8
Automation and Control of Microprocess Systems

Thomas Bayer and Olaf Stange

8.1
Introduction

The basic aspects of a control system are the same, independent of the size of the automated system or the type of the controlled process. However, most microprocess systems are operated today with zero or little automation. This is partly due to a lack of adapted sensors and actuators.

Of course, the first question has to be: Why should I automate my microprocess system set-up at all? Running it manually is cheaper, easier and has worked for me until now – why should I change?

In general, the following aspects often justify automating a process:

- Reproducibility of process control improves product quality.
- Fast and reliable automated reactions to process upsets reduce the risks of product deterioration or loss and prevent the activation of safety shutdowns.
- Operation close to an optimum is often only possible through automation.
- Reduction of operator load enables them to control larger parts of a plant.
- In many cases, only automation allows for running around the clock.
- Automatic recording and archiving of process data and operator behavior allow later analysis as a basis for further improvements.
- Integration/coordination with other equipment can be facilitated through automatic data exchange.

These aspects of automation are useful for microprocess systems also. So the question is how to make a microprocess system automated with adequate effort.

Can we just use standard process control systems from normal process automation for microprocess systems also? Or are there specific requirements for the automation of microprocess systems that aren't encountered in "normal" process automation?

Well, some special requirements are indeed caused by the specific properties of microprocess systems. Due to the small volumes, some process values will have very fast change rates that are not easily covered by standard automation solutions. And

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possibly more important, automation needs sensors and actuators in view of the sizes of micro structured devices. Commercially available process instrumentation is not applicable in every case. This is due to their sizes, but also to the dead volumes caused by the "macro" connections.

Finally, laboratory set-ups will be changed much more often than in production. Therefore, an easy set-up and change of the automation functions without a deep knowledge of automation is required.

In the following sections, some examples of emerging solutions to these specific requirements and answers to the question about automation with adequate effort are presented.

8.2
Automation in Laboratories

High quality of test implementation and documentation, quick adaptation of the automation system to the test requirements, improved preparation of tests and greater reliability thanks to automated and monitored processes help to achieve a high test quality with optimized cost structures. Automation systems for industrial laboratories are subject to special requirements, however. The automation system must be simple and flexible enough that, for example, adding an additional measuring station or changing the existing configuration can also be carried out by employees who are not specially trained for this purpose. There are other, different systems on the market. Some are specially designed for a product; some are self-developed using standard software packages. Two examples are presented below.

8.2.1
Example: HiTec Zang LAB-manager and LAB-box

Automation within the laboratory and mini-plants is essential for increasing efficiency and quality and for cost reduction. Focused on the special requirement within R&D, HiTec Zang offers a specially designed process control system, the LAB-manager system and the smaller version LAB-box system (www.hitec-zang.com) (Figure 8.1) for laboratories and pilot plants. The system has unique flexibility and user-friendly operability. The system is based on the automation units LAB-manager or LAB-box and the software LabVision. The automation units are modular, equipped with the required plug-in connections for laboratory apparatus, sensors and actuators according to the NAMUR Worksheets.

From temperature sensors up to dosage pumps, most equipment can be connected by the operator just by plugging in adapted cord sets. The whole automation hardware is included in one compact unit. Because of its modularity, the system can grow with the requirements of the user – from a small data-logging system up to a complex process control unit.

The system is equipped with the software LabVision, which covers the whole specification range of the continuously operated modular microreaction system. The

Figure 8.1 HiTec Zang Lab-box system.

program is particularly suitable for the visualization and automation of continuous and batch processes in the laboratory, pilot plant, mini-plant and production. It satisfies the requirements of the NAMUR Working Party WP 2.4 in terms of research process control computer systems (RPCCS) and is thus equipped for frequently changes or modified applications. Sampling of the product may also be integrated. In Figure 8.2, a 24-position sampler is integrated in a LabVision user interface worksheet of a microreaction system.

LabVision is well adapted to design special worksheets for microreaction systems. The LabVision software includes a self-explanatory, self-documenting and multi-tasking programming language (HiText) for control, on-line evaluation and communication. Users can easily learn how to use it within a short time without any previous programming experience.

HiText is easily accepted in both the laboratory and technical areas. Input data errors are observed on entry and highlighted. The command unit also offers special commands for theoretical values, dosing control, time schedule or event-driven actions such as controlling an AutoSam sampling unit which fills samples of the product into up to 50 vials. Moreover, it contains all the syntax elements required for on-line assessment, including mathematical functions.

An important field of application for microreaction devices is screening experiments. A series of experiments with different sets of parameters, such as starting material flow rate, temperature or equilibration times, may be executed automatically. It is only required to type in the lowest and the highest value in one set, and the program is able to interpolate the values in between.

The software LabVision can also be equipped with a digital laboratory journal called eJournal. The eJournal (Figure 8.3) increases efficiency by recording and managing all data measured in an experiment. Furthermore, it is able to collect other information: synthesis recipe, information on educts and products, analysis results and every other reasonable item of information are stored and presented in one clear document.

