Optimizing OFC Secondary Coatings

— Use of Nonlinear Models Simplified

by:
Dr. A. Bulsari
AB Nonlinear Solutions OY
PL 953, 20101
Turku 10, Finland
abulsari@abo.fi

and Dr. Mikko Lahti
Nextrom OY
Ensimmäinen Savu
01510 Vantaa, Finland
Mikko.Lahti@nextrom.com

In this update article, the authors describe a newly developed software tool that puts the use of nonlinear modeling techniques within the grasp of OFC plant engineers for the optimization of OFC secondary coating lines.

To optimize a secondary coating line for optical fiber cables (OFCs), such as Nextrom's OFC 40 seen in **Figure 1**, it is necessary to have detailed quantitative knowledge of the line's operation. The OFC 40 shown here consists of a payoff block (typically for 12 reels), followed by an extruder, a water cooling trough and subsequently a capstan and a winding take-up.

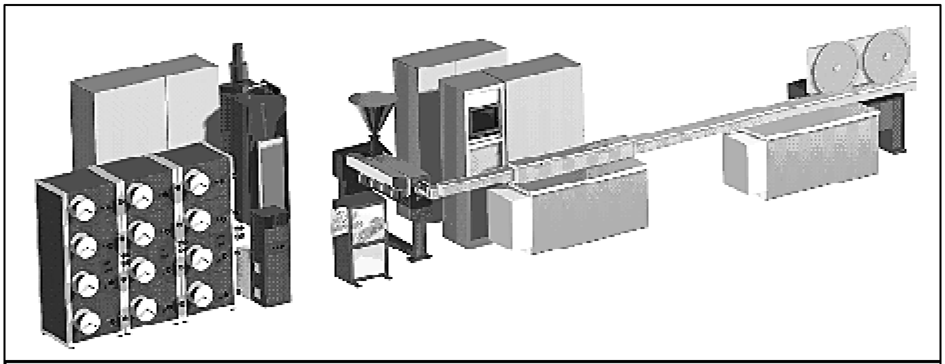


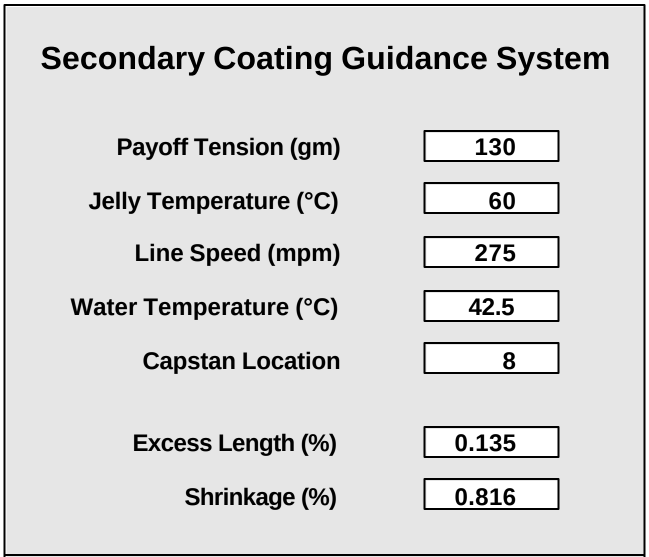
Fig. 1 — Nextrom's high-speed OFC 40 secondary coating line represents an international standard today for the processing of OFCs.

Nonlinear modeling techniques can be used with lines such as the OFC 40 for summarizing the quantitative knowledge about the effects of process variables of secondary coating on OFC properties.

Using such modeling techniques, it is possible to develop accurate and reliable nonlinear models relating process variables such as line speed, cooling water temperature, payoff tension, jelly temperature, etc., with the properties of secondary coatings such as shrinkage and excess length, from a small number of suitably designed experiments.

Nonlinear Models of Shrinkage and Excess Fiber Length

An article written by the authors and appearing in the September 2001 issue of *Wire & Cable Technology International*, (pages 40-42), illustrated how nonlinear modeling essentially solves the problem of describing the relations between process variables and secondary coating properties, quantitatively. It is difficult to imagine any alternative approach which would solve the problem satisfactorily. However, such nonlinear models have subsequently been developed for several product combinations.



