Nonlinear Models Guide Secondary Coating of OFCs

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New techniques of nonlinear modeling make it easier to reduce variations in product properties of secondary coatings of optical fiber cables (OFCs).

Several product properties of secondary coatings are important for the producers and the users of OFCs. These properties include excess length (difference between the lengths of the fibers and the tubes), dimensional accuracy (diameter and circularity) of the coatings, elasticity, etc. Excess length was the first product property to be taken into account while developing the guidance system for secondary coatings. Excess length depends on several process variables, material characteristics of the coating material and the dimensions of the coating (inner and outer diameters). Depending on the priorities and the needs of a given production unit, different input vectors can be implemented in the guidance system.

Figure 1 shows the high-speed secondary coating line OFC 40, which is especially designed for loose tube production, but due to its modularity, can also be modified for fiber bundle or premises cable production. The line comprises multiple new innovations for high productivity and minimized scrap. Secondary coating is the first phase in the manufacturing process of fiber optic cables. The process is important in two ways. Stability and repeatability of the process together with high production speeds and flexibility of operation have been the key criteria in designing this line.

Higher Level Control Systems

At the core of higher level control or guidance systems is mathematics. Mathematical models determine to a great extent the efficacy of these systems. Today's process industries use a variety of quality assurance and quality control systems. Often they work quite well. But, the difficulty is that they are usually not updated often to reflect the present state of the process and the equipment. The models used are often linear, based on linear regression on a large number of variables. The models may sometimes exhibit wrong trends and in some cases misleading trends. The effects of process variables on the main variable of interest may not be predicted reliably.

The World is Not Very Linear

There are hardly any processes in this world that are absolutely linear. It is therefore wise to treat the nonlinearities rather than ignore them. To treat the nonlinearities, one can use new techniques of nonlinear modeling, like artificial neural networks. The proponents of linear techniques draw on their simplicity and the possibility of adding nonlinear terms in linear regression. Often this is not done and is not efficient even if it is done. Nature does not follow the simplicities that we try to fit it in, using linear techniques.

Neural networks on the other hand have the so-called universal approximation capability which makes them suitable for most function approximation tasks we come across in the process industries. The user does not need to know the type and severity of nonlinearities while developing the models.

Artificial neural networks resemble structurally, and to a lesser extent functionally, the networks of neurons in biological systems. Like the neural networks in the brain, artificial neural networks also consist of neurons in layers directionally connected to others in the adjacent layers (see **Figure 2**).

There are many different types of neural networks and some of them have practical uses in process industries.[1] Neural networks have been in use in process industries for about ten years. The multilayer perceptron, a kind of a feed-forward neural network, is the most common one. Most neural network applications in industries[2-6] are based on them. Nonlinear modelling can also be done in many other ways.

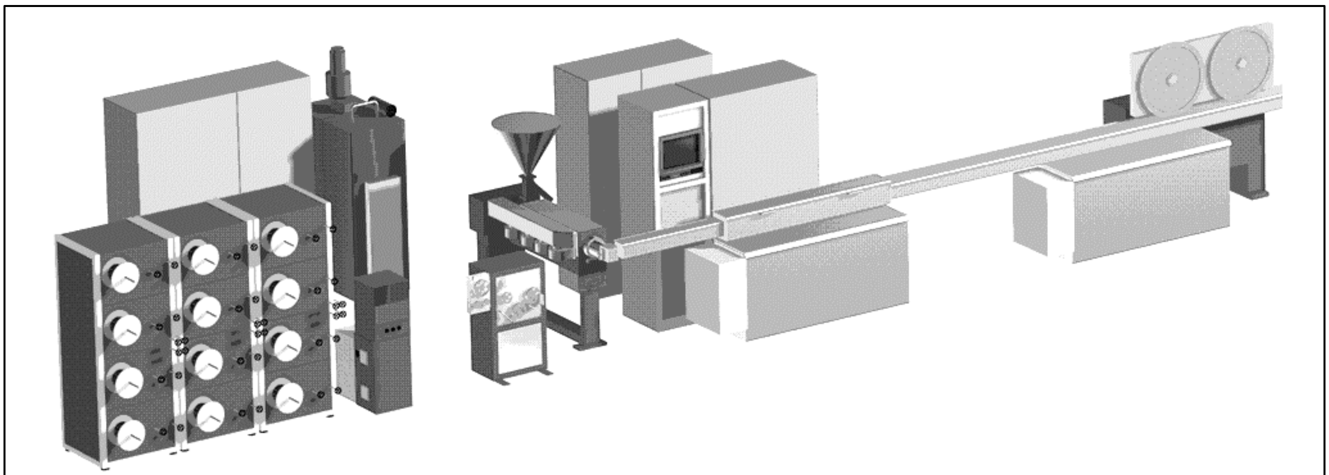

Fig. 1 — OFC lines are relatively well-instrumented. Much data is logged and then left unused or under-utilized.

