# AUTOMATION AND CONTROL IN PROCESS INDUSTRIES

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## Contents



## Summary

This chapter deals with automatic control in process industries. The emphasis is given to mathematical modeling of processes that constitute basic technological units in metallurgical, steel, chemical, food, cement, and paper industries. The processes that are studied from the control point of view can contain time delays, nonlinearities, and are usually multivariable. The principle of feedback control is explained, as well as the principles of PID control. Feedback control is presented in examples of temperature control. This chapter discusses briefly interactions between process control and automation. Finally, process control hierarchy is mentioned.

## 1. Introduction to Process Control and Automation

Technological processes in metallurgical, steel, chemical, food, cement, and paper industries have some basic features in common. In general, they operate mainly continuously. *Continuous technologies* consist of unit processes that are rationally arranged and connected in such a way that the desired product is obtained effectively with certain inputs. Some technologies in process industries are discrete in nature as for example packaging, bottles filling, etc. Control of such processes will not be mentioned here.

The most important technological requirement is safety. Any technology must satisfy the desired quantity and quality of the final product, environmental requirements, various technical and operational constraints, market requirements, etc. The operational conditions follow from minimum price and maximum profit.

*Control systems* are part of technology and in the framework of the whole technology guarantees satisfaction of the above given requirements. Control systems on the whole consist of technical devices and the human factor. Control systems must:

- provide communication between operating personnel and technology,
- guarantee safety,
- consider environmental issues,
- guarantee stability,
- attenuate disturbance, and
- optimize process operation.

*Control* is a purposeful influence of a controlled object (process) that ensures the fulfilment of the required objectives. In order to satisfy the safety and optimal operation of the technology and to meet product specifications, technical, and other constraints, tasks and problems of control must be divided into a hierarchy of subtasks and sub-problems with control of unit processes at the lowest level.

The fundamental way of control on the lowest level is *feedback control*. Information about process output is used to calculate a control (manipulated) signal, i.e. process output is fed back to process input.

All of our further considerations will be based upon *mathematical models of processes*. These models can be constructed from the physical and chemical nature of processes, or can be abstract. The common feature of process control in process industries is the existence of transportation and inertial time delays in processes.

*Process design* of "modern" technologies is crucial for successful control. The design must be developed in such a way that a "sufficiently large number of degrees of freedom" exists for the purpose. The control system must have the ability to operate the whole technology or the unit process in the required technology regime. The processes should be "well" controllable and the control system should have "good" information about the process, i.e. the design phase of the process should include a selection of suitable measurements. The use of computers in the process control enables us to choose an optimal structure for the technology, based on specifications formulated in advance. Designers of "modern" technologies should be able to include all aspects of control in the design phase.

Experience from control practice of "modern" technologies confirms the importance of assumptions about dynamical behavior of processes and complex control systems. The control centre of every "modern" technology is a place where all information about operations is collected and where the operators have contact with technology (through keyboards and monitors of control computers), and are able to correct and interfere with technology. A good knowledge of technology and process control is a necessary prerequisite of qualified human influence of technology through control computers in order to achieve optimal performance.

The topic of process control is related to process automation. Automation in general means replacement of various tasks performed originally by a human with machines and computers.

The reasons for automation are mainly safety, production quality, a larger degree of exploitation of processes and machines, environmental issues, better management information, human factor elimination, etc.

Process automation is never fully accomplished even in cases when the majority of procedures is automated. Operator presence and supervision is always required in tasks of process startup or shutdown, automatic performance change, etc. Even with a high degree of automation of process industries are human interventions for achievement of a satisfactory quality and profitability.

## 2. Process Control History

The history of process control began in prehistoric times, when people worded with furnaces for bronze and iron production. The time of the industrial revolution in Europe is very important for automatic control. At that time J. Watt developed a revolution controller for a steam engine.

Process control developed in connection with the development of control theory and technical devices. Rapid development of discrete-time control theory began after the World War II. A very important step in the development of automatic control was the development state-space theory, in the 1950s and 1960s. It was shown that the optimal linear-quadratic control problem may be reduced to a solution of the Riccati equation. Parallel to optimal control theory, the stochastic theory started its development. It was shown that automatic control problems have algebraic character and solutions were found by the use of polynomial methods. In the fifties of the twentieth century, the idea of *adaptive control* appeared in journals. The development of adaptive control was influenced by the theory of dual control, parameter estimation, and recursive algorithms for adaptive control. Recent theoretic and practical developments resulted in Internal Model Control (IMC) and Model Base Predictive Control (MBPC). The influence of the control theory in recent commercial control systems is evident from control algorithms based on optimal control theory and state estimation.

After the Great War, manual control of temperature, pressure, etc. was continually replaced by automatic control. Instrument companies added to originally proportional gain controller functions to generate automatic reset (integral action) and later also pre-set (derivative) action. In order to dampen process variations, large tanks were included between processes.

In the fifties of the twentieth century, it was often uneconomical and some times also impossible to build technologies without advanced automatic control as the capacities were larger and demand of quality increased. The controllers used did not consider the complexity of controlled processes. Even in pneumatic control dominated, first electronic controllers were introduced.

In the 1960s, process control design began to take into consideration dynamic properties and couplings between processes. The process control used knowledge applied from astronautics and electrical engineering. First automatic analyzers were used in process industries. Digital computers started to be used for information retrieval and transfer.

