AUTOMATION AND CONTROL OF THERMAL PROCESSES

Reinhard Leithner
Technische Universität Braunschweig, Germany

Keywords: automation, control, diagnosis, function chains, life cycle assessment, logic, optimization, simulation, thermal process, virtual power plant

Contents

Summary

The history of automation and control of thermal processes is briefly described, including the currently used technology. An overview is given on thermal processes, involved parameters, and their characteristic structures in the process as well as in models and control systems and over bus systems used. Finally, future developments are mentioned.

1. Introduction

Automation has been used since the time of ancient Egypt and Greece (more than 2000 years ago). For instance automation was used to open the doors of temples. In order to achieve this, a sacrificial fire was lit, increasing the temperature of the air in a vessel below and displacing water from this storage vessel via a pipe to a container connected by a chain drive to the doors.

When the fire was extinguished, the water was drawn back into the storage vessel and the counterweights closed the doors (See Figure 1). The controller was the priest and, if he wanted the doors to stay closed, he could for example make the fire sufficiently small or locate it in the wrong place.

One of the first and most famous controllers in the more recent technical history of control systems is the centrifugal speed-controller for steam engines, invented and patented in 1788 by James Watt. In 1868, Maxwell analyzed the stability of this controller. It consists of two rotating pendulums connected by a link and driven by the flywheel via a belt and gear. The centrifugal forces let the pendulums swing outside if the speed is too high and via a lever a valve reduce the steam flow or vice versa in order to control the speed of the engine.

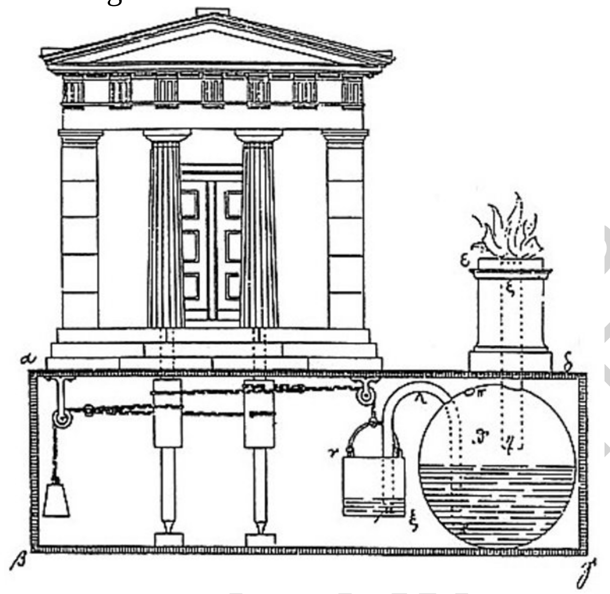

Figure 1. Pneumatic opening of the doors of a temple by Heron of Alexandria (Source: Schmidt, 1899)

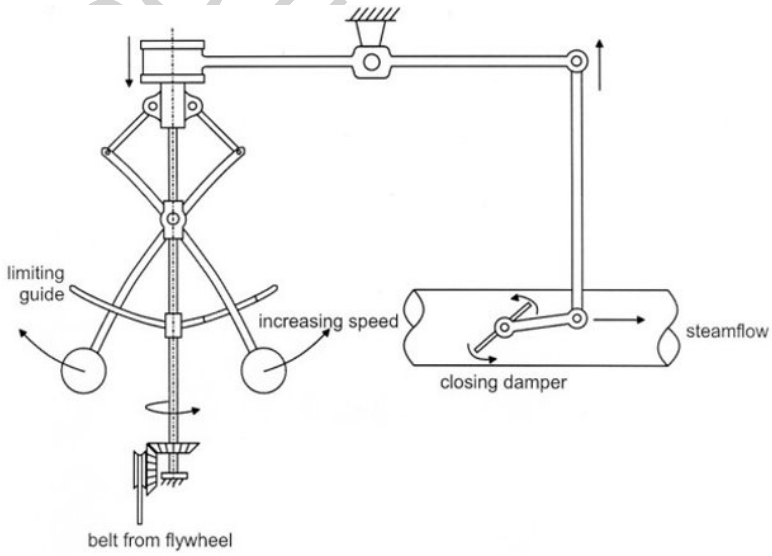

Figure 2. Centrifugal-speed controller for steam engines invented and patented in 1788 by James Watt

The actions of Watt's controller change the steam flow from the boiler, and this in turn requires additional measures, such as changing the fuel and feed water flow, for safe operation. Of course, in the time of James Watt an operator had to perform these adjustments. In addition, the operator was responsible for maintenance and reports to management about fuel and water consumption, unusual events, and so on. Even in the early days of boilers and steam engines, however, safety valves were installed to avoid boiler explosions caused, for example, by failure to adjust the fuel and feed water flow to the steam flow consumed. We can already see three main issues of automation and control of thermal processes:

- safety (especially to avoid explosions);
- the need for operating personnel, the numbers of whom can be reduced by added controllers, thus reducing costs, resulting in a hierarchical automation and control system; and
- information and management, including maintenance and nowadays environmental issues.

