MAGIC ARCHITECTURE AND PILOT APPLICATION

Birgit Köppen-Seliger[1], Reinhard Stücher[2],
Sylviane Gentil[3], Attilio Brighenti[4], Thomas Längle[5],

[1]*Universität Duisburg - Essen, Institute for Automatic Control,*
Bismarckstr. 81 BB, D-47048 Duisburg, koeppen-seliger@uni-duisburg.de

[2] *SMS Demag AG,*
Wiesenstr. 30, D-57271 Hilchenbach, Automation@sms-demag.com

[3]*Laboratoire d'Automatique de Grenoble, INPG, UJF, CNRS - BP 46,*
38402 Saint Martin d'Hères Cedex,France, Sylviane.Gentil@lag.ensieg.inpg.fr

[4]*S.A.T.E Srl.- Systems and Advanced Technology Engineering,*
Santa Croce 664/A, 30135 Venezia, Italy, attilio.brighenti@sate-italy.com

[5]*Universität Karlsruhe, Fakultät für Informatik,*
Kaiserstr.12, D-76128 Karlsruhe, laengle@ira.uka.de

Abstract: This contribution introduces the European research project MAGIC in order to set the ground for a following on stage demonstration of the MAGIC system. The goal is to present the basic architecture of the project "Multi-Agents-based Diagnostic Data Acquisition and Management in Complex Systems (MAGIC)" as well as to describe the first pilot application system. MAGIC, which is funded by the European Commission in the framework of the IST programme, is based on a multi-level-multi-agents architecture integrating all levels necessary for a comprehensive diagnosis into a diagnostic system. The pilot implementation will start with the hydraulic looper in a hot rolling mill.

Keywords: Complex systems, Fault diagnosis, Decision support systems, Intelligent knowledge-based systems, Agents.

1. INTRODUCTION

For over 20 years fault detection and isolation (FDI) and fault diagnosis have been a topic of interest due to steadily increasing demands for higher system performance, product quality, productivity and cost efficiency (Frank, 1990; Frank, 1991; Frank et al., 2000; Isermann, 1994; Gertler, 1998). The rapid development of micro-systems, information and communication technologies further makes it possible to integrate more and more sensors, actuators, control loops, computing units and standardised bus systems in the control system. The progress of control theory has allowed increasing product quality, and reducing production cost, thanks to hierarchical control loops (local regulations, cascade loops, multivariable control, sub-processes coordination). This progress makes possible designing more complex processes which in turn need further advanced methods for monitoring and supervision. All these lead to a continuous growth of the complexity and automation degree of technical processes. Typical instances of such kind of complex and distributed systems are sophisticated vehicles, civil aircraft, environment treatment processes, large fleets and infrastructures etc. Associated with these development trends, high reliability, availability and safety become an important system requirement which is included in many international standards and regulations.

While the complexity of technical systems rapidly increases and the trends show a high integration of different types of subsystems and various technologies in technical processes, the research of FDI technologies in the last ten years is marked by the development of methods and tools, which solve FDI problems for a certain type of system and usually are based on some technology or on the integration of different technologies and schemes to a low degree.

Furthermore it can be noticed that many solutions are presented from a pure theoretical point of view, or eventually on simulated data but very few real industrial applications are reported in the literature. At the scale of the whole plant, the role of a supervisory system is to support and not to replace the human operator teams. The operators must understand what is occurring during normal operation as well as during a fault propagation, in order to ensure that process future states are acceptable (Montmain et al., 1994). It is thus essential for the applicability and acceptance in real industrial applications that the research is not finished with providing some difficult to interpret residual signals but that also decision-making support for the operator is offered. Every FDI system has to prove that it provides not only **reliable** diagnostic results but also really **assists the operator** and helps improving his performance.

The need for know-how and competence in different technical disciplines and in dealing with different types of systems on the one side, and the limited research and development funding for such activities at national level on the other side, make the realisation of this idea however much difficult. A joint research activity by research groups with different scientific and technical backgrounds promises a potential solution for this problem.

In this contribution, an overview about the basic concept and the pilot application of an EC- research project in the field of FDI, “Multi-Agents-based Diagnostic Data Acquisition and Management in Complex Systems (MAGIC)”, is presented.

