PROCESS INSTRUMENTATION AND CONTROL

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Contents

Summary

This article presents an overview of the area of instrumentation and control as applied to food process systems. It is divided into three major areas: control, instrumentation, and digital computer control.

Automatic control in food process systems is necessary to maintain final product quality, improve process efficiency, and reduce waste. Limited understanding of the physicochemical interactions occurring during processing, as well as large and unpredictable variations in raw material composition and characteristics, in addition to large dead time, make it difficult to design proper controls for food process systems.

The combination of empirical modeling together with fundamental modeling will significantly improve the understanding of food process systems dynamics. With improved, faster computers and the development of new on-line smart sensors, advanced control techniques will be easily implemented to handle most of the complexity of food process systems. Great attention should be given to the

advancement of control techniques, such as closed-loop performance monitoring, statistical process control, fuzzy logic, and neural network controls.

The progress in sensors and measuring devices has improved significantly in the last decade. Today, smart-sensors can measure, self-compensate for disturbances, and even amplify signals. Advances in machine-vision technology will contribute to better characterizations of product properties on-line.

Another important area of ongoing improvement is in digital computer control. The integration of Places and Doss, or LC hybrids will efficiently handle the complexity of combining the batch and continuous controls required in the food industry. New programming tools are also being developed to improve control applications and communications.

1. Introduction

The automatic control of food process systems helps improve final product quality, increases process efficiency, and reduces waste from raw materials. Food processes are generally multiple input/output systems that involve complex interactions between process inputs and outputs (see *Food Process Engineering*). They are generally characterized by strong relationships among mass, energy, and momentum transfer, in addition to complex physicochemical transformations that include gelatinization of starch, denaturization of proteins, and browning reactions. Such changes are influenced by the chemical composition and physical state of the raw materials used and by the process conditions.

It is difficult to design proper controls for food process systems because of the limited understanding of physical and chemical interactions occurring during food processing. In the past, lack of on-line sensors has prevented direct control of product quality parameters. Instead, previously proposed control schemes controlled product quality indirectly through secondary process variables.

Raw materials used in food processes are mainly of biological origin and their compositional and physical nature can vary considerably (see *Engineering Properties of Foods*). Such variations introduce significant, unmeasurable disturbances to the process that can make manual control unreliable. In addition to the complexity caused by raw material variability, food process systems also exhibit larger dead time and are typically non-minimum phase systems. For systems with significant time delays, improved control performance over PID (proportional-integral-derivative) controllers has been achieved with the Smith predictor and Minimum Variance controller schemes.

A new class of controllers, Model Predictive Controllers (MPC) or more specifically, Generalized Predictive Controllers (GPC), has been found to overcome the limitations associated with Minimum Variance and the Smith predictor control schemes. The Generalized Predictive Controller with an ARX (auto-regressive with exogenous input) model has successfully been employed to control a twin-screw food extruder and a continuous fryer (see *Extrusion*, and *Frying*). Dynamic Matrix Control (DMC) has been applied to a continuous frying process achieving good results.

A combination of GPC with an on-line identification routine has been shown to be capable of providing stable control to processes with variable parameters and variable dead times, and with model orders that change during the process. This type of controller is referred to as adaptive. In food processing systems, the operating environment can drift to the extent that raw material properties (particle size, moisture content, composition, etc.) will vary and machines wear or deteriorate due to long-term use. Constantly changing dynamics, variable dead times, and model parameters that change depending on the direction and size of control movement are typical in many food processes. These typical disturbances are not easily modeled because on-line sensors are not readily available to measure them. Therefore, fixed controllers may fall short in compensating for such disturbances over time, making adaptive controllers more attractive for food process systems. Adaptive control has been successfully applied to continuous flow grain dryers and food extruders.

One of the difficulties in applying adaptive control to food process systems is that in addition to normal wear of machine parts, abrupt failures caused by actuator and sensor malfunctions and failures arising from the process itself are common. When these faults occur, they must be detected rapidly and be distinguished from wear, so that the process can continue to run safely. In conventional adaptive control, the process model parameters are recursively estimated and used to recompute the controller parameters in every sampling instance.

However, estimator variations due to disturbances and parameter tracking are passed to the controller. Closed-loop performance monitoring is a technique that can be used to update controllers only when the system has changed and the parameters converged with sufficient confidence. This control technique would be of great help for food processing systems and needs to be investigated further.