Up to about the mid-1980s, the operating personnel mostly took care of the third issue, but as the number of operational personnel was further reduced during the years following, and information and management systems were revolutionized by the widespread use of computers, this third issue and its relevance to automation and control systems became increasingly important. This was additionally influenced by the change from analog (mainly PID controllers) to digital and more sophisticated control and automation systems (for example, multivariable control, system identification, adaptive control, robust control, expert system based control, artificial neural network based control, and fuzzy logic based control) including monitoring. This is described in more detail in *Steam Generators and Steam Distribution Networks* and *Automation and Control of HVAC Systems.*

As the integration of processes increases, both in the number of systems involved (using also the possibilities provided by the Internet), and in time (that is, manufacturing, operating, and dismantling), resulting in an increasingly more general exchange of information (including the information about the system itself) among operators, manufacturers, and other operators over the whole life-cycle, this last issue will become more complex than everything before.

2. Thermal Processes

2.1. Plants

Three main types of thermal processes are used:

- Thermal power plants using fossil or nuclear fuels, biomass, solar energy, or the geothermal heat of the earth, and so on, to produce steam, mechanical power, and eventually electricity.
- Heating and cooling processes, air conditioning including district heating with steam—or today, primarily hot water networks—using mainly the same heat sources as mentioned above.

- Heating and cooling of material flows with physical and/or chemical processes, for example, in the chemical, ceramic, or steel industry, using hot water, steam, hot air, fuel, or electricity for heating, and cold water, air, and so on, for cooling.

The first type is primarily an energy conversion process and the second and third types are chiefly application and production processes respectively.

Very often at least two of the above-mentioned issues are interconnected, which of course makes control more complex, but helps to save energy; an example is the co-generation of electricity and heat for district heating or cooling of materials and heating of factory buildings.

One of the main issues in the control of thermal processes is the control of storage values. This usually concerns the system temperature or pressure, for example, in the case of saturated steam, or concentrations, (humidity and so on), that should be kept constant or changed in a specific way by appropriate changes of system inputs (mainly fuel-, heat- and/or mass-flows) according to the changing outputs (mainly heat- and mass-flows) or to the desired change of the storage value. Fuel and air flows may be changed by valves and dampers; other possibilities include changing the speed of pumps and fans.

The above variables have to be controlled during start up, continuous operation at different loads, shut down, and in emergencies. The main concern during start up and shut down is usually the time necessary for these operations. This time should be minimized to save costs but without causing, for instance, thermal stresses, which would shorten the lifetime of sensitive components to an unacceptable degree.

During continuous operation, efficiency is the main issue; for example, in a steam generator temperatures and pressures should be operated close to their limits but at the same time not exceed these limits, to avoid overstress of material. In addition, however, environmental protection (that is, emission limits) must be taken into account, and of course safe operation must always be guaranteed.

All plants can usually be operated by hand, both during commissioning and afterward. However, plants are increasingly becoming totally automated and are sometimes monitored via the Internet, so that for hours or days there is no need for a human presence.

2.2. Main Plant Components

The main components of thermal plants like steam power plants, combined steam and gas turbine cycles, nuclear power plants, district heating networks, air conditioning or chemical, ceramic, glass, cement, and steel processes are:

- All types of recuperative and regenerative heat exchangers (with parallel-, counter- or cross-flow and conductive, convective, and/or radiating heat transfer; preheaters, evaporators, superheaters, reheaters, air heaters, and so on).

- Analogous mass transfer devices of different design, for example, filters, separators, $DeNO_x$-, $DeSO_x$-, water treatment-plants.
- Devices to ensure and control mass flow like pumps, fans, compressors, conveyors driven mainly by electric motors or in some cases by steam turbines (for example, feed water pumps in steam generators), or only for mass flow control like valves, dampers with electric or hydraulic actuators.
- Different types of heat sources: furnaces for gas, oil, coal, biomass, waste with burners, grates, fluidized beds, and so on; nuclear reactors, electric resistance heating, and so on.
- Storage (pressure) vessels, pipes, ducts, silos, hoppers, chutes, and so on for storage and transport of mass (including of course energy and concentrations of special substances).
- Insulation to reduce thermal losses.
- Steam and gas turbines, motors, steam engines, and so on, for energy conversion (power production)
- Electric generators, fuel cells, transformers, switches, and other electric equipment, for example, for power production, automation and control.