2. MAGIC CONCEPT

2.1 Basic considerations

In MAGIC a general purpose architecture and a set of tools to be used for the detection and diagnosis of incipient or slowly developing faults in complex systems have been developed (Köppen-Seliger et al., 2002). The early identification of potentially faulty conditions provides the key information for the application of predictive maintenance regimes. By detecting faults before they fully develop, the operator can organise maintenance actions for his plant or the automatic control system can be reconfigured accordingly. Thereby not only continuation of production can be achieved or maximised but also constant product quality can be ensured (Aström et al., 2000). In this respect, the MAGIC tool is intended to be of great use for maintenance and process engineers. Let us emphasize that a process automatic shutdown may correspond to a huge profit loss (50 000 €/hour for a rolling mill for instance) and thus avoiding a shutdown may be more interesting from an economic point of view than gaining on production cost.

Today's industrial plants are complex and, in order to achieve efficient and safe operation, modern automatic control schemes are required. The current role of the plant's operator is that of a system supervisor responsible for strategic control decisions to maintain the plant within a safe and efficient operating state. In the event of a developing abnormal situation, the operator is often overwhelmed by a mass of low level information, sometimes changing rapidly, and often several stages away from the original source of the faulty component. Time is also playing an important role in the process behaviour and is difficult to handle by the operator in long term situation: when a slowly increasing fault is disturbing the normal behaviour, it is difficult for the operator to relate actual observations with observations made a long time ago and thus he generally suspects multiple independent faults when he is just observing the consequences of an initial misbehaviour developing slowly. In case of malfunction, information is difficult to understand intuitively, due to the action of control loops. This leads to the well known “cognitive overload” (Bainbridge, 1993). This information requires rapid assimilation to allow a potentially dangerous plant's state to be diagnosed and the incipient faults to be located. This demonstrates the necessity of an operator support tool to assist him in his data and information interpretation. The aim of MAGIC in this respect is to provide the plant operator with clear, as detailed as necessary, and easily comprehensible information about the cause of the abnormal plant condition and to suggest appropriate remedy actions or controller reconfiguration.

2.2 MAGIC architecture

The distributed architecture for MAGIC is based on a Multi-Agents-Multi-Level (MAML) concept as depicted in Fig. 1. The idea is that the task of the complex embedded system's diagnosis and operator support is distributed over a number of intelligent agents which perform their individual tasks nearly autonomously and communicate via the MAGIC architecture. Such an architecture can well be distributed on and adapted to existing monitoring and control systems of large scale plants.

The following work is carried out in the MAGIC project: the complete communication infrastructure is designed, developed and tailored to the specific needs. Furthermore, Graphical User Interfaces (GUI), with which the architecture can be controlled, managed and configured, are developed. A development shell for the different agents used in the MAGIC System that can be tailored to the different

