INTRODUCTION TO PROCESS CONTROL

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Contents

1. Theoretical Background

The rather abstract term "process" is generally used to characterize all the interdependent and mutually influencing procedures within a system by which material, energy or information are being transformed, transported or stored (DIN 66201, 1981). There has been deliberately made no statement about the special kind of these procedures so that the above definition has validity in that form without any limitations for all processes that we can observe in the world around us. Commonly known examples for this are processes out of the areas of:

- Biology (e.g. Growth respectively decomposition of cells);
- Chemistry (e.g. Oxidation of materials, polymerization);
- Sociology (e.g. Forming of public opinion, individual development of personality);
- Medicine (e.g. Healing of a wound, contraction of a muscle);
- Environmental technology (e.g. Spreading of pollutants in the air, warming-up of the atmosphere);
- Communication technology (e.g. Delivery of a letter, message transfer via satellite); and
- Transportation technology (e.g. train ride from A to B, forming of a traffic jam).

An important subset is represented here by the class of the so-called "technical processes" which is to be subject of the present chapter. Following DIN 66201 (1981) a process is called a technical process if the physical variables of the process are acquired as well as manipulated by technical means. Figure 1 illustrates the basic functional chains relevant in this context.

Here, the gray covered arrows allow two different ways of interpretation. On the one hand, they may be understood in such a way that a certain initial state is converted by means of the technical process to a defined final state. An example of this is the filling of a tank, where the empty tank (= initial state) is filled with liquid (= process) till the liquid level reaches a desired value (= final state). On the other hand, the arrows may also be interpreted in the sense of a continuously operating process, wherein the flow of an input quantity is constantly converted by the process into a certain specified flow of an output quantity. This is e.g. the case when the fed water mass flow (= input quantity) is converted within a steam generator (= process) continuously into a steam mass flow (= output quantity). Depending on the respective intention both interpretations are useful and will therefore be used repeatedly throughout Chapter Process Control Systems.

