Overview: Process Control Concepts

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Title Overview: Process Control Concepts

Abstract Commercial textile processes are controlled by defining desirable process parameters (e.g. time, temperature). Then control systems are applied to ensure maximum conformance with those process specifications. We have evaluated the performance and feasibility of other options, including real time adaptive multichannel parametric control as well as nonparametric methods (e.g. neural networks, fuzzy logic). Our methods focus not so much on the process parameters per se, but more on the result of the process. This presentation will provide the perspective for our presentations of these studies.

By Brent Smith

Introduction

Process control is one of the most critical aspects of quality assurance. In textile operations, such as batch dyeing, there are many variables which are under the dyer's control, but many more which are not. Typically, these controllable and uncontrollable factors interact in a very complex way. The dyehouse of the future must feature even better process controls.

Traditional manual control methods in textile processes have been automated using microprocessor systems, with corresponding improvement in process repeatability. However, this mode of control utilizes only a minuscule fraction of the total capabilities of modern microprocessor hardware.

In an attempt to improve microprocessor utilization, there are essentially two avenues to pursue. The most celebrated of these is the macro scale global linking of information referred to as Computer Integrated Manufacturing (CIM), to which much attention has recently been devoted. In typical CIM implementations, sophisticated user interfaces, attractive graphics and computer networking capabilities are employed to make information from
machines and machine groups available to managers for real time and post process analysis. The focus is on the use of state-of-the-art computing hardware and sensors to acquire data from processes, set up common database formats, link islands of automation, and provide management information in a timely manner in a macro or global sense.

An important but far less traveled avenue for enhanced microprocessor utilization is the development of novel control strategies which fully utilize data processing capabilities at the micro level, which use improved control models and also employ improved theoretical and empirical process models. The key at this level is not only a better understanding of processes but a willingness to evaluate known control technologies from other disciplines (e.g. aerospace) and to develop new textile wet processing technology and science for feasibility testing.

The state of the art in microprocessor control of textile wet processes is quite advanced, as can be seen from the above, but there is still potential for a quantum leap in performance if one is willing to discard certain traditional constraints in textile control concepts. Many of these constraints have become embedded in controller design concepts over time during the evolution of modern textile wet processing control systems. In contrast, we have focused on discarding many of these preconceived notions about control in order to evaluate the feasibility of novel systems in terms of performance and overall cost. Methods under evaluation include adaptive, real time, multichannel control strategies which include sophisticated empirical and theoretical dye models, and which are based on innovative control algorithms.
Traditional dye process control methods attempt to conform as closely as possible to a specific predetermined process profile (e.g. time, temperature) to achieve correct results. Discipline is emphasized. Uncontrollable variances are accepted and, in some cases, remedied after the fact, for example by shade sorting or dye adds.

**A Novel Approach**

Several innovative concepts are embodied in this feasibility study. Our approach attempts to control the ultimate product property of interest (in this case, dye shade) by adjusting controllable process parameters in such a way as to arrive at the desired end result. In this approach, the process may or may not be the same each time it is run, but the goal is only to arrive at the correct result. The process may be varied each time it is run to compensate for non controllable factors, such as variances in water quality, substrate preparation, and raw materials.

The first and most fundamental departure from traditional control concept is the use of predictive result-oriented strategies, as opposed to process conformance strategies. Sophisticated and theoretically sound dyeing models are combined with extensive real time data acquisition to assess the state of the system and predict process outcome (i.e. final dye shade) about every two minutes during the dyeing. These predictions are the basis for real time process modifications and departures from nominal process specification. Controllable process parameters are used to offset uncontrollable variances.

Another departure from traditional methods is the use of multi/multi control strategies as opposed to the traditional one-to-one approach. For example, in a traditional control algorithm, a standard temperature of 200° F may be the
process specification. If temperature deviates from the process specification, the controller will open steam valves to correct. This one-to-one control strategy senses temperature and controls steam. The novel approach does not control temperature for its own sake, but rather predicts the effect of a temperature variation. If no undesirable effect arises from that situation, the controller does nothing. However, if a problem such as an unacceptable dye shade is predicted, then the controller takes action, but not necessarily by opening a steam valve to correct temperature to a nominal value. Rather, action is taken by whatever means will correct the predicted outcome to the desired result (shade) at minimum cost and production time. The best action may be, for example, to add salt or change the pH. Of course there are constraints built in to prevent the controller from taking absurd actions. For example, rate of temperature change or permissible pH or temperature values may be limited. Central to this concept is the ability to accurately predict a result from the present state of the system. Several prediction methods will be described in other parts of this meeting.

Accurate real time data acquisition is another prerequisite for this approach. The present work was done with a system capable of monitoring real time values of temperature, rate of rise and cooling, conductivity, pH, time and up to three dye concentrations in exhaust dye baths. This system, comprising control logic units, dyeing machine, sensors and interfaces, has been described in detail in other publications.