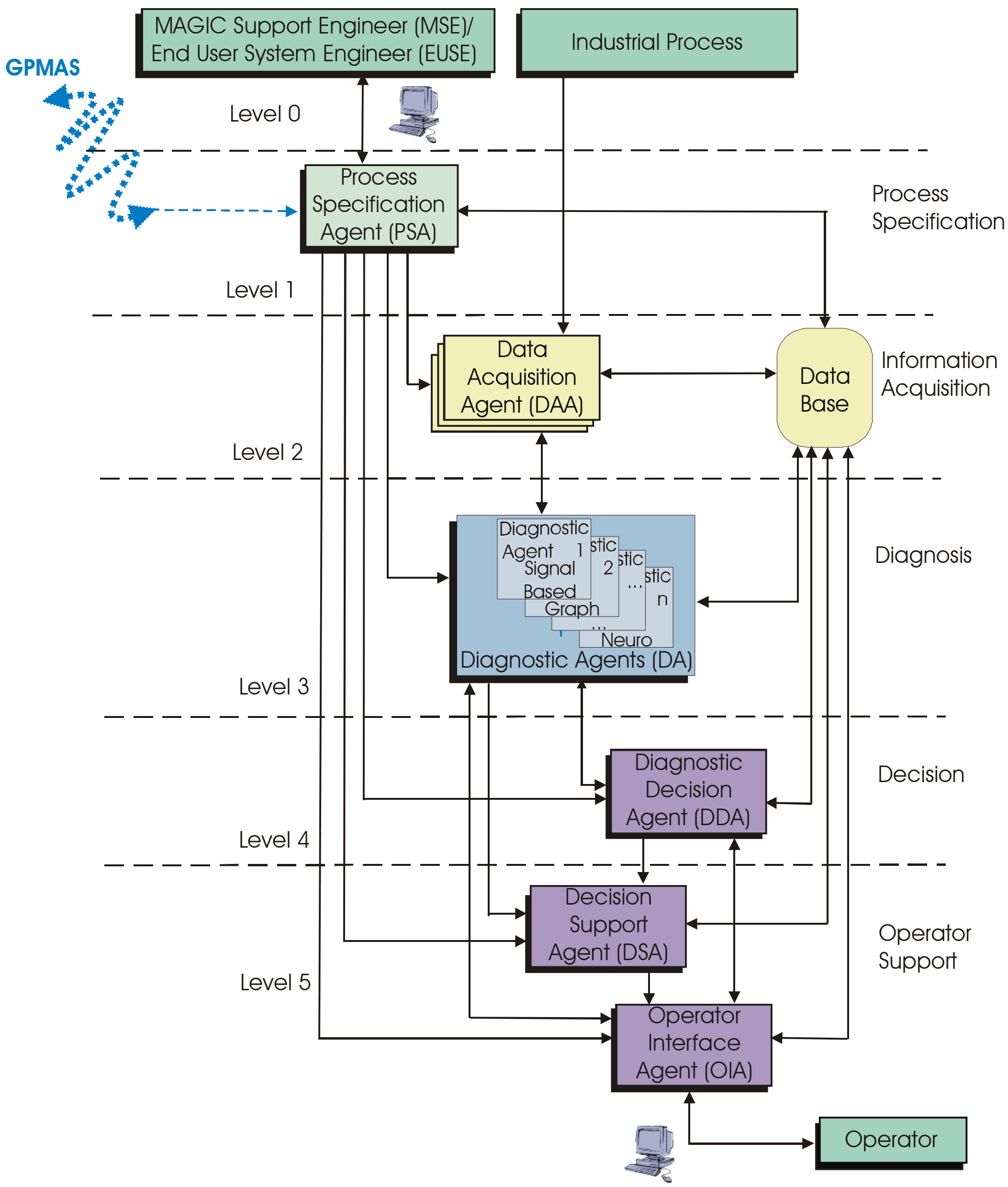

Fig. 1. Multi-Agents-Multi-Layer (MAML) Concept

application areas has been produced.

For the prognosis and diagnosis of incipient or already occurred faults, software procedures and routines have been developed. These algorithms were tested at a demonstrator and then implemented into the Diagnostic Agents employing the agent development tool. In order to specify the process to be monitored and diagnosed and to configure the agents for a specific problem, a Process Specification Agent was developed and implemented, which interacts with the operator and the process. Depending on the process specifications, the appropriate data acquisition is being performed by another agent, which is part of the MAGIC agent development. In a next step, a Diagnostic Decision Agent and a Decision Support Agent propose a final diagnostic decision from the results of the Diagnostic Agents involved in the actual evaluation of the process situation, and an Operator Interface Agent displays diagnostic information to the operators. They also provide support to the operator by giving advice. In general, the MAGIC tool is intended to be applied and implemented in any industrial sector where diagnostic data acquisition and management is necessary to ensure a reliable and safe performance of complex technical processes. Application areas range from steel and automotive industry over chemical plants, nuclear reactors, power plants and mass transports systems, e.g. in the railways, naval and aviation industries.

The whole MAGIC tool set will be implemented in a pilot application in a hot rolling mill plant starting with a hydraulic looper as described in the following.

3. THE HYDRAULIC LOOPER SUBSYSTEM

As suitable test components the hydraulic looper in a hot rolling mill was selected in order to test and optimise the algorithms for fault detection in advance. Benchmark data from simulations and measurements and diagnostic results were provided.

3.1 Physical description

Hydraulic loopers are typically sited between two mill stands. They measure the mass flow disturbances during the rolling process, eliminate them by the loop control and build up the strip tension and keep it as constant as possible. These tasks have a great influence upon productivity and the product quality of the plant. The fulfilment of these tasks presupposes a high system dynamics in conjunction with very precise measurement of position and force, in particular with thin end gauges and at high rolling speeds. Appropriate dimensioning and design are necessary in order to achieve this, Fig. 2