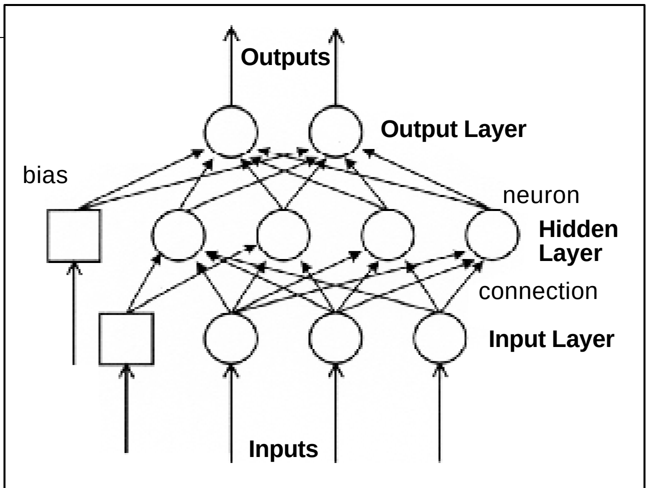

Fig. 2 — A feed-forward neural network has an input layer, output layer and typically one or two hidden layers.

The output of each neuron i in a feed-forward network is:

$$z_i = \sigma\left(\sum_{j=0}^{N} w_{ij} x_j\right)$$

Where the activation function is usually the logistic sigmoid, given by:

$$\sigma(a) = \frac{1}{1+e^{-a}}$$

Incoming signals to the neuron are x_j, and w_{ij} are the weights for each connection from the incoming signals to the i^{th} neuron. The w_{i0} terms are called biases. This results in algebraic equations that relate the input variables to output variables. So for each observation (set of input/output variables), the outputs can be predicted from these equations based on a given set of weights. The training process aims at determining the weights that result in the smallest sum of squares of prediction errors. There are various training methods used today.

Model Quality is the Quality of the Control

A large number of people today claim to be able to develop neural network models. A large number of people can offer you impressive user interfaces that hide the details of the neural network models inside. However, not many people can solve real-world problems. Very few are able to produce industrially usable systems of good quality. Fewer are consistently successful in every project they agree to take. The result is that there is a wide variation in the quality of nonlinear models. How do you know which models are good and which models are not? In other words, what are the characteristics that you look for in a good nonlinear model? What kind of software tools and techniques help ensure a good quality?

Characteristics of Good Nonlinear Models

The simple answer to the first question is that the proof is in the performance: a good model has to work. There is of course more to it than that. A good model for industrial purposes has to be reliable. Accuracy is secondary. A good industrial model has to be robust. You want a model that can be updated relatively easily. You want the model to have some transparency (the simpler the better). At the same time, a good model efficiently treats all the important nonlinearities. Reliability, robustness, simplicity and maintainability often come at the cost of accuracy and efficient treatment of nonlinearities. These conflicting demands make nonlinear modeling a harder task.

That does not leave too many people who will offer you all these attributes. Most are satisfied with claiming accuracy. It is important to insist on highly reliable and robust models because several decisions might be made based on the answers from these models. Considering the possible effects these decisions can have, it becomes quite obvious that the models should be of as good quality as possible.

The quality of a nonlinear model is much more than accuracy, and there is a scarcity of quality of nonlinear modeling today. There are no simple ways of measuring reliability and robustness of nonlinear models. How does one ensure these and other features? Experience and expertise are essential for neural network model development. However, a good software tool goes a long way by offering you a variety of measures that tell you of possible undesirable features in the models.

Nonlinear Models of Product Properties

Neural network models have performed well in predicting product properties of various materials [3-6] including material characteristics of pulp, paper, metals, plastics, cement, concrete, etc. These include mechanical properties of metals like tensile strength, yield strength and elongation, as well as the impact strength of plastics.

The Guidance System

In the examples seen in the successive screens, four input variables are considered: payoff tension, jelly hose temperature, line speed and cooling water temperature. **Figure 3** shows simple calculations predicting excess length from these four variables.

It is easy to change the models, which may also have a different configuration. The system expects the models to be in files of a certain format. These files can be replaced to change the models. In the future, the user will also be able to pick the model of his choice at run time.

Another series of screens (see **Figure 4** on next page) allows the user to see the effects of the input variables on the product property of interest. These plots also give a hint of how the performance can be improved.

The guidance system also allows the user to calculate suitable process variables within specified limits with single click of a mouse in less than a second (**Figure 5** on next page).