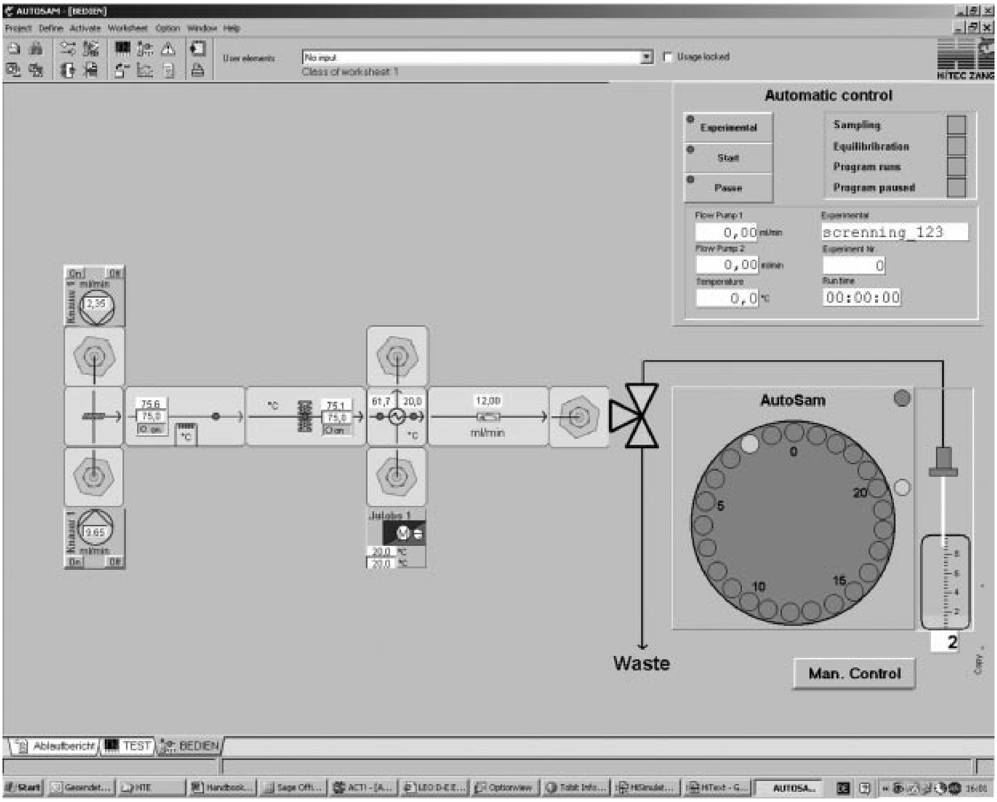

Figure 8.2 Screenshot of user interface with the modular microreactor system from Ehrfeld Mikrotechnik BTS: sample collector.

A computer-based laboratory journal has significant advantages: errors from reading and writing are ruled out and the database may be searched for experimental data or results. A tamper-proof storage with digital signatures is possible. Experimental parameters, measured values and results are presented on clearly arranged protocol sheets.

The laboratory staff are relieved from non-productive routine activities such as reading meters and plotting of results; the data evaluation is assisted by automated analysis routines. For validated processes or Good Laboratory Practice (GLP), a digital laboratory journal is evident.

The relevant measured values, experimental parameters, results and descriptive texts and annotations are recorded during the experiment. These data are presented in report sheets together with tables, charts, single values and text. Due to the free configuration of the report sheets, an optimal documentation is warranted. Manual handling of data – one of the main error sources – is rendered unnecessary. Unattended operation is possible, and nights and weekends are gained as experimentation time in order to complete the experiments as soon as possible. The batch

Figure 8.3 The digital laboratory journal eJournal of LabVision.

report, containing measured values, results, automatic and manual manipulations and all other relevant data, is prepared on-line.

Pictures, chemical formulas, results of external analyses, links to other files or websites, annotations and so on may be placed in the report. Therefore, the eJournal provides a step towards the paperless laboratory. Authenticity and integrity of the information are assured.

8.2.2
Example: Siemens SIMATIC PCS7 LAB

Siemens offers laboratories the SIMATIC PCS7 LAB system (www.siemens.com/simatic-pcs7) (Figure 8.4), which addresses the challenges in this field:

- fast set-up/conversion and commissioning thanks to plug-in connections;
- reliable control and monitoring of the responses through integrated management and safe handling of alarms;

Figure 8.4 SIMATIC PCS7 LAB complete system with configurable I/O station for binary and analog signals, PT100 and serial interfaces RS 232.

- simple configuration of the integrated control system using off-the-shelf solution options, such as for dosing, mixing or temperature adjustment processes;
- simple options for evaluating measured data using export functions, for example to Microsoft Excel;
- high reliability due to automated and reproducible processes.

Based on the tried and tested standard components of the SIMATIC range, the system offered is highly flexible and can be used in a distributed configuration in stable housings and can be moved from location to location. The integrated instrumentation and control system ensures safety by means of reliable monitoring and alarm functions.

The heart of SIMATIC PCS7 LAB is the processing station, based on the SIMATIC PCS7 Box. In this device, the PCS7 functions for automation, operator control and monitoring and engineering are combined in one compact system. As a fully fledged member of the SIMATIC PCS7 family, it works with the standard system software of SIMATIC PCS7. It is scalable and can be expanded with no compatibility problems.