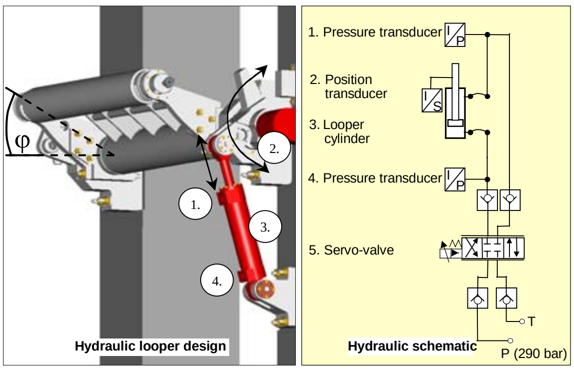

Fig. 2: Design of the hydraulic looper

The physical system is divided into four model parts:

- Technological control system
- Hydraulic system, consisting of servo valve, pipes and cylinder
- Mechanical system
- Sensors, actuators and final control elements

3.2 Technological control system

The electric control used for automation of the hydraulic looper is shown in Fig. 2. It consists of a position control with underlaid force control:

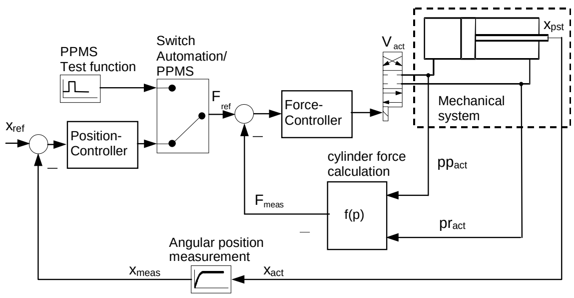

Fig. 3: Electric control of the hydraulic looper system

In normal operation the force and position reference values are made available by the process control system. During breaks, such as work roll changes, diagnosis tests are generated by the test functions of the implemented plant and process monitoring system (PPMS).

3.3 Hydraulic system

Hydraulic transmission systems typically consist of four components: the hydraulic supply, the servo valves, hydraulic pipes and the hydraulic cylinder . A physical model of the system is shown in Fig. 4. Normally the pressure of the hydraulic supply can be assumed constant, as bladder accumulators are used to provide an additional oil reserve and thus pressure reserve.

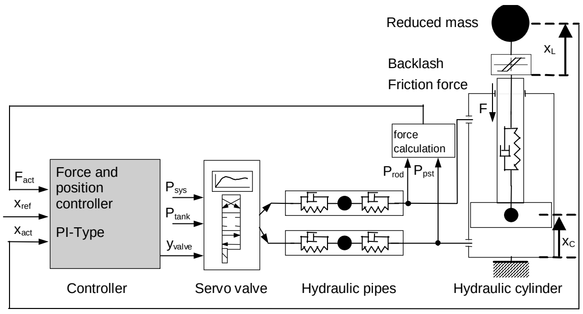

Fig. 4: Modelling of the hydraulic system

3.4 Mechanical system

The mechanical system follows a certain angular geometry as shown in Fig. 1. The current position of the looper is represented by the measured angle φ, which is a function of the geometry and the current hydraulic cylinder position. The hydraulic looper is actuated by a conventional hydraulic cylinder with sliding seal featuring self aligning roller bearings at both ends.

3.5 Sensors, actuators and final control elements

The hydraulic looper subsystem has the following sensors:

- Analogue pressure transducers, attached to the hydraulic pipe on piston / rod side. They are used to calculate the forces acting on the piston of the hydraulic cylinder.
- Digital angle transducer. Attached to the looper main shaft. Directly measures the angle φ (Fig 2).

For controlling the hydraulic system, servo valves are used.

4. MATLAB / SIMULINK SIMULATION MODEL

The hydraulic looper system is a typical example for a hydraulic control loop. The simulation is based on Matlab/Simulink models, which contains the dynamic behaviour of the mechanical structures, consider hydraulic influences and model the control structures.

For the hydraulic looper model, some simplifying assumptions are made, e.g.:

- The system pressure and the tank pressure at the servo valve are assumed to be constant
- The kinematics of the hydraulic looper is not considered, as there are limited movements around one working point. Just one reduced mass is considered

5. MEASUREMENTS AND SIMULATED FAULTS

For the simulation of the imposed faults the step response in force control as a typical dynamic test function was used. The following simulated signals had been recorded:

- time
- reference force
- reference angular position
- measured pressure on piston side
- measured pressure on rod side
- measured angular position
- servo valve reference position
- servo valve actual position
- cylinder force
- actual force on rod
- actual angular position

5.1 Step response test in force control

Fig. 5 shows the signals of the simulation for the step response without imposed fault. The rod force acts within the cylinder rod.