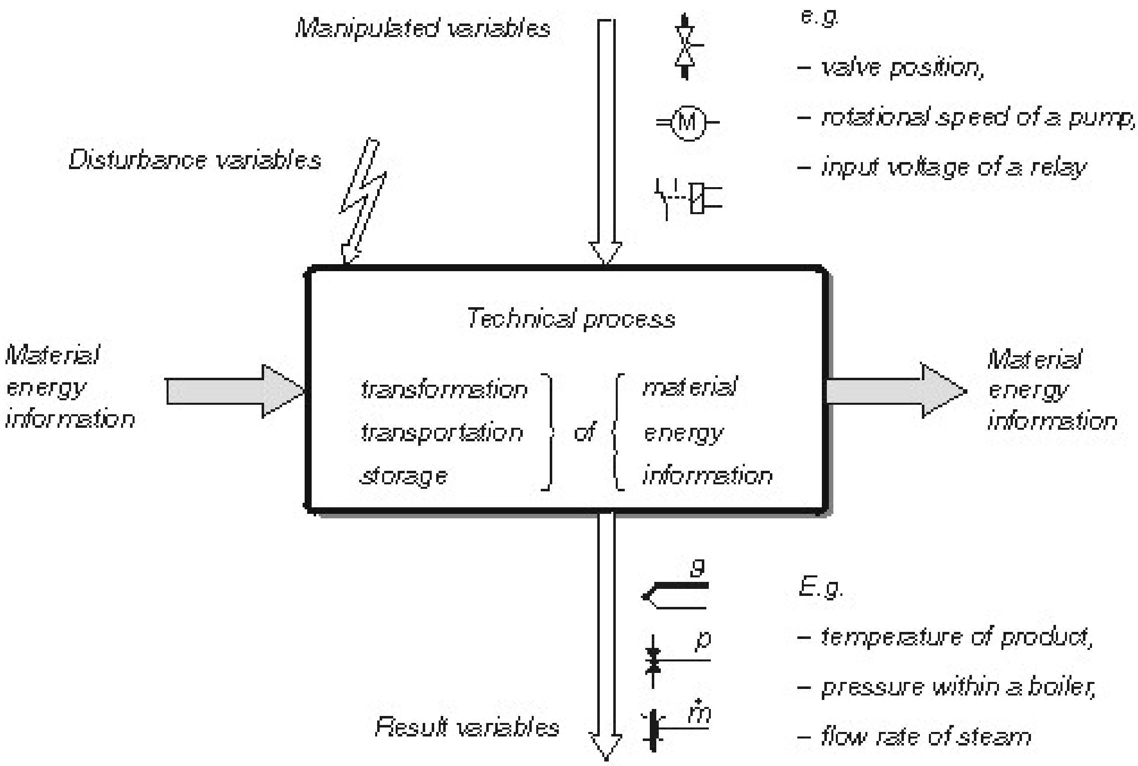

Figure 1. Fundamental structure of a technical process.

Furthermore, for every process certain result variables can be defined. They are usually acquired by means of so-called sensor elements and allow an objective rating of the properties of the final state (e.g. the level within a tank), respectively the flow of an output quantity (e.g. temperature, pressure etc. of a steam mass flow) at a certain moment.

The procedures taking place within the process and therefore the properties of the final state, respectively the output quantity flow are influenced by different influence variables. On the one hand, these are the manipulated variables, that allow a specific influencing of the internal procedures from the outside by means of so-called actuators (e.g. opening of a valve, variation of the rotational speed of a pump, switching of a relay etc.). On the other hand, a real process is always subject to several disturbance influences, too. These also have an effect on the internal procedures and the result variables. However, contrary to the manipulated variables the disturbance variables are subject of several stochastic influences and therefore are inaccessible to specified interventions.

With a technical process one very often follows the objective to establish a special characterized final state (e.g. fix the liquid level in the tank at 3.2 m) respectively to produce an output product flow with exactly specified properties (e.g. supply of 1000 t steam per hour with ϑ = 500°C and p = 180 bar). To achieve this the process has to be influenced by means of suitable actuators in such a way that the output shows the desired behavior.

The example of the simple process shown in Figure 2 illustrates the above outlined aspects of process characterization more clearly. Here the task consists of stabilization of the liquid level within the tank at a certain level L_0. Of course, it is evident that in order to avoid any shift of the liquid level one has to open the valve V in such a way that the liquid mass flow at the inlet is identical to the liquid mass flow taken from the tanks outlet at any time.

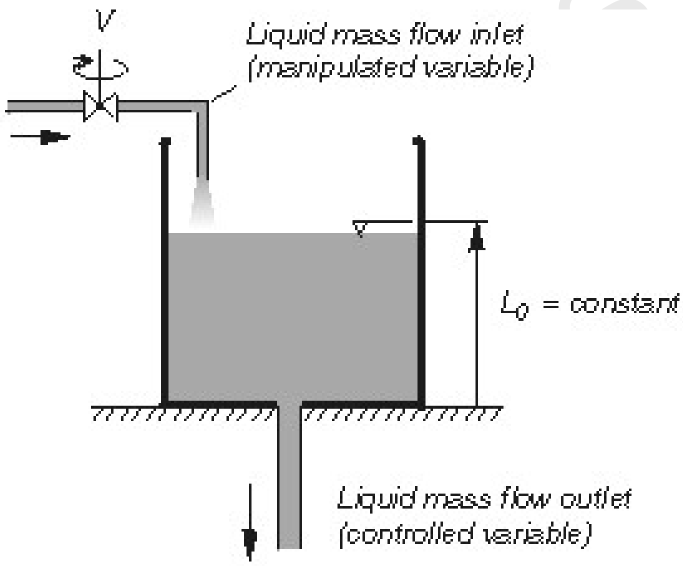

Figure 2. Motivation for process control on the example of a simple process.