SIMATIC PCS7 LAB provides a number of I/O channels (analogue, binary) that are preconfigured in the I/O station (Figure 8.5) such as serial ports for connecting laboratory scales. The individual channels are designed as plug-in connections, which considerably simplifies setting up the laboratory set.

The system is configured using equipment modules for the most important standard processes used in laboratories, such as dosing, mixing and temperature adjustment. The reuse of tried and tested solutions reduces the time required for

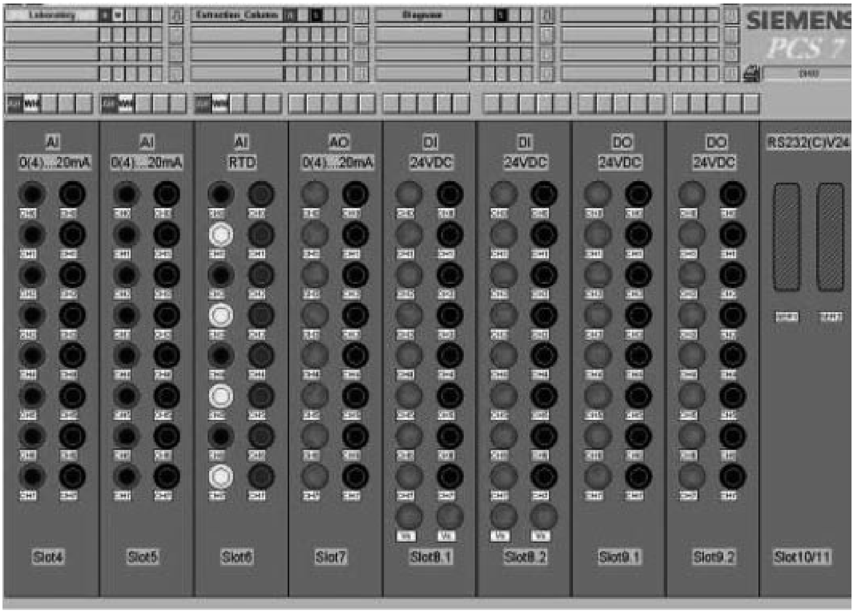

Figure 8.5 SIMATIC PCS7 LAB operator station. Screen shot: I/O handling.

developing laboratory applications on the one hand and increases the quality on the other, because the developed solutions are specifically refined over time.

The automated process and the integrated recording of the parameters ensure the reproducibility of the laboratory work and the verification of the results. Monitoring of the configured limit values and a reliable alarm system allow for continuous work 24 h per day and 7 days per week, even without laboratory personnel being present, since the automation system allows remote viewing and intervention, by means of web technologies, for example.

SIMATIC PCS7 LAB uses components from the SIMATIC family. The open-loop and closed-loop control solutions can be transferred with no problems in the scale-up for use in pilot plants, in pilot systems and in production. Seamless integration into the process automation system of the plant is ensured.

8.3 Automation in Production

In general, the following aspects often justify automating a process:

- Reproducibility of processes, by eliminating the differences in the quality of process control across shifts or times of year or load situations, normally improves product quality and reduces power consumption.
- The optimization of process working points by conducting the process closer to an optimum working point may increase product yield or quality and reduces waste.

- Automated reactions to process upsets are fast and reliable and therefore may reduce the risks of product deterioration or loss and prevent the activation of safety shutdowns. In hard-to-control processes, operation close to an optimum is often only possible through automation.
- The reduction of operator load by freeing the operating personnel from monotonous, repetitive or even dangerous tasks enables them to control larger parts of a plant and to concentrate on super ordinate objectives.
- Longer operating times around the clock for weeks or years without the need for continuous human supervision are in many cases only possible by automation.
- Through automation, the automatic recording of measured values and of process alarms, operator acknowledgements and interventions is achieved as a "side-effect". Long-term archiving allows later analysis as a basis for further improvements.
- The interplay of different pieces of equipment can be enabled or facilitated through automatic data exchange.

The so-called distributed control systems (DCS) originated from a background of large and complex process plants, and have been on the market since the late 1970s. As a tool for smaller or less complex process automation tasks, programmable logic controllers (PLC), together with a superordinate PC-based visualization (supervisory control and data acquisition systems – SCADA), have gained importance since the 1990s. Originally developed for machine control in discrete production, PLC/SCADA solutions have grown to cover more complex requirements, making it possible to apply them for process control.

On the other hand, vendors of DCS systems have over the years strived to make their systems smaller and more economical, and the two worlds are merging today.

Today almost all production plants in process industries are automated. Normally DCS are used from large-scale continuous plants for basic chemicals to batch small-scale plants in the fine, specialty and pharma industries.

The basic aspects of a control system are the same, independent of the size of the automated system or of the type of the controlled process. The fundamental automation tasks, which are independent of the control system used, have to be described and implemented. An example of such a control task is closed-loop control. The system tries to move a measured process variable (e.g. temperature) towards a desired, typically analogue, value (set point) and keep it there by manipulating an output variable by controlling the current flowing through a heating jacket in a stirred vessel.

