

Design and Development of a Dynamic Quality Control System for Textile Processes

Code: S06-NS02

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Introduction

Development of textile science and engineering during the last 100 years has been truly remarkable based on the published research reports and claims. However, Prof. John Hearle (UMIST) once said that it was quite troublesome to find only a small fraction of what has been discovered and reported by him and others being applied in textile manufacturing operations today [1]. According to Suh [2], the large textile science and engineering knowledge base has not been much utilized for textile production and quality control for reasons that can be amply justified. Observing this as a failure, he emphasized the need and importance for new quality control systems while describing the main reasons for failure of the past textile research in quality control and improvement.

Textile quality control often involves keeping output of individual processes in control through the use of Shewhart control charts. The use of such control systems that are static and inflexible for accommodating the complex, dynamic and interactive nature of textile production environment hasn't yielded much productive results for textile manufacturers and instead have resulted in loss of production time, materials and consequently profit [1]. A feedback control in textiles often leads to disappointing guesswork rather than an effective corrective action due to 1-to-N nature of manufacturing processes [3]. To remedy this difficulty, a dynamic EWMA control chart procedure [4, 5] was employed. This undoubtedly is a terribly inefficient control process completely void of structural relationships already known for the causes and effects and is effective only for short-run process control situations.

Therefore, in this research we have designed and are currently developing a new quality control system which is dynamic and one of most attractive alternatives to the current practices in dry and wet textile processes. The key strategy is to estimate the output process averages and variances as functions of the input process averages and also the variances originating from the prior process stage.

Project Goals

1. Develop general theories and design an effective dynamic quality control system which would be applicable to textile manufacturing processes, especially for staple spinning processes as a model case.
2. Survey and analyze the structural/functional relationships in the production and control of ring-spun yarns and consolidate them to form a final set of equations for the design of a Dynamic Quality Control System for a few control factors.
3. Develop a concept for an algorithm (FAMSE) aimed at obtaining one structural equation from a set of multiple structural/functional equations that may be similar to each other, redundant, incompatible or contradictory to each other.

4. Use variance tolerancing method [Suh *et al.*, 8, 9] to obtain the mean and variance of an output factor at k^{th} process stage based on the means and variances of the input factors observed at $(k-1)^{\text{th}}$ stage and apply the concept to a staple yarn spinning process as a special case of a comprehensive dynamic control system.
5. Develop a general system software package for obtaining the dynamic process averages and dynamic control limits at all process stages, both numerically and graphically, applicable to either an on-line continuous textile process or an off-line contiguous textile production process.

Progress Summary

I. System Development

A. Development of a General Framework

In recent times, the production efficiencies in most of the continuous processes have gone up substantially as they are being equipped with automation modes such as sensors, microprocessors and control software and hardware. But there hasn't been any substantial improvement in the process qualities. According to Suh [6], the main reason behind this is the 'static control' systems and methods wherein each processing stage is controlled independent of other stages in the multi-stage control units. Under a static control mode, the control limits at a given stage are fixed and non-reactive to the dynamic changes of the previous stages. Thus, an error or bias introduced in one stage may cause all of the subsequent stages to be out of control, often shutting down the entire unit. Experiences have shown that the only practical remedy to such a situation is to widen the control limits for all of the subsequent stages. By continuing the practice, however, all control limits become so wide to make the so-called statistical limits useless.

Hence, we believe, a new dynamic quality control system is one of the most attractive alternatives to the current practices in dry and wet textile processes. It is accomplished by combining the known structural models linking the process input to the output variables through time-dependent statistical models.

The concept of a "dynamic control chart" procedure incorporates the following:

1. Additive effects of the system biases and random errors

In any continuous process type of manufacturing, such as ring spinning, each process stage is tied to the next as the output material from the previous processing stage is the input feed for the subsequent processing stage, as shown in Figure 1. Generally the input error σ_0^2 comes from raw materials, preconditioning, etc. The input bias B_0 may or may not be zero as the raw material that enters into processing is not perfectly uniform. Each (i) of the k stages is assumed to generate certain amount of bias (B_i) and random error (σ_i^2) inherently. If B_k is the bias introduced at the K^{th} stage, it will be added to the sum of all biases generated from the previous processes to make up the observed process average, and the process variance σ_k^2 originating at the K^{th} stage would be added to the total variance channeled down from the $(K-1)^{\text{th}}$ process through the structural/functional

relationship. At K^{th} stage, the total bias (B_T) must be separated from the random component σ_T^2 , the total error variance. This is the only way the K^{th} stage control limits can be examined independently of the expected total bias. Thus, the control limits at the K^{th} stage are generated from the sum of the biases and the total expected variance.