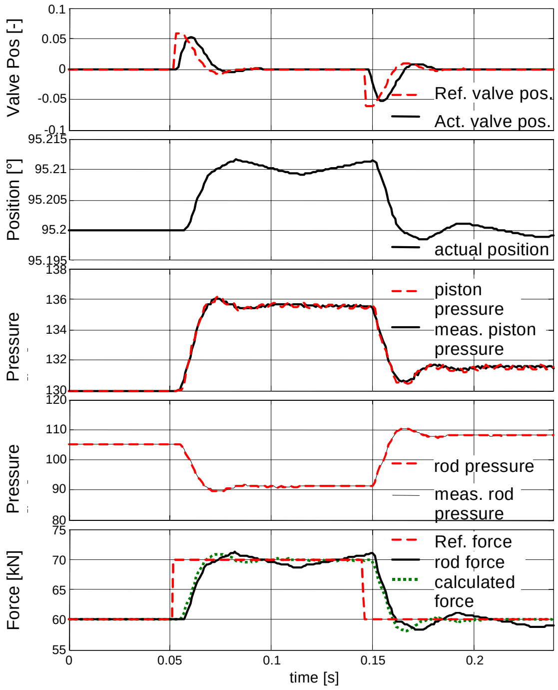

Fig. 5: Step response in force control: normal operation

A step response in force control is triggered by running the looper up to the end-of-run position and pressing it against an end stop. At the beginning of the test, in this position first there is a constant force F_0 of 60 kN. After 1.2 ms, a reference force F_R of 10 kN is applied in force control and held for 95 ms. Then F_R is again decreased by the same amount and held for the same time interval. In the simulation after applying F_R a settling time of 500 ms ensures that the system is in a steady state.

5.2 Simulated faults

First 14 different faults were simulated and made available for further examination:

F1 gain fault angle transducer
F2 offset fault angle transducer
F3 backlash in angle transducer coupling
F4 gain fault pressure transducer piston side
F5 offset fault pressure transducer piston side
F6 gain fault pressure transducer rod side
F7 offset fault pressure transducer rod side
F8 outer leak in hydraulic pipe, piston side
F9 outer leak in hydraulic pipe, rod side
F10 inner leak in hydraulic cylinder between piston and cylinder wall
F11 wear of control edges in servo valve
F12 system pressure reduced
F13 hydraulic cylinder friction increased
F14 hydraulic cylinder rod stiffness reduced

5.3 Interpretation of the simulated faults

Case F10 step response with inner leak in hydraulic cylinder between piston and cylinder wall was selected as an example. The simulated signals are shown in Fig 6.

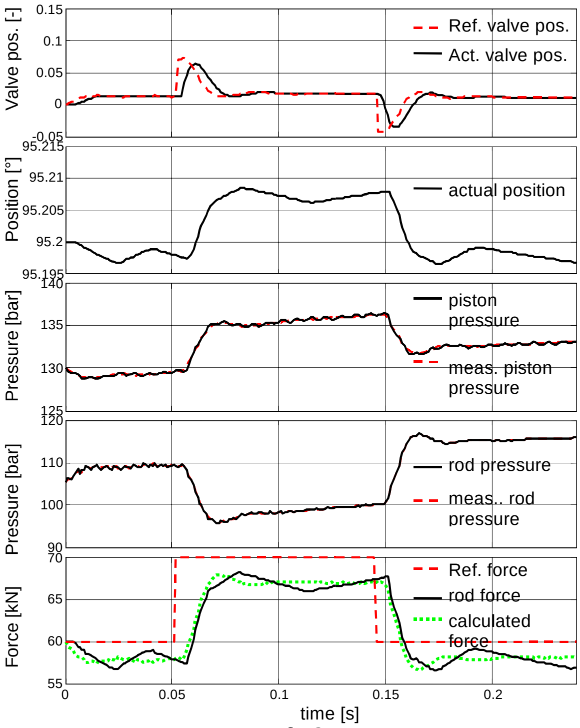

Fig. 6: Inner leak of $10^{-6}m^2$ in hydraulic cylinder between piston and cylinder wall

It can be seen that the controller increases the pressure on the piston side in order to compensate the difference of reference force and measured force. Due to the leakage flows, also the rod-side pressure increases.