These control tasks can be solved, for example, by discrete hardware modules (relays, specialized control electronics) or a programmable device (for example, see Figure 8.6) of some sort (PC, PLC or DCS).

Another important task of process control systems is the visualization of the process. Of course, it is not so much the display of the mechanical layout of the plant, but rather the display of live values of process values that is important to the user. And, of course, alarm functions and data management have to be defined.

Figure 8.6 SIMATIC PCS7 operator station with basic hardware.

8.4
Special Requirements for Automation in Microprocess Technology

Let us check to what extent the arguments for the automation of today's existing production plants can be applied in the case of microprocess technology:

The reproducibility of processes is definitely desirable for microprocesses also.

The optimization of process working points is one of the well-known advantages of microstructured systems that tighter process control is made possible through the high surface-to-volume ratio and the intense mixing; to make full use of these possibilities, the externally controllable variables also have to be controlled tightly.

While automated reactions to process upsets may be less crucial than with conventional processes, in view of the small hold-up volumes involved in microprocess systems, this feature is still desirable in order to prevent damage to the equipment or spoiling an experiment/production run.

Today, the typical microprocess is run in a laboratory, so the term "operator" should probably be replaced by "laboratory worker", but reducing their workload is no less valuable. In addition, the first production applications for microprocesses are starting to show up already and this aspect will be as important as in a conventional process.

Longer operation times, whether in laboratory experiments (with an automated parameter screening) to obtain results faster, or in production, where continuous operation is always a prerequisite, are also needed.

Automatic recording and archiving of process and operator behavior are needed in laboratory experiments; these data (together with the analysis of the end product) may actually be the most important result, more than the material produced.

Integration/coordination with other equipment may not be directly obvious, but this is also required both in laboratory and in production. Each microsystem needs to interact with its macro environment (raw material tanks, product storage facilities, heating and cooling supply). Using standard automation tools makes it easy to achieve such integration. This will become even more important in the case of production applications with numbering-up and integration in an existing production environment.

To sum up: practically all aspects of automation are useful for microprocess technology also.

8.5 Process Instrumentation for Microprocess Technology

For some microprocess systems, small, conventional field devices may be used. As opposed to laboratory devices, these offer the reliability and long-term stability required in process applications.

However, to make full use of the capabilities of microprocess systems, specialized new sensor designs are needed, such as miniaturized pressure sensors (see below).

Many more miniaturized sensors and actuators have been demonstrated as prototypes and would be interesting candidates for automated control of microprocess systems. The challenge here is the transition from a laboratory stage to industrial production and stability of the devices.

There is also a need for reduction in size in the connections, combined with low dead volume and easy assembly in the field. All of these implementations would help to reduce size, minimize hold-up and increase the efficiency of the system.

The development of bulk materials, stable coatings and fabrication techniques for these to withstand chemical attacks on the fluid-contacting surfaces is a challenge for the near future.

8.5.1 Temperature Measurement

Temperature is a very important parameter in microprocess technology, especially for reactions and processes which need precise temperature control, such as very exothermic reactions. For this, temperature sensors are available as stand-alone modules (Figure 8.7), integrated sensors inside the modules or as peripherals, for example an integrated pressure-sensor unit or the glass-fiber thermometer based on spectroscopy technology.

8.5.2 Pressure Measurement

Pressure is one of the most important parameters for chemical reaction control and its measurement is essential. Small reaction channels (~1–2 mm) without dead volumes require special sensor configurations. Some different systems for small systems are available, and one example is presented here.

T-shaped coupling cannot be applied due to priming and rinsing problems and the use of oil transmission of the pressure provides new obstacles if applied to small

Figure 8.7 Heat exchanger module with temperature sensors.

dimensions. Therefore, pressure sensors forming a fluid channel have been developed. The sensors can be mounted as modules with U-shaped fluid guide (Figures 8.8 and 8.9). The pressure is mechanically transmitted to a piezo-resistive transducer by the deflection of a micromachined membrane in the channel wall.

The challenge to meet industrial requirements is the necessity to decouple external mounting forces and internal clamping forces from the transducer in a small available space. This is a precondition for good performance and long-term stability. The digital pressure output signal is conditioned to adjust sensitivity and to compensate for thermal effects. A precision of 0.5% of the sensor's full scale (30 bar) and a resolution of 2 mbar can be achieved.

8.5.3
Flow Measurement

Reproducible processes in continuously operated reactors depend on, in addition to pressure and temperature measurements, precise control of the mass throughput of chemicals. To meet these demands, metering devices in modern microreaction

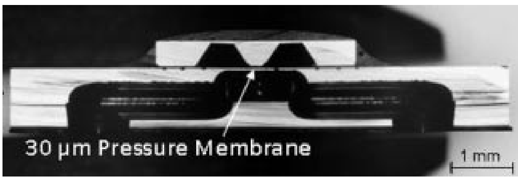

Figure 8.8 Internal structure of the micropressure sensor. Fluids are passed directly along the pressure membrane; no dead volumes occur.