The 1970s brought the demands on higher quality of control systems and integrated process and control design. Programmable logic controllers (PLC) were applied to solve the problems of start-up, switch-over and shutdown. Introduced were distributed control systems (DSC) and visual display units (VDU). In the whole process control development, knowledge of processes and their *modeling* played an important role.

The development of process control was also influenced by the development of computers. The first ideas about the use of *digital computers* as a part of control system emerged in about 1950. However, computers were rather expensive and unreliable to use in process control. The first use was in *supervisory control*. The problem was to find the optimal operation conditions in the sense of static optimization and mathematical models of processes were developed to solve this task. In the 1960s, the continuous control devices began to be replaced with digital equipment – the so called *direct digital process control*. The next step was an introduction of mini and microcomputers in the 1970s as these were very cheap and also small applications could be equipped with them. Nowadays, the computer control is decisive for quality and effectiveness of all modern process industries.

## 3. Process Models and Dynamical Behavior of Processes

*Mathematical modeling of processes* explains general techniques that are used in the development of mathematical models of processes. Schemes and block schemes of processes help to understand their qualitative behavior. To express quantitative properties, mathematical descriptions are used. These descriptions are called *mathematical models*. Mathematical models are abstractions of real processes. They give the possibility to characterize the behavior of processes if their inputs are known. Validity range of models determines situations when models may be used. Models are used for control of continuous processes, investigation of process dynamical properties, optimal process design, or for the calculation of optimal process operating conditions.

A process is always tied to the apparatus in which it takes place. Every process is determined by its physical and chemical nature that expresses its mass and energy bounds. Investigation of any typical process leads to the development of its mathematical model. This includes basic equations, variables and description of its static and dynamic behavior. *Dynamical model* is important for control purposes. To construct the *mathematical model of a process* it is necessary to know the problem of investigation and it is important to understand the investigated phenomenon thoroughly.

If computer control is to be designed, a developed mathematical model should lead to the simplest control algorithm. If the basic use of a process model is to analyze the different process conditions including safe operation, a more complex and detailed model is needed. If a model is used in a computer simulation, it should at least include that part of the process that influences the process dynamics considerably.

From the process operation point of view, processes can be divided into *continuous* and *batch.* It is clear that this fact must be considered in the design of mathematical models.

Mathematical models can be divided into three groups, depending on how they are obtained:

**Theoretical models –** developed using physical and chemical principles.

**Empirical models** - obtained from mathematical analysis of process data.

**Empirical-theoretical models –** obtained as a combination of theoretical and empirical approach to model design.

Theoretical models are derived from mass and energy balances. Unsteady state balances are used to obtain dynamical models. Mass balances can be specified either in total mass of the system or in component balances. Variables expressing quantitative behavior of processes are *natural state variables*. Changes of state variables are given by *state balance equations*.

Dynamical mathematical models of processes are described by differential equations. Some processes are processes with distributed parameters and are described by partial differential equations. These usually contain first order partial derivatives with respect to time and first and second order partial derivatives with respect to space variables. However, the most important are dependencies of variables on one space variable. The first partial derivatives with respect to space variables show the existence of transport, while the second derivatives follow from heat transfer, mass transfer resulting from molecular diffusion, etc. If *ideal mixing* is assumed, the modeled process does not contain changes of variables in space, and its mathematical model is described by ordinary differential equations. Such models are referred to as *lumped parameter* type.

To use a mathematical model for process simulation we must ensure that differential and algebraic equations describing the model give a unique relation among all inputs and outputs. This is equivalent to the requirement of a unique solution for a set of equations. Hence, the number of unknown variables must be equal to the number of independent model equations. In this connection, the term *degree of freedom* is introduced. Degrees of freedom are defined as the difference between the total number of unspecified inputs and outputs and the number of independent differential and algebraic equations. The model must be defined such that the degrees of freedom are equal to zero, and then the set of equations has a unique solution.

An approach to model design involves finding of known constants and fixed parameters following from equipment dimensions, constant physical and chemical properties and so on. Next, it is necessary to specify the variables that will be obtained through a solution of the model differential and algebraic equations. Finally, it is necessary to specify the variables whose time behavior is given by the process environment.

Next, some typical properties of processes in process industry will be illustrated.

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**Biographical Sketch**

**Ján Mikleš** obtained the degree Ing. from the Mechanical Engineering Faculty of the Slovak University of Technology (STU) in Bratislava in 1961. He was awarded the title PhD. and DrSc. by the same university. He has been a member of the Faculty of Chemical and Food Engineering at the STU since 1963. He has been head of the Department of Process Control of the STU since 1985. He was the vice-rector of the STU between 1994 and1997. In 1968 he was awarded an Alexander von Humboldt fellowship. He has also worked at Technische Hochschule Darmstadt, Ruhr Universität Bochum, University of Birmingham, and others. He has published more than 200 journal and conference articles. He is the author and co-author of five books. During his 38 years at the university he has been the scientific advisor of many engineers and PhD students in the process control area. He is scientifically active in the areas of process control, system identification, and adaptive control. He cooperates actively with industry. He has been chairman and member of the program committees of many international conferences.

He was president of the Slovak Society of Cybernetics and Informatics, a member of the International Federation of Automatic Control-IFAC, between 1991and 1996. He has been a member of the IFAC Technical Committee on Control Design since 1997.