Coating Control for Electrical Steel

- LORENZO BONAGIUNTI
Proposal and Sales
Tenova Strip Processing, Milan (Italy)

MARCO RAVERA
Process Technlogy
Tenova Strip Processing, Milan (Italy)

Electric insulation coating quality is of paramount importance for electrical steel as market demands ever broader coating thicknesses with narrower coating tolerances. Coating machines and relevant control system are continuously improved by plant builders in order to meet these key factors.

This paper reports a recent commissioning by Tenova Strip Processing of four coating machines for NGO electrical steel in which a dedicated control system to automatically control the coating process was implemented.

The main results and trends are highlighted.

Design Stage

Electrical insulation coating is a primary process for NGO electrical steel production since it ensures the necessary electrical resistivity to the material for its use in the electric appliances assembly.

Therefore NGO steel market demands broad coating thicknesses with ever narrower tolerances from thinner to the thick layers. More frequently NGO electrical steel users require a precise mapping of the coating thickness of the purchased coils.

To meet these requirements the steelmakers need to control accurately and continuously the final coating thickness on their steel products.

This is the target of a recent upgrading project of NLMK Group for two of its existing Annealing and Coating Lines. The project, conceived as a fast and convenient way to improving product quality, includes the installation of two new coating sections in lines that were originally commissioned in the 80'.

These new coating sections are made of :

- 2 high precision and automatic coating machines
- 2 preparation systems that allow switching from one product to the other
- in-line gauges (upper side) for dry coating thickness continuous measurement.
- electrical and automation system for process control.

The goal of the project is the installation and the integration into the existing lines of new coating process control system to meet tighter accuracies.

Commissioning of the Coating Machines

A few words on the coating machines employed.

The coating machines are fully automatic and provided with 2-coating rolls on both the upper and lower coating heads.

Two electro-mechanical actuators, one per side, finely carry out the positioning of each coating roll. The pressure between the applicator and the pick-up roll is remotely controlled and continuously measured by means of force measurement systems.

These coaters are supplied as stand-alone equipment, i.e. complete with its own electrical and automation systems already tested in the manufacturing shop.

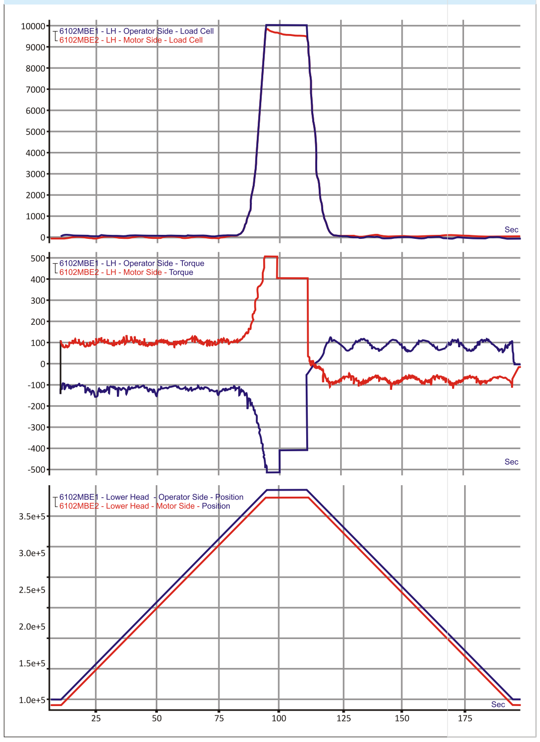
These coaters are designed to run in both forward and reverse application mode to cover a wider range of coating thicknesses. Typically forward application mode is usually needed with thin coatings or high-viscosity varnishes, whereas reverse application mode is needed with thick coatings or low-viscosity varnishes.

Load tests during commissioning are first carried out in forward mode.

Once on site, load tests are performed simulating coating rolls opening or closing repeated cycles and maximum coating rolls NIP pressure in continuous mode. Trials readily confirmed the symmetrical behaviour of the load cells with equal values on drive and operator side, without hysteresis, and of the coating rolls position actuators with equal torque values measurements on both drive and operator side.

Only a negligible motor torque ripple during rolls opening was recorded, slightly more significant during the loading motion: the phase of the ripple lead to the recirculating ball screws as a cause. How was it solved ?