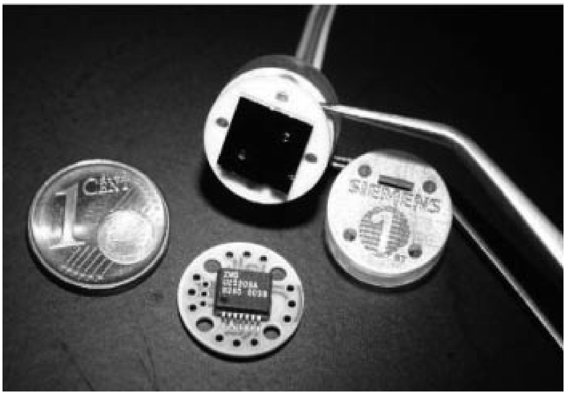

Figure 8.9 In-line micropressure sensor with 0.7-mm connecting channels and electronics.

systems require matched dimensions and extremely high resolution (as low as 1 mg s^{-1} and below). Several systems are available.

Resonant oscillating structures combined with newly developed electrical control and readout techniques are a promising basis for the fabrication of devices for future fully automated control of microchemical engineering systems. This flow sensor (Figure 8.10) is able to measure liquids and gases (Figure 8.11) with high accuracy and needs no further calibration when using different chemicals.

8.6
On-line Analysis for Microprocess Technology

A great advantage of continuous processes such as are always applied in microprocess technology is the application of on-line analysis. In most cases standard

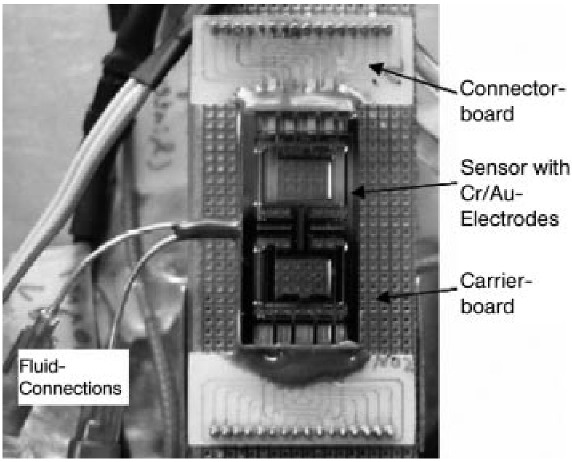

Figure 8.10 Micro Coriolis sensor prototype. Miniaturized structure of tubular resonator on the test bed.

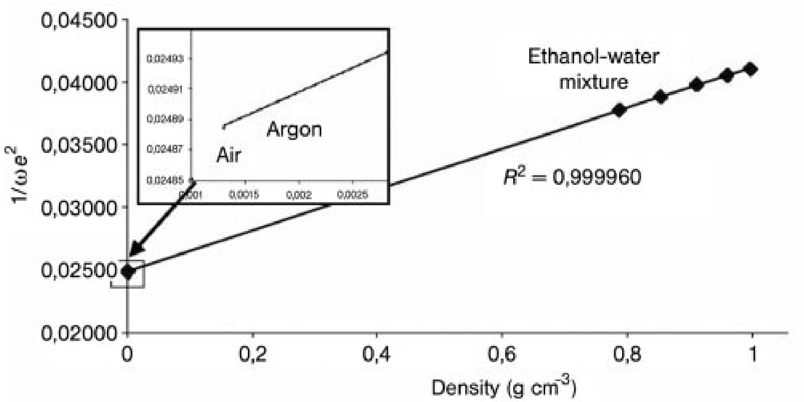

Figure 8.11 Demonstration of density measurements with gases (air–argon) and liquids (ethanol–water mixtures) within one device.

equipment will be used as an end-of-pipe or a bypass solution. However, in recent years some new modules and apparatus have come on to the market that are specially designed for small systems. Some examples are given below. However, on-line analysis is still a field within microprocess technology where special developments for the requirements needed are still necessary.

8.6.1 pH Measurement

pH measurements are one of the most often used on-line analytical tools in process engineering. In microprocess technology, this kind of sensor has become more and more important for process control and quality management. For this reason, some developments are in progress and prototypes already exist from different producers (e.g. Figure 8.12).

8.6.2 Spectroscopic Methods

Spectroscopic methods used in microprocess technology are on the market. Normally they are used in a bypass, they are adapted using optical flow-through modules (Figure 8.13) or the sensor itself is built in a module and connected via an optical fiber. However, some other connections are also suitable.

8.6.3 Gas Chromatography (GC)

Conventional process GC has been improved in the last few decades. High-performance analytical hardware such as valveless column switching with a completely

Figure 8.12 pH sensor from JUMO (www.jumo.net) with flanges 1/4 in UNF thread.

electronic pressure controller and multi-detection has been developed. Additionally, a general trend in favor of miniaturization has also characterized GC in recent years. This has led to the use of microelectronic mechanical system (MEMS) technology, a very common technology for many consumer goods, in this field. Micro-GC systems incorporating this technique, such as MicroSAM (www.siemens.com/microsam) (Figure 8.14), are very small and offer very fast analysis times. The MicroSAM is based on a new, miniaturized and modular design. The explosion-proof enclosure (which makes installation close to the sample point possible) contains the electronic components and an oven module with all the analytical equipment, such as live injection or a thermal conductivity detector (TCD) integrated into a small device.