2. Background

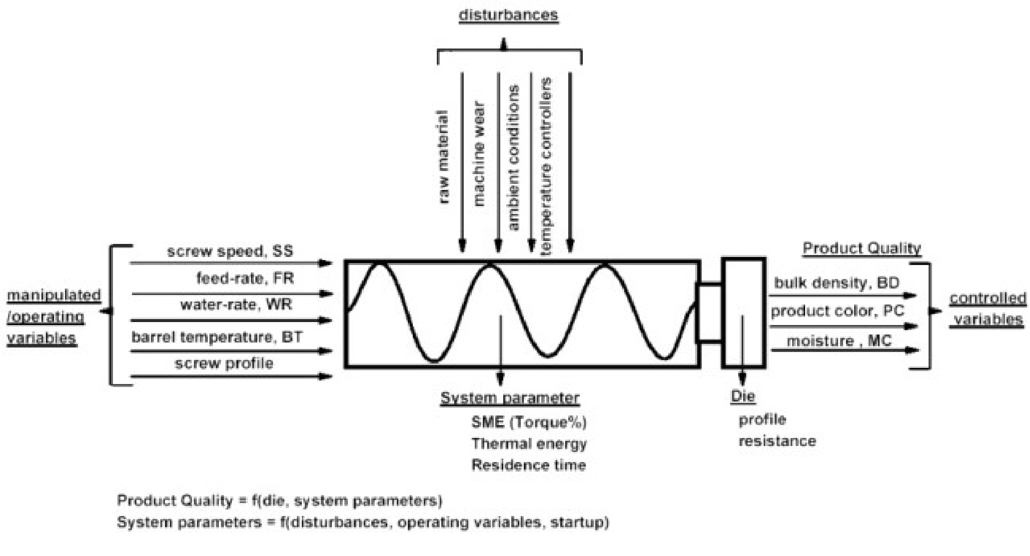

Figure 1. Manipulated, controlled, and disturbance variables in a food extrusion process.

Consider, for example, a schematic of a food extrusion process with all the important variables needed for process control shown in Figure 1. From the production point of view, a process can be defined as a progressively continuing operation that consists of controlled actions systematically directed toward a desired product. Food extrusion is a process that consists of feeding, mixing, cooking, forming, and puffing.

The major functional ingredient in expanded products is starch. During extrusion, starch is plasticized with water and subjected to a specific mechanical and thermal energy treatment as it moves through the extruder. The physicochemical changes that occur in starch at high shear, low moisture, and high temperature conditions dictate final product quality.

Expansion at the exit of the die is driven by internal steam pressure in the extrudate. At the die inlet, the process pressure and temperature maintain the vapor in a superheated condition. When the product reaches the die exit, the sudden release of pressure causes a flushing of superheated vapor into steam. The large pressure differential between the inside of the extrudate and the surface causes steam to rapidly expand and migrate toward the surface of the product. The steam exits into the atmosphere through the product porous spaces created during the expansion process.

2.1. Variables in a Control System

From the control point of view, the number of manipulated variables must be at least as large as the number of controlled variables. The controlled variables should measure product quality directly or strongly affect it. Manipulated variables should have a large effect on the controlled variables (large gain), rapidly affecting the controlled variables (minimum delay, small time constant) directly rather than indirectly.

Extrusion process parameters include raw materials, feed rate, water rate, screw speed, barrel temperature profile, and the screw/die configuration. They are considered independent operating variables, with the exception of the screw/die configuration, which is typically fixed for a specific application. Changes in these operating parameters will cause changes in the dependent process variables, such as die product temperature, die pressure, and viscosity, as well as product quality attributes (PQA), through changes in the specific mechanical (SME) and thermal energy input during the products residence in the extruder. To produce high quality products, the critical processing parameters must be controlled and the effect of disturbances minimized. Following is a description of the variables used in process control.

Controlled Variables: these are the independent variables of a process and can be defined as the parameters of the process indicating product quality or the operating conditions of the process. It is also called output, a factor (variable) that is caused by a system and which is used as a measure of performance for the given system. In a food extrusion process (Figure 1), the controlled variables are the products quality attributes, such as density, color, moisture content, etc.

Manipulated Variables: these are the dependent variables of the process used to cause a change in the process. It is also called control input and is defined as a factor (variable) used to modify the system behavior. Therefore, inputs are variables that cause or stimulate a change in system behavior. Extruder variables (Figure 1) that have a significant effect on process variables or product attributes, and can be readily changed or manipulated during processing, are considered manipulative variables for control purposes. These manipulated variables include the screw speed, barrel temperature, feed-rate, and water rate.

Disturbances: a signal that tends to adversely affect the value of the system's output and can be classified by internal or external disturbances. An internal disturbance is referred to as those disturbances originating within the system, while an external disturbance originates outside the system. In a food extruder (Figure 1), screw wear is an internal disturbance and raw material variability is an example of external disturbance to the system in control.

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Biographical Sketch

Dr. Rosana G. Moreira was born in Brazil where she earned a Bachelor of Science in Agricultural Engineering from Campinas State University in 1980. She received a Master of Science in 1992 and a Doctor of Philosophy in 1989 in Agricultural Engineering from Michigan State University. Her dissertation topic was in fundamental modeling and adaptive control of continuous flow grain dryers. Dr. Moreira worked at Michigan State University for 6 months (1990) in the area of process control of food extrusion processes as a post-doctor researcher. She joined the Department of Agricultural Engineering at Texas A&M University in 1990, where she developed a research and teaching program in Food Engineering. Currently, she is an Associate Professor and teaches courses in unit operations in food processing and food rheology. Her research emphasis is in fundamental modeling of food processing systems (deep-fat frying, food dehydration, extrusion, etc.) and automatic control (predictive model control) for food processing systems, such as food dehydrators, food extruders, and continuous fryers. She has published more than 40 papers in professional journals, two book chapters, more than 50 abstracts and proceedings, and a book. Dr. Moreira is member of the American Society of Agricultural Engineers and the Institute of Food Technologists and is a licensed Professional Engineer for Texas.