Secondary Coating Guidance System

Payoff Tension (gm)	130
Jelly Temperature (°C)	60
Line Speed (mpm)	275
Water Temperature (°C)	42.5
Capstan Location	8
Excess Length (%)	0.135
Shrinkage (%)	0.816

Fig. 2 — Two product properties are calculated from nonlinear models in a fraction of a second.

Figure 2 illustrates a typical calculation using nonlinear models. The five input variables shown are payoff tension, jelly temperature, line speed, cooling water temperature (all zones) and the capstan location. The two output variables shown are the percentage of excess fiber length and the percentage of shrinkage.

The nonlinear models can also be used to predict the effects of process variables. **Figure 3** and **Figure 4** show the effects of cooling water temperature on excess fiber length as well as shrinkage, respectively.

The product under calculation in the secondary coating guidance system in **Figure 2**, **Figure 3** and **Figure 4** is 1.5/2.3 12f Ultradur 6550L, Macroplast 250.

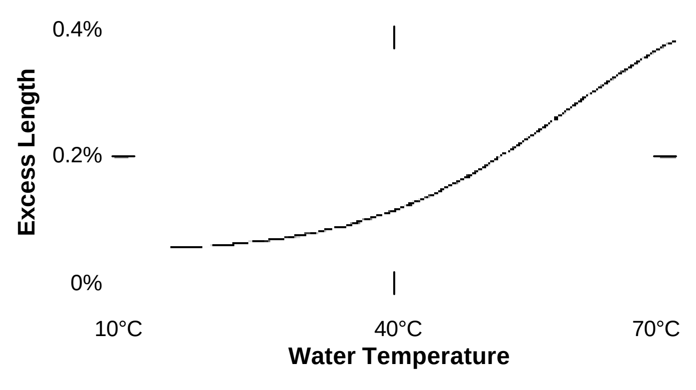


Fig. 3 — Effect of cooling water temperature on excess fiber length.

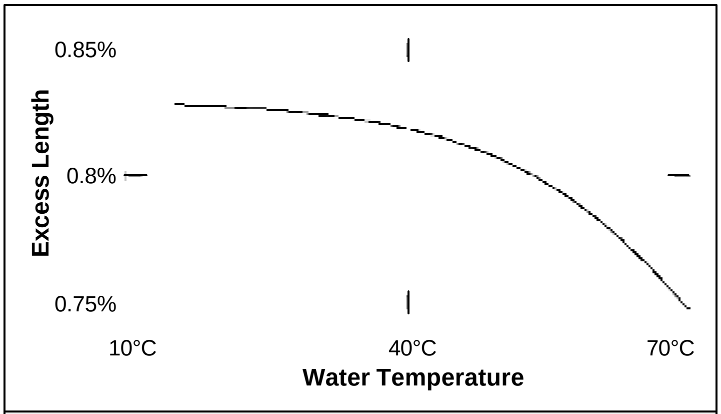


Fig. 4 — Effect of cooling water temperature on shrinkage.

Optimization Results in Maximum Performance of an OFC Secondary Coating Line

One advantage of having process knowledge in the form of mathematical models is that such models can also be utilized for optimization. Maximizing quality, maximizing production and maximizing profitability are all optimization problems.

These problems usually come with constraints of two kinds—equalities and inequalities. All the process variables have to stay within operable limits, which are inequality constraints, and several results such as the product properties of operating conditions are defined by models which are equality or inequality constraints.

In mathematical terms, such an optimization problem can be written as the following:

$$\begin{aligned} &\underset{x \in R^n}{\text{maximise}} && F(x) \\ &\text{subject to} && c_i(x)=0, \text{ for } i = 1 \text{ to } m \\ &\text{and} && c_k(x)\geq 0, \text{ for } k = 1 \text{ to } p \end{aligned}$$

In process optimization, the inequality constraints are usually the limits on process variables and possibly also product properties, and are therefore simple inequalities in single variables. The problem can be rewritten more specifically as the following where n is the number of process variables:

$$\begin{aligned} &\underset{x \in R^n}{\text{maximise}} && F(x) \\ &\text{subject to} && x_k \geq a_k, \text{ for } k = 1 \text{ to } n+n' \\ &\text{and} && x_k \leq b_k, \text{ for } k = 1 \text{ to } n+n' \end{aligned}$$

Typically, the n' constraints pertaining to product properties come from $n'+1$ product properties. It is possible in principle to maximize or minimize two or more variables at a time, however such multi-objective optimization methodology does not yield straightforward answers and is not used often in practice. Many books including *Practical Optimization*, by **P. E. Gill**, **W. Murray** and **M. H. Wright**, describe various techniques for these kinds of optimization problems in varying degrees of detail. Many of the techniques are based on gradient descent.