Figure 8.13 Optical flow-through cell for on-line analytics.

Figure 8.14 MicroSAM on-line process gas chromatograph (diameter 25 cm), using silicon micromachining techniques.

8.7 Automation of Microprocess Systems for Process Development and Production

Of course, the effort to achieve automation has to be in proportion to the resulting benefits, so the question is how to make a microprocess system automated with adequate effort. Can we just use standard process control systems from normal process automation for microprocess systems also? Or is the development of dedicated automation solutions just for microsystems required and feasible?

A second question is whether there are specific requirements for the automation of microprocess systems not encountered in "normal" process automation.

Some special requirements are indeed caused by the specific properties of microprocess systems:

- Due to the small volumes, some process values will have very fast change rates, which are not easily covered by standard automation solutions, hence some dedicated, fast control may be needed.
- Automation needs sensors and actuators, but in view of the sizes of microprocess systems, commercially available process instrumentation is not really applicable. This is due to their sizes, but also to the dead volumes caused by the "macro" connections, hence new generations of miniaturized sensors and actuators including appropriate connection technologies will have to be developed.
- A laboratory set-up will be changed much more often than a production process and in the laboratory workforce there are no automation system specialists available, hence an easy set-up and change of the automation functions without a deep knowledge of automation is required.

The thesis of this chapter is that standard process control systems – with a few enhancements and in the right configuration – are indeed suited for the task of automating microprocess systems.

In the following sections, some examples for emerging solutions to these specific requirements and for answers to the question about automation with adequate effort will be presented.

8.7.1
MikroSyn from Mikroglas

This MikroSyn system is available as a ready-to-run system in different versions: with one or two reactors, without or with integrated IR analytics (http://www.mikroglas.com/mikrosyn.htm) (Figure 8.15).

The control system used is a PLC/SCADA solution (SIMATIC S7 and WinCC from Siemens). The S7 controller consists of

- one S7 CPU 315-2 with integrated interface for the bus system PROFIBUS DP
- one CP 340 communication card for serial coupling to the syringe dosing subsystems
- one digital input card for up to 32 binary signals
- one digital output card for up to 32 binary signals
- two analogue input cards for up to 16 thermocouples
- two analogue input cards for up to 16 analog signals
- one analogue output card for up to four analogue output signals.

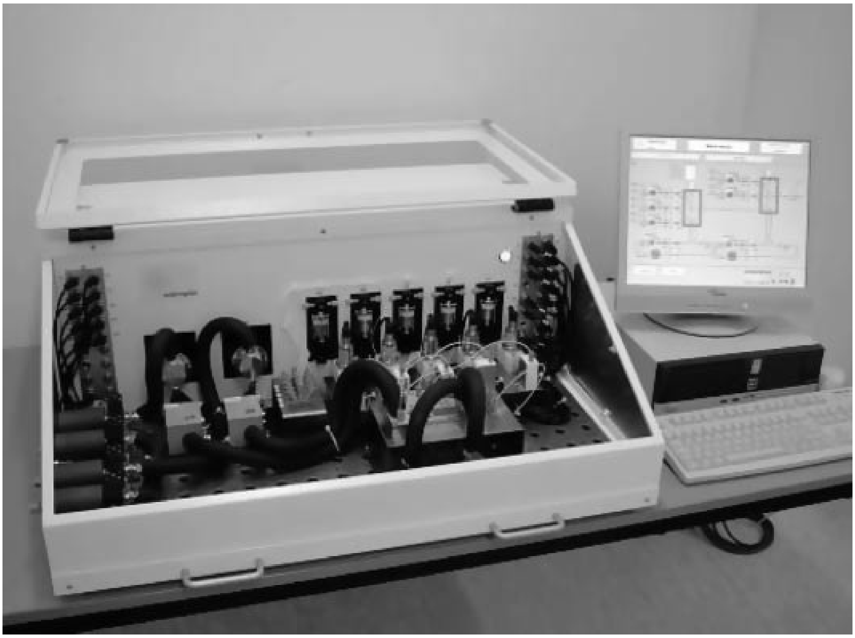

Figure 8.15 MikroSyn system from Mikroglas (www.mikroglas.com) for a two-step catalytic reaction for up to five starting materials (flow rate $\sim$0.1 mL min^{-1}).

The SCADA system is a Siemens PC Esprimo with Windows XP running the WinCC package. In a two-reactor-system, there are

- two temperature controllers (one per reactor) including a circulation pump each and control of the external heating/cooling system;
- control of the five educt syringe pumps via serial link, five miniature valves for educt selection and cleaning, tracking of current dosing speed, dosed volume and remaining volume;
- display of 17 measured temperatures, seven pressures, two flows.

8.7.2
Modular Microreaction System from Ehrfeld Mikrotechnik BTS

Ehrfeld Mikrotechnik BTS (see www.ehrfeld.com). offers the Modular Microreaction System (MMRS), a highly flexible and efficient development and production toolbox connecting the advantages of microprocess technology with high flexibility and a wide range of applications. The system consists of more than 40 individual microstructured modules, which can be arranged freely on a base plate, forming changeable and controllable microreaction plants. These plants, based on the micromodules, are able to perform essential chemical engineering operations, such as highly efficient mixing, heat transfer and reactions.

