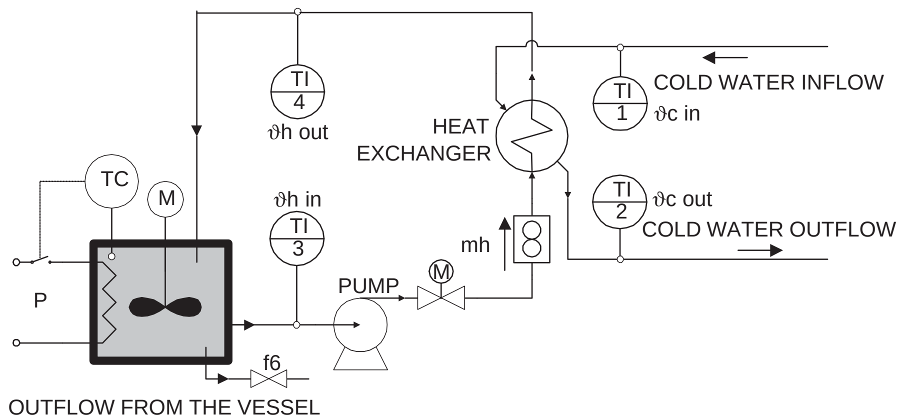

Fig. 1. Process scheme of the heat exchanger.

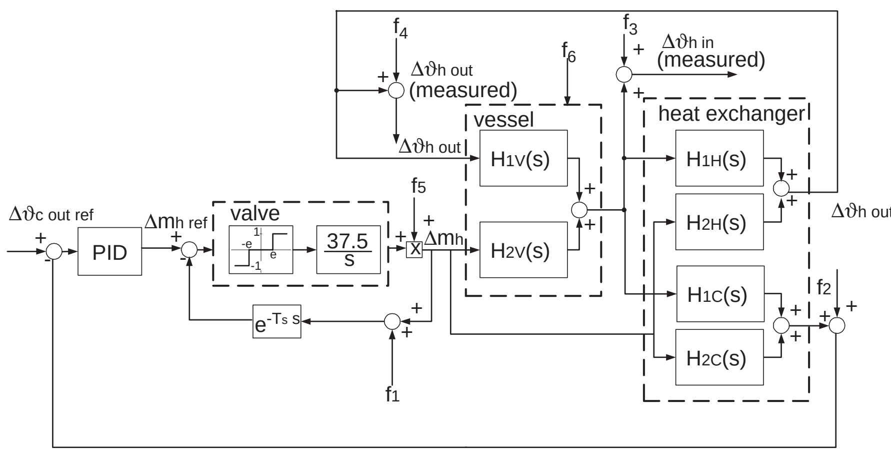

Fig. 2. The mathematical model of the plant including all the faults to be detected.

(m_h) in primary circuit. This is regulated by PID-controlled electric valve, and it highly influences the static behaviour of the heat exchanger.

The following variables, parameters and annotations are used in the system description:

- P power of the electric heater (W)
- m_h mass flow of the heating water (primary circuit) (l/s)
- c_p specific heat constant (general) (J/kg K)
- $\vartheta_{h\,in}$ temperature of the heating water (primary circuit) entering the heat exchanger (K)
- $\vartheta_{h\,out}$ temperature of the heating water (primary circuit) leaving the heat exchanger (K)
- $\vartheta_{c\,in}$ temperature of the cooling water (secondary circuit) entering the heat exchanger (K)
- $\vartheta_{c\,out}$ temperature of the cooling water (secondary circuit) leaving the heat exchanger (K)
- M mass of the water in the vessel (kg)

A heat exchange in such a system is a process that cannot be modelled with a high accuracy. A dynamic response of a heat exchanger also depends strongly on its operating point. For the mathematical representation of the heat exchanger, a set of linear partial models is used as shown in Fig. 2. The model of the heat exchanger was first developed by Isermann (1965) and later expanded by Goedecke (1985). The model was derived as a multivariable two-input, two-output model:

$$\Delta\Theta_{c\ out}(s) = \underbrace{K_2(H_2^1(s) + H_3^2(s)e^{-T_{dh}s})}_{H_{2C}(s)}\ \Delta V_h(s) + \underbrace{H_1^1(s)(H_1^2 e^{-T_{dc}s} - H_1^3 e^{-T_{dh}s})}_{H_{1C}(s)}\ \Delta\Theta_{h\ in}(s), \tag{1}$$

$$\Delta\Theta_{h\ out}(s) = \underbrace{K_2'(H_1^{2'}(s) + H_3^{2'}(s)e^{-T_{dh}s})}_{H_{2H}(s)}\ \Delta V_h(s) + \underbrace{H_1^{1'}(s)}_{H_{1H}(s)}\ \Delta\Theta_{h\ in}(s). \tag{2}$$