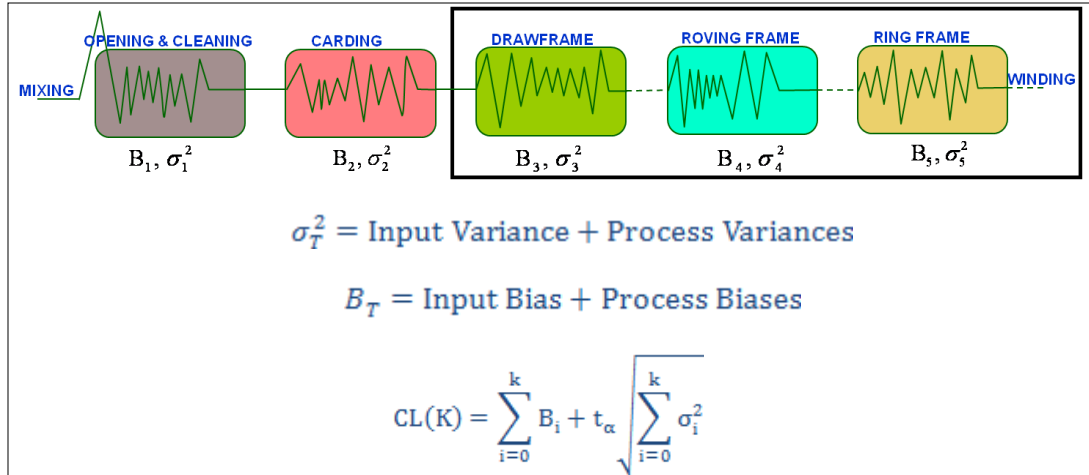


Figure 1: Conceptual Frame for Dynamic Control Limits from Mixing/Blending to Ring-frame via the Structural Relationships Developed.

2. Magnification of biases on subsequent process stages through “structural or functional relationships”

Generally, the structural equations form the link between any two stages of a continuous/contiguous manufacturing and processing industry. The fiber properties thus can be studied and traced with the use of the existing structural and functional relationships from the literature. Also, the structural and functional relationships in the literature explain the relationship between the input and output process variables in a better and efficient way. A structural and function relationship uncovers particular structural parameters which govern economic behavior. As the structural equations generally are based on a specific theoretical model they provide the most direct way of testing a particular theory.

3. Feedback/ Feedforward control mechanisms for excessive biases and errors

Several methodologies for the estimation of the performance bound in terms of output variance have been established for the feedback/ feedforward systems in the recent past in continuous manufacturing industries such as the textile industry. A feedback control system can be utilized even when the source of variation is unknown or its magnitude is unknown. A feedforward system measures the input disturbance directly and with that knowledge takes measures so as to eliminate the impact of the disturbance on the process output [7]. Hence, in order to eliminate the effect of process disturbances, to stabilize the process and to keep the process within the desired specification levels, this dynamic quality control system makes every effort to automatically compensate via combined feedforward/ feedback control system.

4. Estimation of the process variance at each stage and the total upto a given stage to provide “dynamic control limits”

The key strategy in the construction of a dynamic control chart is to estimate the output process averages and variances as functions of the input process averages and also the variances originating from the prior process stage. Hence, in order to estimate the process averages and variances of the final structural equation which is developed linking the various structural equations from different processing stages the variance tolerancing and channeling technique developed by Suh and Koo [8, 9] is employed. Based on the dynamic process average and the “toleranced” variances, we can establish the Dynamic Control Limits.

B. Design of a Dynamic Control System

The new control system is designed taking into account the complex, dynamic and interactive nature of textile production environment. For the design of the *Dynamic Control Chart* we have coupled the traditional static process average and the corresponding control limits with the dynamic process average and its control limits which reflect the biases of the previous stages. The decision scheme is as shown in the Figure 2. One important point is that the out-of-control situation based on the static limits has to be “swallowed” even if it is neither desirable nor acceptable. The only remedy would be to correct the previous stage processes through the known structural relationships via feedback algorithms. The graphics can be modified in various ways in order to make the dynamic control most practical and easy to understand. The importance is to understand and quantify the inter-dependence of all the processes in advance in order to make the process control system more responsive to the ever-changing conditions of the process.