Even this trivial example already makes clear two problems of quite fundamental significance for the whole area of process automation:

- In Figure 2 there is obviously no information available concerning the liquid mass flow taken from the tanks outlet. So time-dependent changes of this process variable cannot be detected directly but only indirectly by means of an observation of an increase or a decrease of the liquid level within the tank. For this reason the liquid mass flow taken from the tanks outlet clearly has the character of a disturbance variable. Of course, we can remedy this drawback easily by adding a sensor element which gives the current value of the liquid mass flow taken from the tanks outlet. But this solution is still unsatisfactory because in spite of the knowledge of the outlet mass flow long term drifts of the tank level cannot be avoided with certainty due to errors in the measuring value acquisition or leakages of the tank not detected by the sensor element.
- In view of the fact that the liquid mass flow taken from the tanks outlet

(= disturbance variable) is subject to time-dependent changes, for maintenance of the desired liquid level L_0 therefore a continuous monitoring of the current liquid level (= result variable) and, resulting from this, a continuous adaptation of the valve position (= manipulated variable) is necessary.

More generally speaking we can summarize that a real process is always subject to more or less significant disturbance influences. Mostly the affecting disturbance variable cannot be detected directly but only indirectly by their effects on the final state, respectively the final product. Finally, this circumstance makes a continuous adaptation of the manipulated variable necessary that performs a suitable compensation of the disturbance variables effect.

In order to achieve an automatic mode of operation without any manual (human) intervention at the beginning of the industrial epoch the principle of closed loop control was discovered. It must be emphasized here that this principle is not a technical invention but indeed a natural phenomenon which may be observed in all areas of the world around us. Strictly speaking it even represents an important prerequisite for the development as well as the existence of all kinds of life on our planet.

The fundamental basis of every closed loop control is the principle of feedback illustrated in Figure 3. The interesting result variables are acquired continuously by means of suitable sensor elements and compared with their aimed setpoints. Every deviation between both variables is then evaluated by a so-called controller and transformed to a corresponding change of the manipulated variables following the goal to counteract the current deviation immediately. Finally, these changed influencing variables are fed back as new manipulated variables to the process input by means of the actuator elements and take effect there.

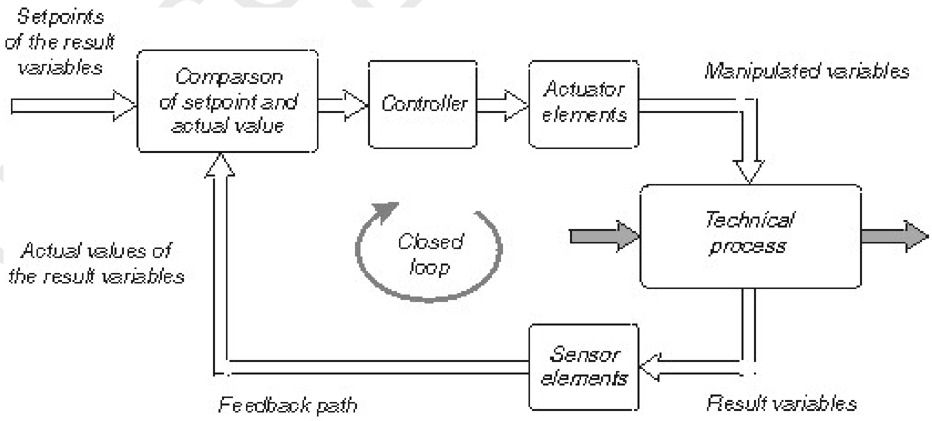

Figure 3. Basic principle of closed loop control.

James Watt invented the commonly known centrifugal force controller in 1788 and it worked exactly according to the principle described above. It was also used for controlling the rotational speed of the steam engine invented by him, too, and made its stable operation possible. James Watt was also the one who dealt at first more generally with the interconnections between the controller and the object to be controlled, the so-called controlled system, within the closed control loop. The first analytical investigations concerning the behavior of the closed control loop were carried out by Clerk Maxwell (1867-68) so he can be designated as the founder of the actual control theory.

Characteristic for all systems containing feedback loops is that their time behavior under certain circumstances may become unstable. The fundamental significance of this important characteristic for the field of control technology in general and for the design of a suitable controller in particular, was already realized at the end of the 1920s. In this context, fresh impetus was given by the discipline of telecommunications being already established at that time. Special emphasis should be given here to the well-known Nyquist criterion derived by Nyquist (1932) which allows an exact calculation of the conditions to be fulfilled so that the closed control loop works in a stable manner. Furthermore, it gives the user a deeper and more fundamental insight into the behavior of the closed control loop. Up to now, the Nyquist criterion is still an indispensable element of every basic education in control theory.