5.4 Measurements

The measured values for the step response were recorded by the PPMS system during normal operation of a real plant. Discontinuities of the angle at top and bottom position of the hydraulic looper were detected by the PPMS trend analysis but not by the PPMS step response tests. They were also detected within the MAGIC benchmark tests (Marcu et al., 2004). Fig. 7 shows the trend of the angle at top position of the looper.

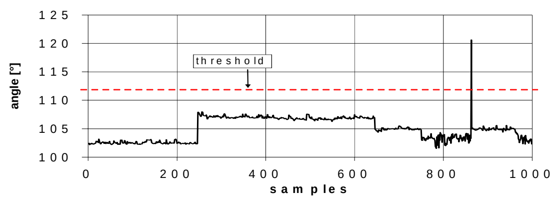

Fig. 7: Trend of the angle at top position of the looper

In the measurements, a permanent control deviation was detected by the PPMS, Fig. 8.

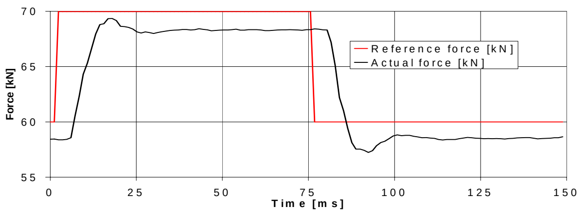

Fig. 8: Measured step response

This deviation is not compensated by the proportional controller. The small quantity of the deviation does not lead to any impairment during normal operation, but a detailed analysis has shown, that the calibration of the zero position of the valve was not correctly calibrated.

4. CONCLUSIONS

The key concept for a distributed multi-agent approach to process monitoring and fault diagnosis is briefly presented in this contribution. The most important aspect of the EU RTD project MAGIC is the development of a general purpose architecture and a set of tools for complex process' monitoring and diagnosis.

Furthermore, in this paper simulations and measurements of the hydraulic looper of a hot rolling mill are presented. The benchmark data created a basis for the test of the planned fault diagnosis algorithms.

These simulations of different fault scenarios may contribute to determine the sensitivity, robustness and reliability of the fault diagnosis algorithms.

The experience already gained form the starting point for additional benchmarks with further measured data from other plants. It is planned to expand the system for other hydraulic systems.

The simulation model builds the starting point of a linearised model, which shall be used for the development of model based FDI algorithms.

This contribution sets the base for an on-line demonstration of the whole MAGIC system within an invited session dealing with the MAGIC project.

ACKNOWLEDGEMENT

This work is supported by the European Commission under the project EU-IST-2000-30009 MAGIC.

REFERENCES

Aström, K., Albertos, P., Blanke, M., Isidori, A., Schaufelberger, Sanz, R. (Eds.) (2000). *Control of Complex Systems*, Springer Verlag.

Bainbridge, P (1993). The change in concepts needed to account for human behaviour in complex dynamic tasks, *IEEE-SMC Congress*, 126-130, Le Touquet, (France).

Frank, P. M.(1990). Fault Diagnosis in Dynamic Systems using Analytical and Knowledge-Based Redundancy - A Survey and some New Results; *Automatica*, Vol. 26, No. 3, pp. 459 - 474.

Frank, P. M. (1991). Enhancement of Robustness in Observer-Based Fault Detection; *SAFEPROCESS '91*, Baden-Baden, Vol. I, pp. 275 - 287.

Frank, P. M., Ding, S. X., Köppen-Seliger, B. (2000). Current Developments in the Theory of FDI, *SAFEPROCESS 2000*, Budapest, Vol.1, pp. 16 – 27.

Gertler, J. J. (1998). *Fault Detection and Diagnosis in Engineering Systems*, Marcel Dekker, NY.

Isermann, R. (1994). Integration of Fault Detection and Diagnosis Methods, *SAFEPROCESS '94*, Helsinki, pp. 597-612.

Köppen-Seliger, B., Ding, S. X. and Frank, P.M. (2002). MAGIC – IFATIS: EC-Research Projects; *IFAC World Congr.*, Barcelona, Spain.

Marcu T., Köppen-Seliger, B. and Stücher, R. (2004). Hydraulic Looper Fault Detection and Isolation Using Dynamic Neural Networks, *Symposium on Automation in Mining, Mineral and Metal Processing, Nancy, France.*

Montmain, J., Leyval, L., Gentil, S. (1994). Qualitative analysis for decision making in supervision of industrial continuous processes, *Mathematics and Computers in Simulation,* Vol. **36**, pp 149-163.