If a process performs as per the design, there would be no *out of control* situations arising. But because of inherent variations and biases generated during processing stages the process average is bound to deviate from the actual mean. In the case of a *Dynamic Control Chart* three different cases of *out of control* situations arise which are shown in Figure 2. This provides an option for choosing an optimal control. The three different cases are:

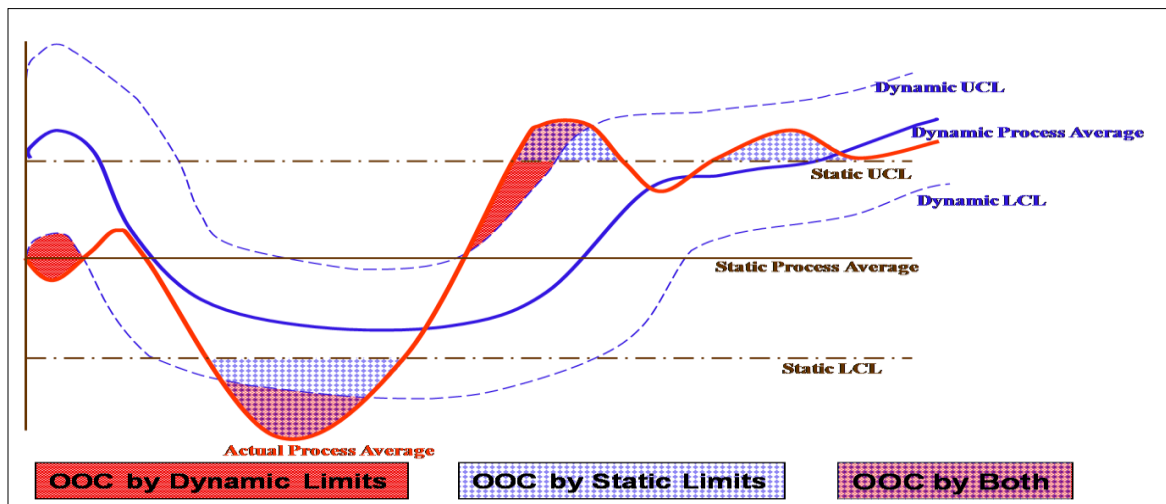


Figure 2: Schematic Diagram of a Dynamic Control Chart

Case A: The actual process average is found to be out of control with respect to the static control limits. This case is where no corrective actions may be justified even when the process average exceeds the static control limits.

Case B: The actual process average is found to be out of control with respect to the dynamic control limits. This case is considered to be the case where a corrective action in the particular stage can be justified independently of the biases generated prior to that stage.

Case C (A&B): The actual process average is found to be out of control with respect to the both the static and dynamic control limits. This is the situation where a corrective action is fully justified based on both the static and dynamic limits. This is the most serious case since the process as well as the product specifications may not be most in the absence of a corrective action.

II. Survey, Analysis and Development of Structural Equations in Staple Spinning

Literature survey was done extensively to identify various intrinsic components in various processes in spinning. Staple yarn spinning was chosen among all textile processes due to the importance and amount of research and experimental work done in the past. Because of the contiguity of the processes, the biases in the process means and the process variances are generated sequentially, thus necessitating construction of dynamic process averages and control limits at all stages.

Various input factors (mass, strength, fineness, etc.) are considered which exhibit certain amount of variation at every processing stage. Well-known properties of cotton fiber assemblies such as mass uniformity and strength were traced along the spinning process through the structural relationships surveyed and established at various stages of yarn production. After the structural equations for the mass variations were found/ developed from literature, they have to be consolidated into a final structural equation/model which will be tolerated to obtain the dynamic control limits.