The models for this system were developed from experimental data. The experiments were carried out to measure the variables of interest, within the range of interest. However, this is an expensive process and most production units cannot afford to carry out this kind of experimentation. Nextrom,

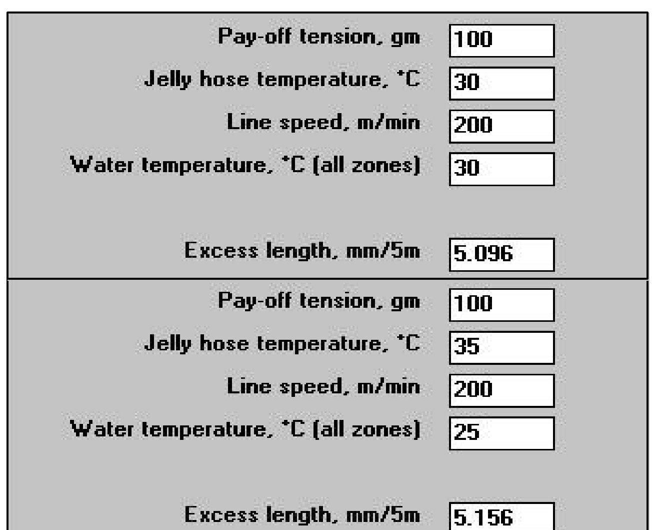

Fig. 4 — Excess length predicted from four input variables.

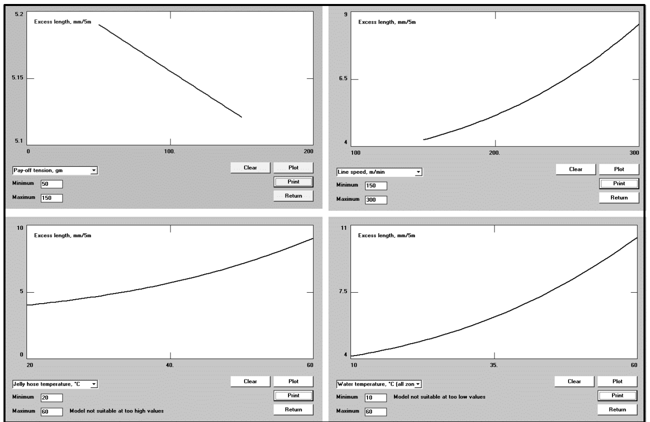

Fig. 4 — The effects of input variables can be studied to improve performance of the coating line. The Y axes in the screens above are excess length in mm/5 m. The X axes in the screens above are (clockwise from top left) payoff tension as g, line speed as mpm, jelly hose temp as °C and water temp as °C.

on the other hand, has the facilities to carry out such experiments for its customers.

In the future, the requirements for experimentation will be reduced as much as possible. Additionally, model development will be made possible from normal production data. Such models will have a narrower range, but will nevertheless be very useful for improving the performance of the secondary coating lines.

Main Features of the Guidance System

Features of the guidance system developed for Nextrom's secondary coating lines are many and include the following operational advantages:

- The system is easy to use.
- It is easy to learn how to use the system.
- The system can be operated even by novice personnel with little training.
- The guidance system has a GUI which operates in the Windows® environment.
- System is based on advanced nonlinear models.
- System is based on reliable and robust models, tested for various limitations.
- Can take different models for different materials and different types of products.
- Is flexible in many ways, for example, input vectors can be changed with little effort.
- Is easy to maintain – it is easy to replace models.
- System has a highly modular code, which is easy to modify if necessary.
- System has a compact executable code, typically 4 to 5 megabytes, depending on the configuration.
- Allows the user to feed inputs manually or pick them from a text file.

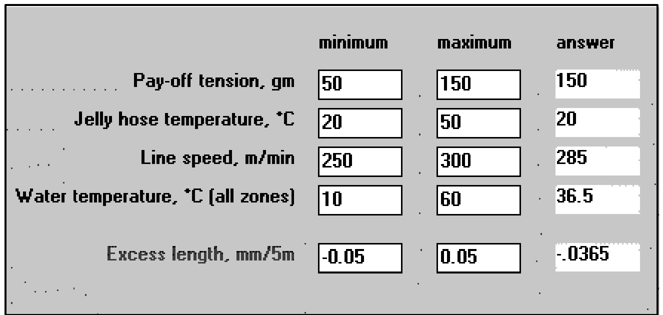

Fig. 5 — The guidance system lets the user calculate process variables within specified limits quickly and easily.

- Allows the user to record results in an output file.
- Allows the user to print the results.
- Shows the user the effects of input variables.
- Shows comparisons with earlier recorded experiences.
- Communicates with other software through plain (ASCII) text files.

In order to receive additional information on this new technology for nonlinear process modeling and quality control during the OFC secondary coating process, contact the authors or **Circle 201.** WCTI

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Company Profiles...

AB Nonlinear Solutions Oy *provides assistance to the manufacturing industries in improving quality, reducing consumption of raw materials and energy, reducing defects particularly using nonlinear modeling, primarily the use of neural networks*

Nextrom Oy*, with its headquarters (****Nextrom Holding****) in Ecublens, Switzerland, has been a manufacturer of production systems and solutions for telecom fiber and copper wire cable, energy wire and cable and plastics film and pipe. However, the company announced in the latter part of 2000, that it will concentrate solely on the fiber optic business area and divest all other businesses by summer of 2002.*