FIGURE 0 : PRESSURE, TORQUE AND COATING ROLLS POSITION VALUES RECORDED DURING TRIALS



Dedicated tests are carried out for determining the elastic behaviour of coating rolls.

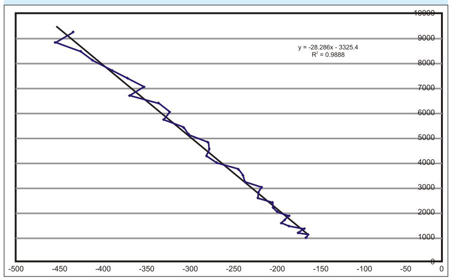
First it is evaluated the correlation between the torque applied by the coating rolls actuators and the resulting coating rolls NIP pressure. Data recording show an almost perfectly linear correlation (Figure 1). This finding allows controlling, at least theoretically, the coating rolls NIP pressure by regulating the torque of the coating rolls actuators (force control).

This positive correlation provides a further control tool that can be used as a functioning mode to calculate with a fair degree of accuracy the NIP pressure in case of load cells failure.

Then the coater control system is tested.

The gains of the coating process control software that adjusts the coating rolls NIP pressure and speed need to be set up in order to tune the model. *Quadratic interpolation can describe the correlation between ……. (???) with a high degree of accurately,* as already unveiled in other projects. Linear interpolation, simpler to use, is anyway rather accurate over the entire working range of the coater and can be used instead (Figure 2).

FIG. 1 : NIP PRESSURE VERSUS COATING ROLLS ADJUSTMENT MOTOR TORQUE



Following these trials the elastic coefficient of the coating rolls can be calculated.

Its value, calculated through linear interpolation, varies across the working range for the NIP pressure: it's higher for higher NIP pressure and lower at lower NIP pressure values. It ranges around 450 kg/mm.

This interpolation allows, at least theoretically, calculating the coating rolls elastic coefficient in every working condition by using the steepness of the (quadratic interpolation) curve.

….a cosa o quando può servire?

In-line Thickness Sensors

Experience has shown that the most suitable measuring sensors for these applications are based on the infrared technology. Following this concept, two measuring gauges are installed to scan the upper and lower strip sides between stabilizing rolls that ensure a stable and flat strip passline.

The measuring instruments are first calibrated *(with the help of samples….?)* and then easily interfaced with the coating section automation system.

Testing of the sensors can provide also some tool for diagnostic.

For example Figure 3 shows the coating thickness measured in the very first trials: a non-uniform cross-wise coating thickness is significant and can be spotted visually. In this case, such non-uniformity was found to diminish with higher NIP pressures but alas persisted over the entire pressures working range. Eventually this ripple phenomenon was due to the defective roll shape tolerance across its width, as can be seen from the here below pictures.

FIG. 2 : NIP PRESSURE VERSUS COATING ROLLS SPEED

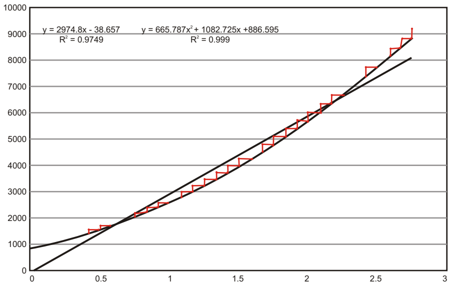
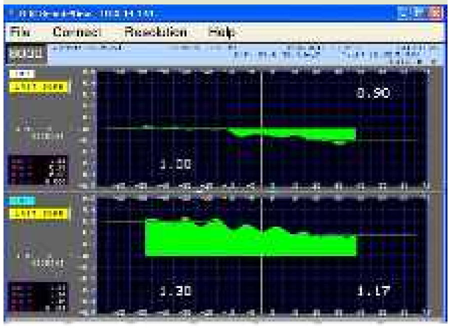


FIG. 3 : UN-EVEN COATING THICKNESS PROFILE OVER WIDTH DUE TO ROLLS OUT OF TOLERANCE



Once the coating rolls profile was corrected an even coating thickness profile across strip width was achieved (Figure 4).

Coating Varnish

A concern of the operators involved in the project is that the physical characteristics of the varnish (notably the dry residual) may vary over time during coating.