For the case mass uniformity in spinning, we have tied the different stages in the spinning process as they are linked to each other. A process chain is thus formed by tying the various processes involved in the spinning process [10]. The output mass variance from mixing and blending is now the input mass variance at the Carding stage. Hence, the output variance biases will be a cumulative of input biases /variances generated at the Carding stage and also the biases carried over from the previous process stage i.e., Mixing and Blending. Finally, the output mass variance obtained at the spinning stage [11] is a cumulative of mass variances from the previous process stages and the present stage which can be observed in this final structural equation derived.

$$V^2 = \frac{1}{n} \left[\frac{t^2 e^{-2t/c}}{4c^2} + AN_0(z-1) \left(\frac{S}{\bar{L}} \right) + BN_0(z-1)^2 z \right] + nd$$

where V – Output mass variance at spinning, n – number of doublings, t – instantaneous time, c – expected residence time of fiber in the card, A & B – coefficients of mass irregularity and draft respectively, N_0 – hank of input stand, z – draft ratio, S – drawframe settings, \bar{L} – mean fiber length, d – constant.

III. Application of Variance Tolerancing Techniques in Ring Spinning

Suh and Koo [8, 9] developed a novel concept for separating and estimating random errors associated with raw materials and yarn structures from process-induced errors based on structural relationships governing the strength of a spun yarn. The variance of a textile product characteristic can be estimated from the input variances of intrinsic components through variance tolerancing based on geometric, probabilistic and structural models. Variance tolerancing uses these models to depict characteristics of textile products, decomposing the output product characteristic into relevant sub-components. A set of variance ranges are then setup for these sub-components. Applying these ranges to sub-components, out-of-control situations in the output characteristic can be easily identified. By examining the ranges for the input sub-components one at a time, it is possible to find out the set of input variances which were significantly deviating from the norms established and comb out the responsible factors or processes that produced the specific out-of-control situation. Thus, dynamic control limits are obtained by tolerancing the variance of the input variable to the variance of the output variable through an applicable structural, probabilistic or geometrical model/ relationship.

Estimation of variance tolerancing using Variance Tolerancing technique

Once the final structural equation is obtained, the *vital few* components have to be identified for variance tolerancing. This is done to estimate the variance of response variable with high precision. If the variance estimated from a component of the process is within the set-limits, the component can be termed as an *innocent factor* and can be thus eliminated from the list of suspicious factors or processes which cause *out of control* situations.

The input and output variances constitute the factors linking the structural equations and the variance tolerancing and channeling are accomplished by estimating the variance of the *output mass variance* as a function of the input variances from the previous processes.

The coefficient of variation at a spinning frame can be expressed using above equation as

$$V^2 = \frac{1}{n} \left[V_i^2 + AN_0(z-1) \left(\frac{S}{L} \right) + BN_0(z-1)^2 z + nd \right]$$

where V_o^2 is the output variance and $V_i^2 = \frac{t^2 e^{-2t/c}}{4c^2}$ the input variance.

For variance tolerancing, we need to compute the variance of V_o^2 , that is, we must calculate

$$\text{Var}[V_o^2] = \frac{1}{n^2} \text{Var}[V_i^2] \quad (\text{since the other terms are constants})$$

Equation below gives us the output variance of the “mass variance of roving” as a function of the input mean μ and input variance σ for $x = t/c$, as defined.

$$\begin{aligned} \text{Var}[V_o^2] = \frac{1}{n^2} [& e^{-4\mu} \{ \sigma^4(8\mu - 20\mu^2 + 16\mu^3 - 4\mu^4 - 1) \}] \\ & + [\sigma^2(6\mu^2 - 16\mu^3 + 8\mu^4)] - [\sigma(2\mu^2 - 8\mu^3 + 4\mu^4)] \end{aligned}$$

Work in Progress

I. Developing a FAMSE Algorithm

We are in process of developing an algorithm called *Fusion Algorithm for Multiple Structural Equations (FAMSE)* in order to obtain one (1) structural equation from a set of multiple structural equations that may be similar to each other, redundant or incompatible with others. Based on the logic trees appropriate for *FAMSE*, mathematical algorithms and simulation methods are developed and applied for the consolidation processes.

This method would be general enough for applications to all engineering sciences. Almost in each and every continuous manufacturing process, we find many structural equations for various intermittent stages in processing in the literature which exist in different forms with varied number of input and output parameters. As each research finding from each researcher around the globe yields new and mostly a different structural equation sometimes we may even find hundreds of equations on the same processing stage. Sometimes we may face a situation wherein we come across the same equation written in different forms by various researchers. Hence, it becomes a very tough task to pick the right and the best fit equation among those as each one has its own merits and de-merits. In order to find the right structural equations and to consolidate equations into one final equation when there is more than one structural equation at each stage of spinning, we are currently developing a novel concept called the FAMSE Technique which is used to consolidate the multiple structural equations of any form.