2.3. Measuring Instruments

In thermal processes almost all types of instruments are used for measuring temperature, pressure, mass flow, concentrations (especially for instance, for firing systems' O_2, CO, CO_2, SO_2, NO_x, and fly ash concentrations), levels, voltage, amperage, frequency, stress, strain, and so on. Such measurements are used for monitoring load, temperature and pressure limits, emissions of pollutants, calculation of energy- and mass-balances, efficiency calculations, calculations of items such as fuel consumption, power production, costs, and lifetime consumption, and last but not least, for programmable logic and control.

-
-
-

Bibliography

Albrecht H. and Meyer D. (2002). XML in the automation technology: Babel of information exchange (XML in der Automatisierungstechnik – Babylon des Informationsaustauschs?) at-Automatisierungstechnik 50 (2002) Oldenbourg Verlag

Baehr H.D. and Stephan K. (1994). *Heat- and Mass-Transfer* (Wärme- und Stoffübertragung). Springer Verlag. [A textbook that presents essential principles of heat- and mass-transfer.]

Bejan A., Tsatsaronis G., and Moran, M. (1996). *Thermal Design and Optimization*. Wiley. [A textbook providing a comprehensive and rigorous introduction to thermal system design and optimization.]

Bird R.B., Stewart W.E., and Lightfoot, E.N. (1960). *Transport Phenomena*. Wiley. [This is a widely used textbook that presents the essential principles of heat- and mass-transfer.]

Bryden K.M. and O'Brien T.J. (2000). Virtual Pilot Plants. *What is the Goal and What Technology Development is Needed?* (The Proceedings of the 25th Int. Techn. Conf. on Coal Utilization and Fuel Systems, 6–9 March, 2000 Clearwater Florida, USA) ASME.

DIN 19222

DIN 40719 part 6 (Teil 6) (1992). *Logic description: Rules for Function Charts* (Schaltungsunterlagen – Regeln für Funktionspläne),

DIN IEC 1131-3 (1992). *Programmable Logic System–Program Languages* (Speicherprogrammierbare Steuerungen – Programmiersprachen),

Föllinger O. (1998). *Nonlinear Control* (Nichtlineare Regelung I). R. Oldenbourg Verlag. [A textbook on nonlinear control.]

Föllinger O. (1994). *Optimal Control* (Optimale Regelung und Steuerung), R. Oldenbourg Verlag. [A textbook on optimal control.]

Gassen, H. (2000). A software for the whole process chain. (Eine Software für die ganze Prozeßkette). *CITplus* **3.**

Gevatter H.-J. (Hrsg.). (1999). *Handbook of Measurement and Automation Technology* (Handbuch der Meß- und Automatisierungstechnik). Springer-Verlag.

Jopp K., (2000). Road to virtual power plants. (Auf dem Weg zum Gläsernen Kraftwerk). *Brennstoff-Wärme-Kraft (VDI),* **52**,(7/8).

Jörns C., Litz L., and Bergold St. (1995). Automatic production of logic–programs based on Petri-nets. (Automatische Erzeugung von SPS - Programmen auf der Basis von Petri-Netzen). *atp–Automatisierungstechnische Praxis* **37**(3), 10–14.

Kaiser V., Niemann K.-H., Otte R., and Wippermann, B. (2000). Asset optimization: technology and contribution to profit (Technik und Beitrag zur Wertschöpfung). *atp* **42**(12).

Kakac S. (1991). *Boilers Evaporators, and Condensers.* Wiley. [This book is a collection of various contributions on heat exchangers and thermal power plants (fossil-fuel-fired and nuclear reactors).]

Klefenz G. (1983). *Control of Steam Power Plants* (Die Regelung von Dampfkraftwerken). Heidelberg: Hochschultaschenbücher Verlag. [A textbook on steam power plant control.]

Koschel J., Müller U., and Nicklaus E. (2000). Asset management: diagnosis in production processes (Zustandserkennung in Produktionsanlagen). *atp* **42**(12).

Kreider I.F. *Handbook of Heating, Ventilation, and Air Conditioning*. Boulder, CO: Kreider. [A volume in the Mechanical Engineering Series edited by Frank Kreith.]