At the beginning theoretical investigations regarding a technical closed loop control solution were always carried out very closely focused on the individual device-specific features. So, it does not wonder that all the methods used to document these investigations were formatively influenced by the respective discipline to which the process could be assigned (e.g. mechanical or electrical engineering, thermodynamics, chemical engineering or similar). Only at the end of the 1930s it was realized that all concepts, independent of their individual physical background, finally can be reduced to one common theory. There, it does not matter whether it concerns the closed loop control of a steam generator or a chemical process, the description of feedback processes taking place in the nature surrounding us, or whatever. They all follow the same basic principles valid for systems containing feedback loops. So, in a way, this can be seen as the time when control engineering began to establish itself as an independent discipline.

Many treatises worked out during that important time dealt with an abstraction of the basic principles from the individual device-specific solution to find out relevant things in common with other applications. As well as a standardization and a systematization of the specific terms used in this area, an important result of these activities that deserves mention is the description of control systems by means of graphical symbols, the so-called block diagram introduced by Leonhard (1949). An easy example for this is given in Figure 4. Even though the block diagram was the subject of repeated modifications regarding the used symbols, it hasn't lost some of its fundamental significance for the description of system- and control-theoretical connections up to the present day.

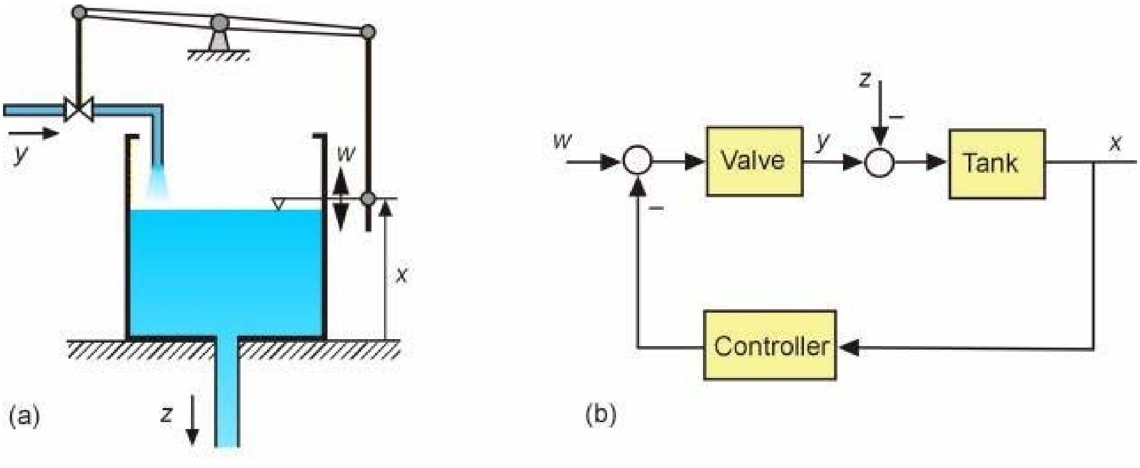

Figure 4. (a) Abstract description of a physical process; (b) respective block diagram .

Based on this theoretical foundation, in the following years a wide spectrum of different methods was derived with the goal to describe, to support a deeper comprehension and last but not least to enable a precalculation of the dynamic behavior of important classes of closed control loops. More and more use was made of the efficient methods and algorithms already provided by mathematics at that time, where in general two fundamental lines of investigation can be distinguished. The first was based on an analysis of the interesting processes directly within the time domain using different kinds of differential equations which finally led to the so-called state space methods. The second advanced the ideas introduced by Nyquist and made extensive use of the frequency domain methods like the Fourier or the Laplace transformation with all their well-known advantages. From today's point of view it can be said that the results of both lines of investigation - the state space as well as the frequency domain method - complement one another very well and allow the user an comprehensive insight in the process of the closed loop behavior and a reliable design of a suitable controller.

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