Components of FAMSE

There are two significant components in designing the fusion algorithm.

- A. Factor Decision:** Number of factors to be considered is an important aspect in the design of algorithm as most of the polynomial functions/structural equations exist in varied forms with different number of input and output factors. In order to identify the best fit polynomial functions/structural equations in the spinning process, key fiber properties which influence the processing are considered and among those key properties number of input factors are decided based upon the level of significance of each of those factors.

- B. Consolidation:** When many polynomial functions with same/similar number of input terms are identified they can be consolidated into a single structural equation in many ways. By equating/ By submerging/ By simplifying into congruent forms/ Solving using mathematical computational tools such as Maple, Matlab, TK Solver! etc are some of the forms or ways in which the structural equations could be consolidated.

II. Computation of Dynamic Process Average and Dynamic Control Limits

By examining the ranges for the input sub-components one at a time, it is possible to derive a set of input variances that deviate significantly from the norms established. It is also possible to identify the responsible factor(s) or process(s) that produced the specific out-of-control

situation. Thus, dynamic control limits are obtained through use of consolidated structural equations for the process averages and the “toleranced” variances corresponding to the equations.

III. Extension to Continuous Textile Wet Processes

The same concept will be applied to a continuous textile wet process. The on-line real-time dynamic control system would be more readily applicable to a continuous dyeing or finishing process by considering all relevant input and output factors and their variances. Establishing a set of dynamic control limits for an on-line, real-time system is a significant challenge since the concept of dynamic control limits are rarely used although the structural relationships have been used quite often for obtaining the process averages.

IV. Software Development

Efforts will be made to develop a software program for the dynamic process control system that will include dynamic process averages, the matching dynamic control limits, and the graphical representations of the dynamic control charts for selected processes. The data acquisition system, measurement methods and instrumentation will also be incorporated for the software application.

References

1. Suh, M. W., Gunay, M., Vangala, R., “*Dynamic Textile Process and Quality Control Systems*,” NC State University, NTC Annual Report (Project No. S06-NS02), 2008.
2. Suh, M. W., “*Improving Textile Product and Process Qualities: Failure Mechanisms and New Directions for the future*”, Journal of the Textile Institute (Invited Paper), Vol. 85, No. 4, p476-483, 1994.
3. Friauf, W.S., “*Feedback Loop Stability Analysis*”, McGraw-Hill, 1998.
4. Crowder, S.V., “*Design of EWMA Schemes*”, Journal of Quality Technology, (21): 3, p155-189, 1989.
5. Wasserman, G.S., “*Short-run SPC using Dynamic Control Chart*”, Computers & Industrial Engineering, 27 (1-4): p353-356, Sep, 1994.
6. Suh, M. W., “*Statistical Process Control for Needlepunch Fabrics*”, Proceedings of Needlepunch Conference, Mar 17-18, Charlotte, North Carolina, 1992.
7. Foxboro, “*Introduction to Process Control*”, Foxboro, MA: Foxboro Company, 1986.
8. Suh, M.W., Koo H.J., and Woo J.L., “*Variance tolerancing and decomposition in short staple spinning processes, Part I - Simulation and application to ring carded, ring combed and o-e spun yarns*”, Textile Res. J. Vol. 71(2), p105-111, 2001.
9. Suh, M.W., Koo H.J., and Woo J.L., “*Variance tolerancing and decomposition in short staple spinning processes, Part II - Simulation and application to ring carded, ring combed and o-e spun yarns*”, Textile Res. J. Vol. 71(2), p105-111, 2001.
10. Suh M. W, Gunay M, Vangala R, “*Dynamic Textile Process and Quality Control Systems*”, Proceedings of 9th Asian Textile Conference, Taiwan, 2007.
11. Grishin P.F, “*A Theory of Drafting and Its Practical Applications*”, Textile Institute Journal, V 45, T 167- 266, March 1954.

Project Website: <http://www.ntcresearch.org/projectapp/?project=S06-NS02>

Project Statistics

Graduate students involved:	1
Undergraduate students involved:	0
Thesis completed:	1
Presentations:	7
Publications:	3
Papers submitted:	4
Patent applications:	0
Patents granted:	0
Notices of invention:	0
Copyrights:	0
Industry interactions:	7
Non-NTC Academic Interactions:	9
Others:	6