The use of Lagrange multipliers is a very effective tool for dealing with these problems. The mathematical details of these techniques are perhaps not suitable for this article, which primarily aims at making personnel working with OFCs aware of the new possibilities that have emerged with nonlinear modeling technology.

Making Optimization Accessible to Engineers in OFC Plants

It is good to have the quantitative knowledge in the form of models, but it is also important to be able to use that knowledge. As mentioned in the previous section, a variety of techniques exists for optimization. However, engineers in OFC plants cannot be expected to be familiar with them.

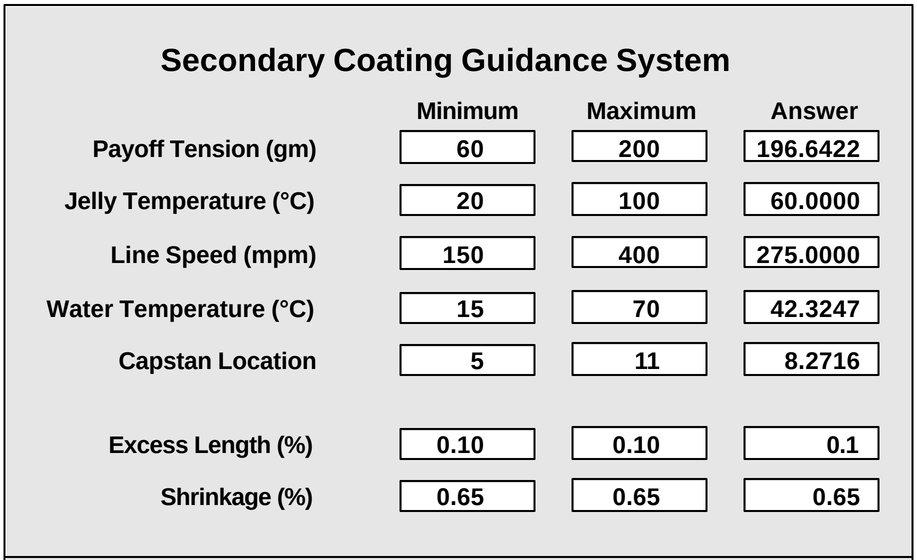
Therefore, a software tool has been developed that permits OFC plant engineers to utilize optimization techniques without knowing the details of the technologies themselves. This software has been incorporated in the secondary coating guidance system which was discussed in the authors' article published in *Wire & Cable Technology International* in September of 2001. This brings the new technology to these engineers' fingertips. They only need to know what they want to maximize or minimize as well as the limits on the variables.

Sometimes, one may only want to determine the process conditions which will result in given product characteristics. This is essentially solving two equations in five unknowns (as in the case shown in **Figure 5** on the next page of this article), which has under normal circumstances, an infinite number of solutions. One may instead specify the minimum and maximum acceptable limits for the two product properties as well as for the process variables. This is referred to as constraint satisfaction. The process is not exactly optimization, but it is often the first step required in many constrained optimization problems. **Figure 5** shows an example of this technique.

What is often of greater interest to production people in OFC plants is to determine the conditions under which one of the properties can be minimized while keeping the other one below an acceptable limit. The limits for the process conditions can be specified and one click on the mouse finds the minimum in a few seconds. **Figure 6** (on the next page) shows an example where excess fiber length is minimized while keeping shrinkage limited to a maximum of 0.65%.

In the solution seen in **Figure 6**, the line speed was 292 mpm (958 fpm). The software was free to find the minimum subjecting line speed to limits of 150 to 400 mpm (492 to 1312 fpm). One could then constrain the line speed to be within 350 and 400 mpm (1148 and 1312 fpm) and try to find a minimum. If the excess length is acceptable, then this permits a higher production rate.