The MMRS can be equipped with process automation system such as the LAB-box/LAB-manager measurement and control system shown in Figure 8.16 as an automation tool. It includes a hardware box which can be connected to the different microreaction modules of the MMRS, a software tool for measurement and control of

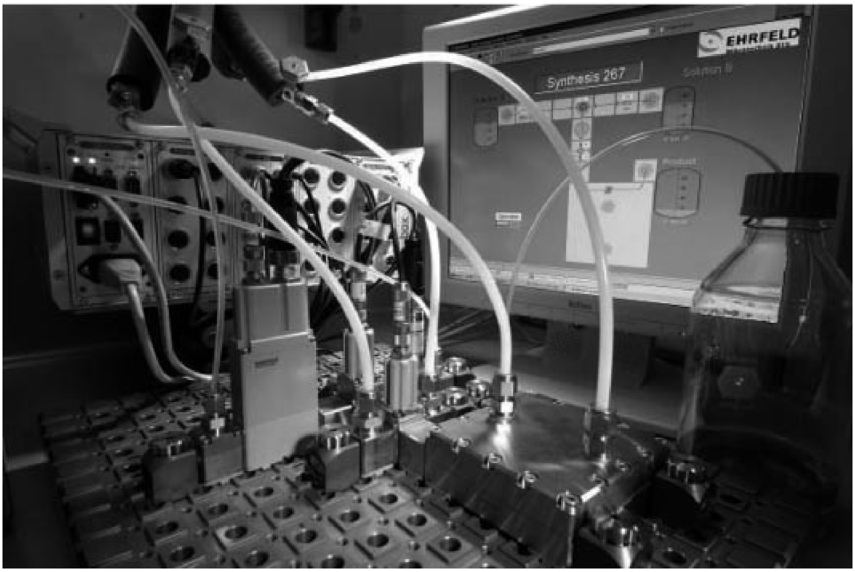

Figure 8.16 Modular microreaction system (MMRS) with a process automation system.

microreaction plants and module-specific cables for the connection of the LAB-box/LAB-manager with different microreaction modules.

The modular developed hardware consists of a housing with various modular analogue and digital interface panels (each eight channels), which can be exchanged according to the requirements of the user. These interface panels include, for example:

- Pt 100 temperature sensor inlet panel;
- analogue input panel;
- analogue output panel;
- digital output panel;
- serial interfaces for peripherals and analytical devices (e.g. pumps, thermostats)
- PID controllers to build up control loops for temperature sensors, gravimetric dosing units and so on;
- power supply panel actuators and sensors.

This package is supplemented by the data library SL-Microbib, which includes all necessary data and symbols of the different microreaction modules of the MMRS (Figure 8.17). These symbols can easily be placed on the screen by simple drag and

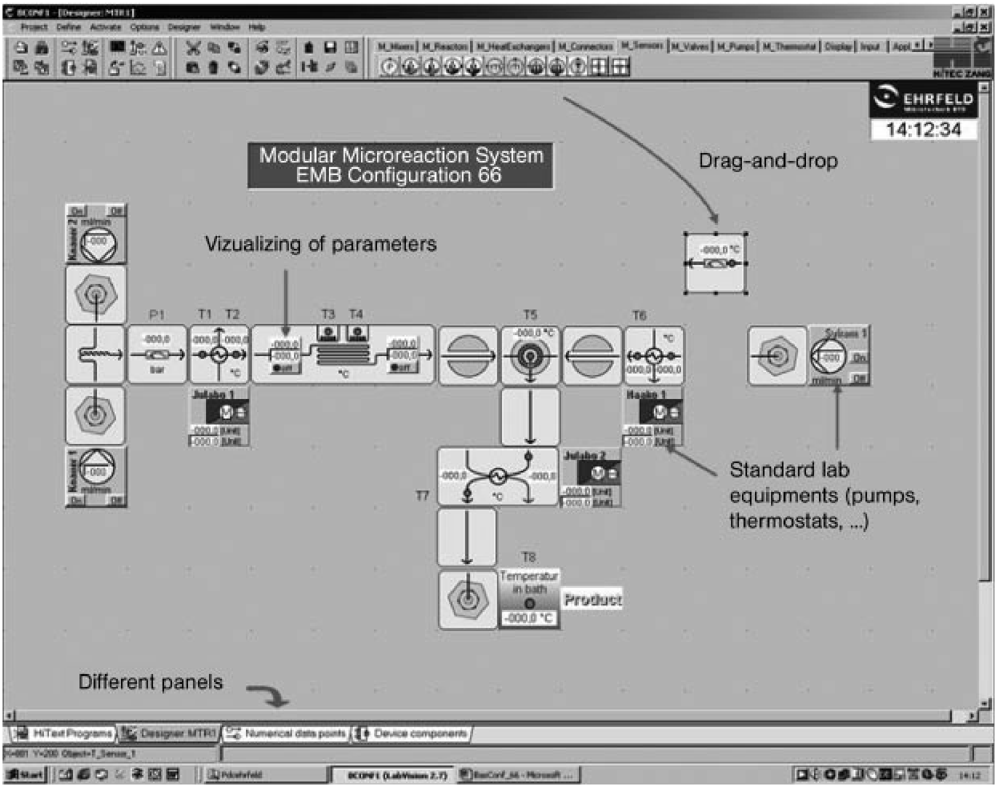

Figure 8.17 Screenshot of the SL-Microbib data library for the MMRS.

drop for the visualization of the configuration of the microreaction plant. The combination of the software and hardware allows the easy and flexible connection of the LAB-box/LAB-manager unit with the microreaction plant to build up a unit that is extremely fast and flexible.