Lausterer G.K., (1995). *New Structures in Automation of Power Plants*. German Society of Mechanical/Electrical Engineers, Society of Measurement and Automation. [Congress: Automation of Energy and Chemical Processes (Neue Automatisierungsstrukturen im Kraftwerksbereich, VDI/VDE-GMA-Tagung: Automatisierung energie- und verfahrenstechnischer Prozesse), 18. Mai 1995, VDI-Bezirksverein, Darmstadt, Germany.]

Leithner R., (2000). Tendencies of developments in modeling and simulation (Entwicklungstendenzen in der Modellierung und Simulation). *VDI-Report (Bericht)* **1534**. [Gives an overview on the development of modeling and simulation in power plant technology (history and state of the art).]

Linnhoff B., Polley G.T., and Sahdev V. (1988). General process improvements through pinch technology. *Chemical Engineering Progress*, June 1988. [Basis of pinch technology.]

Marquardt W. (1999). From process- to life cycle-simulation 2000. (Von der Prozeßsimulation zur Lebenszyklusmodellierung 2000). *Chemie-Ingenieur-Technik* **71**(10), 1119–1137. [Shows the increasing importance of a more general view.]

Profos P. (1962). *Control of Steam Plants* (Die Regelung von Dampfanlagen). Berlin: Springer Verlag. [Provides a (historical) comprehensive overview on steam plant control.]

Profos, P. (1974). *Handbook of Industrial Measurement Technology* (Handbuch der industriellen Meßtechnik). Essen: Vulkan Verlag. [Provides a comprehensive (historical) overview on measurement techniques.]

Profos P. and Pfeifer T. (1995). *Handbook of Industrial Measurement Technology* (Handbuch der industriellen Meßtechnik), Oldenburg-Verlag. [Provides a comprehensive overview of measurement techniques.]

Recknagel, Sprenger and Schramek (2001). *Handbook for Heating and Air Conditioning* (Taschenbuch für Heizung + Klimatechnik 2001). Germany: R. Oldenbourg Verlag.

Schmidt W. (1899). *Printings and Automatic Theatre of Heron of Alexandria* (Herons von Alexandria Druckwerke und Automatentheater). Leipzig: Library of the University of Leipzig. [Presents historical machines.]

Schnieder E. (1999). *Methods of Automation* (Methoden der Automatisierung). Braunschweig, Wiesbaden: Vieweg-Verlag. [A comprehensive overview on automation and control and method of description including, for example, Petri-nets.]

Schuler H. (1999). *Process Control and Automation* (Prozeßführung). R. Oldenbourg Verlag. [A textbook.]

Singer J.G. (1981). *Combustion-Fossil Power Systems: A Reference Book on Fuel Combustion and Steam Generation.* Windsor, CT: Combustion Engineering.

Thierfelder H.G. (1996). Revamping of existing power plants: progress in automation, monitoring, and operation (Modernisierung bestehender kraftwerke: fortschritt im automatisierungsgrad und prozeßbedienung und –beobachtung). *VGB-Kraftwerkstechnik* **5**.

VDI-GET. (1996). *Control Technology: Guidelines for Design, Assessment, and Application* (Leittechnik - Leitfaden für Planung, Auswahl und Anwendung, Informationsschriften der VDI-GET).

VDI. (2002). *Heat Transfer-Atlas* (VDI-Wärmeatlas). [Provides an overwhelming wealth of examples, calculation methods, and calculation sheets for heat transfer (including conduction, convection, radiation, evaporation, condensation, and so on).]

VDI/VDE. Automation and Control Handbook: Guidelines 3501–3508 (Handbuch Regelungstechnik, Richtlinie 3501-3508).

Welfonder E. (1994). VGB-conform documentation of automation and control systems (VGB-konforme Dokumentation), *VGB-Kraftwerkstechnik* **74**(11), 942–973.

Biographical Sketch

Prof. Dr. techn. R. Leithner was born in 1945 in Schärding, Austria. He graduated as Dipl.-Ing. (Mechanical Engineering) from the Technical University in Vienna in 1970 with a diploma thesis on measurement and simulation of a heat exchanger. From 1971 to 1983 he worked in different positions with Energie- und Verfahrenstechnik GmbH (now Alstom Power Boiler GmbH), Stuttgart, one of the leading steam generator manufacturers in Germany. During his work at EVT he wrote a doctoral thesis on the mass flow from an equally heated tube at constant pressure and graduated as Dr. techn. from the Technical University in Vienna in 1976.

His last position in the company was head of the Main Department for Steam Generator Design, Development, and Commissioning including stress analyses and control systems; and also procurement. In 1983 he was appointed professor and director of the IWBT - TU BS. In all these positions he has always been involved in power plant design, calculation, control, and simulation.