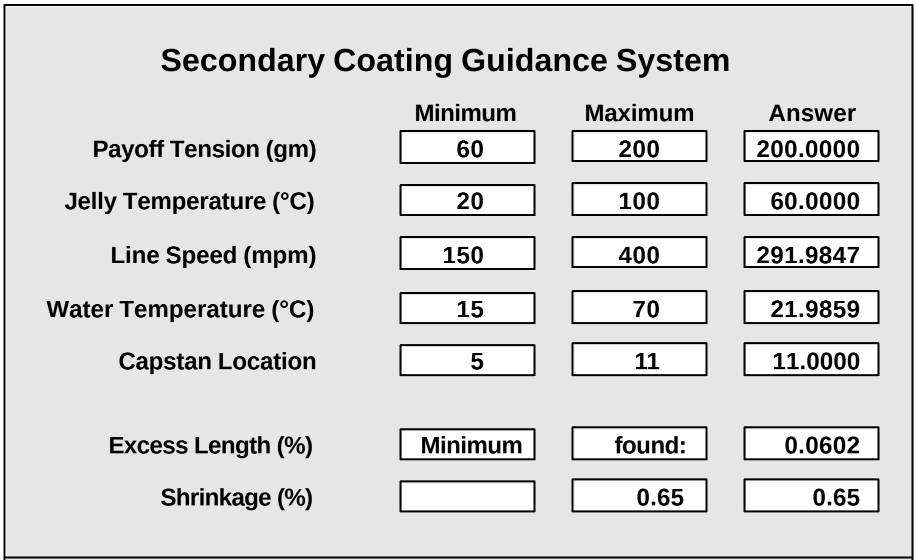
However, it is also possible to make impossible demands on the set of equations and inequalities, in which case, even constraint satisfaction does not succeed and the software then attempts to determine the best compromise. The product under calculation in the secondary coating guidance systems in **Figure 5** and **Figure 6** is again 1.5/2.3 12f Ultradur 6550L, Macroplast 250.



Secondary Coating Guidance System

	Minimum	Maximum	Answer
Payoff Tension (gm)	60	200	196.6422
Jelly Temperature (°C)	20	100	60.0000
Line Speed (mpm)	150	400	275.0000
Water Temperature (°C)	15	70	42.3247
Capstan Location	5	11	8.2716
Excess Length (%)	0.10	0.10	0.1
Shrinkage (%)	0.65	0.65	0.65

Fig. 5 — It is simple to determine a set of process conditions within specified limits that result in desired product characteristics (e.g., excess fiber length of 0.1% and shrinkage of 0.65%) with this software.



Secondary Coating Guidance System

	Minimum	Maximum	Answer
Payoff Tension (gm)	60	200	200.0000
Jelly Temperature (°C)	20	100	60.0000
Line Speed (mpm)	150	400	291.9847
Water Temperature (°C)	15	70	21.9859
Capstan Location	5	11	11.0000
Excess Length (%)	Minimum	found:	0.0602
Shrinkage (%)		0.65	0.65

Fig. 6 — Using newly developed software, OFC plants can perform constrained optimization in a matter of seconds.

Conclusions

The best of the secondary coating lines can offer better performance with very little additional effort. Deriving maximum mileage out of a secondary coating line for OFCs is an optimization task. More specifically, it is a constrained optimization task. For optimization, it is necessary to have detailed quantitative knowledge of the line's operation.

Such quantitative knowledge can be summarized in the form of nonlinear empirical models describing the effects of process variables of secondary coating on the OFC properties. Nextrom, together with AB Nonlinear Solutions Oy, has developed unique understanding of this process over the last few years. Now several nonlinear models are available for a variety of product combinations (number of fibers, inner and outer diameter, jelly type and polymer type), and it has become feasible to utilize this new technology in practice.

Since these nonlinear models can be quite complicated, and the typical engineers in OFC manufacturing plants cannot be expected to be experts on optimization techniques, a simple software tool has been developed that brings these new possibilities within the reach of OFC plant engineering personnel.

In order to learn more about the optimization of OFC secondary coating lines and to receive additional information about the newly developed software to assist engineering personnel in the optimization process, contact the authors or **Circle 205.** **WCTI**

Company Profiles...

***AB Nonlinear Solutions Oy** assists process industries to improve their processes, materials and products, particularly with nonlinear modelling. A number of wire and cable sector industries have cooperated with Nonlinear Solutions.*

***Nextrom S.A.**, of Ecublens, Switzerland, is a world leader in production equipment for optic fiber cables. The company offers unique service packages to its clients.*