8.7.3 SIPROCESS from Siemens

SIPROCESS (Figures 8.18) is an open automated modular microprocess system with integrated automation for chemical synthesis in process development and production. This system makes it much easier to use microstructured components. Its modules address all functions required for chemical synthesis: metering, mixing and reacting, sampling and pressure adjustment and maintenance. Each module includes sensors, actuators and automation electronics with preconfigured functions.

The system consists of six different module types mounted on a rack:

• flow distribution (FD) module:	distribution of reactants and cleaning fluids
• pump (PU) module:	dosing of reactants
• reaction (RE) module:	chemical reaction (mixing, heat transfer)
• delay (DL) module:	residence time loop for completion of conversion
• pressure control (PC) module:	control of pressure in system
• sample (SA) module:	sampling and sample conditioning (e.g. dilution).

The modules are connected to the industrial approved SIMATIC PCS7 process control system (Figure 8.19). The modules are operated centrally using the human–machine interface station and the automation software. Closed-loop and open-loop

Figure 8.18 SIPROCESS microprocess system (modules and operator station).

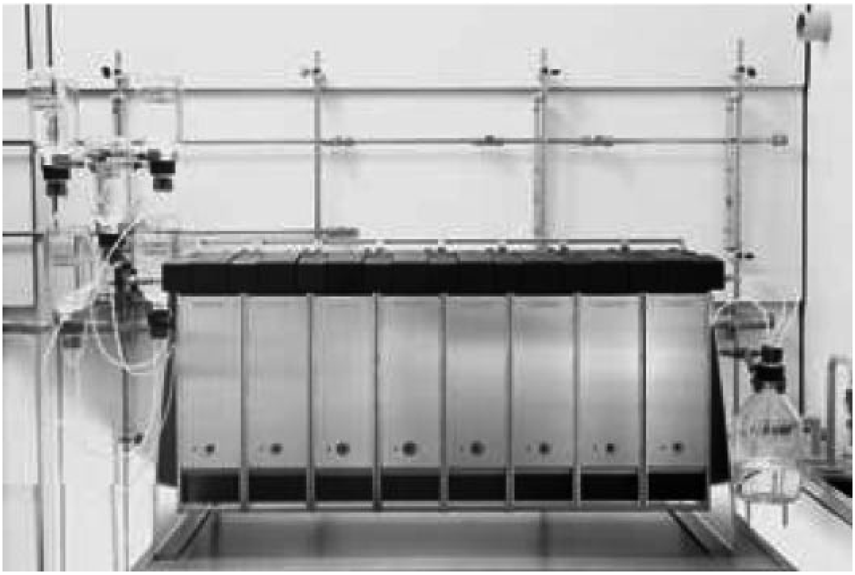

Figure 8.19 SIPROCESS: a modular, automated system mounted in a laboratory fume-hood.

control of the module functions are carried out in a distributed configuration in the relevant modules in accordance with the set points specified by the automation software. The modules are equipped with sensors and actuators for this purpose. The modules communicate with the automation software by means of a communication bus. The automation hardware and software is located in the control cabinet along with the power supply.

The system has a simple automation configuration that can be set up by the operators themselves. SIPROCESS supports up to three fluid streams. The system can be adapted in a very short time to specific tasks, including automation, thanks to the ease with which the module configuration on the rack can be changed.

Liquids can be routed out of and into the laboratory environment by means of connectors and connection adapters. This makes SIPROCESS open for individual expansions.

The temperatures of fluids can be controlled in the two module types in which chemical reactions are to take place. This requires the connection of a temperature control box (optionally available) and the use of two thermostats (not included in the scope of supply).

8.8 Conclusion

The automation of microprocess systems is still in its infancy. However, existing solutions from the automation of large processes – distributed control systems – and from laboratory automation can be adapted and used.

For pure research applications, manual operation of the microprocess components may still be sufficient. However, in many applications, the benefits of automation are notable. The typical results:

- reproducibility of process control
- optimization of process working point
- automated reactions to process upsets
- reduction of operator load
- longer operating times
- automatic recording and archiving of process and operator behavior
- integration/coordination with other equipment

are all welcome improvements that will help to make use of the full potential of microprocess technology.

These aspects will gain in importance as the microprocess systems become more of a standard tool and as their use for production applications begins to gain importance.

Further Reading

1 H. Berger, *Automating with SIMATIC*, 3rd ed., Wiley-VCH Verlag GmbH, Weinheim, **2006**.