Another feature of the novel control strategies is their adaptive nature. Most colorists are aware of the necessity of making numerous standard dyeings as data input for laboratory color matching systems. Of course, this would not be
feasible in a commercial production setting; therefore the controller must have some adaptive method of altering its database and control algorithm, i.e. to "learn" from actual production dyeings. Traditional control strategies do not do this and, in fact, dyers are constantly altering dye recipe percentages to adjust to standard. The set point temperature, for example, would rarely if ever be changed for an individual shade. In this novel approach, nominal starting set points for various controllable process parameters (temperature, etc.) are adjusted, according to results of previous dyeings, to optimum values which would produce desired shade at the lowest cost and minimum production time.

By combining the above concepts of real time, adaptive, multichannel, predictive process control with state-of-the-art computing devices and sensors, outstanding results have been achieved and, in fact, as will be shown in the following examples, dye bath exhaustion can be brought consistently to a desired target value, thus producing excellent shade repeats in batch dyeing. The same novel control principles could apply to any process. We have selected batch dyeing as our example for feasibility evaluations.

Due to the complexity and uncertainty of dyeing processes, they are very difficult to control. Possible control schemes can be divided into two categories: parametric methods and nonparametric methods.

**Parametric methods** require prior knowledge of process model structure and the range of process model parameters. Nonlinear robust control and adaptive control belong to this category.
Nonparametric methods include artificial neural network (ANN) control, fuzzy logic (FL) control and expert system (ES) control, which are also called knowledge based control or intelligent control.

A Systems Approach to Control
Another important aspect of this work is the use of "systems" concepts, which are broadly applicable to many types of manufacturing operations. Several important concepts and key system analysis and quality tools associated with the approach, when properly understood and applied, can be powerful assets in a manufacturer's quality control and troubleshooting efforts. These ideas can significantly contribute to optimization and control of textile wet processing operations.

A dyeing system consists of highly integrated and interconnected sub-systems; e.g., design, planning, performing, control of product development. Quality control in the dyehouse is one of those subsystems, which is closely related to external influences—customer, market and business environment—as well as internal ones—product design, scheduling and procurement. Dealing with these complex interactions requires extension of traditional textile quality control thinking. The system approach to quality control is a broadly applicable method and consists of five major steps:

- System definition
- Management system improvement
- Robust product and process design
- Process control planning
- In-process verification
Thorough understanding of system components, their interactions and system boundaries is the key to success in design and control. Therefore, system definition should be the preliminary step of the system approach to total quality. When properly executed, this provides critical information for better design of product and processes and for better process control. It can also expose flaws and inefficiencies in the system and indicate corrections.

Corrections are done at the second step of the approach, which is management system improvement. The objective of this step is to increase efficiency of support activities such as marketing, information processing, production planning, procurement, inventory control, material and service supply. This ensures that decision making at various levels of design and production are supported well and losses due to problems such as insufficient material and poor scheduling can be prevented.

The third step is robust design of product and processes, which aims to identify product and process characteristics meeting customer requirements and to make the design insensitive to uncontrollable sources of variation. This is an off-line quality control activity which can be accomplished successfully by using principles of quality function deployment together with that of quality engineering, both originally developed in Japan. Robustness of product design is critically influenced by selection of materials, as well as the choices of target values and tolerances for product characteristics. Similarly, robustness of process design is achieved both by selecting equipment and manufacturing processes which can produce the product within specified limits at the lowest cost and highest conversion efficiency and by identifying target values and tolerances for process parameters, which minimize the variation in the parameters.
The fourth step is another off-line quality control activity, process control planning, which is, in fact, development of process control limits and monitoring and inspection strategies to produce uniform products at their targeted levels.

The final step of this approach, in-process verification, verifies product quality during the process so that the need for inspection after the fact is eliminated. At this stage, feedback control mechanisms, calibration and preventive maintenance play significant roles, as well as statistical process control. IPV can be considered as an on-line quality control activity.

Summary
Textile dyers and finishers have traditionally used time and temperature profiles to control batch dyeing. This method of process specification control works; however, it usually results in inconsistent lot-to-lot shade repeats for a color from different dyebaths.

Adaptive control methods use product color specification to eliminate color differences and prevent manufacturers from having to sort shades. Information on salt and dye concentrations, pH levels, and temperature are gathered in real time to determine how dyes interact with textile fibers and solutions. These data are then used to produce consistent dyebath exhaustion and excellent shade repeats.

The Dye Applications Research Group (DARG) of North Carolina State University's Polymer and Textile Chemistry Program has, for five years, been investigating batch dyeing optimization and control. DARG's research has received strong support from the textile industry, North Carolina State University.
College of Textiles, and the U.S. Department of Commerce, via the National Textile Center.

During the next two days, we will present a wide variety of information on many topics, including:

- Real-Time Measurement of Dye Concentrations, pH, and Conductivity in Dyebath Mixtures
- Flow Injection Analysis of Dyebaths
- Theoretical and Practical Dyeing Models
- Control Models
  - Parametric
  - Neural-network
  - Fuzzy Logic
  - Ruled-based
- Multichannel Adaptive Control Strategies
- Post-process Analysis and Diagnosis
- Control Simulations, Hardware, and Interfacing

These presentations will indicate new ways to solve the old problem of dyeing control.