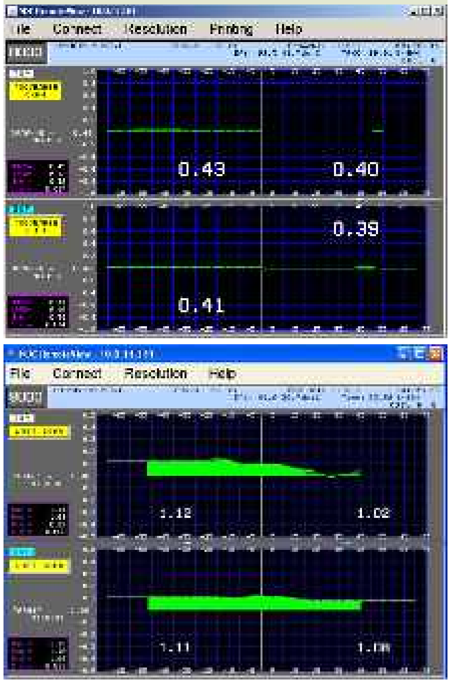
With the help of the coating thickness control system a strong correlation between the varnish level in the preparation tank and the dry coating thickness was unveiled during normal running, confirming the operator remarks.

The phenomenon is more relevant for thin coating gauges where the coating thickness may vary up to 20% within a single batch of varnish.

Several process parameters were investigated in an effort to reduce such drift of the varnish properties.

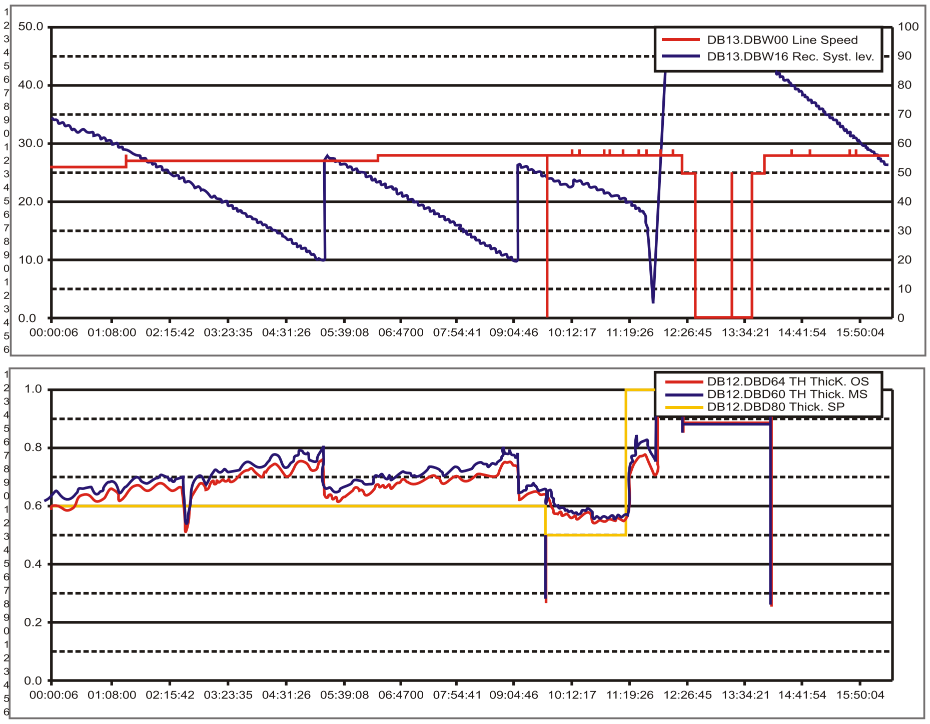
This abnormal behaviour can be definitely

FIG. 4 : EVEN COATING THICKNESS PROFILE OVER WIDTH



solved by using the coating process control software in the close loop mode: in this mode the in-line coating gauge provided in real time the necessary feedback for adjusting the coating parameters and hence meeting the target value continuously.

FIG. 4B : DRIFT OF VARNISH CHARACTERISTICS PRODUCING VARIATION OF DRY COATING THICKNESS CAN BE SOLVED BY USING A CLOSE LOOP CONTROL SYSTEM.

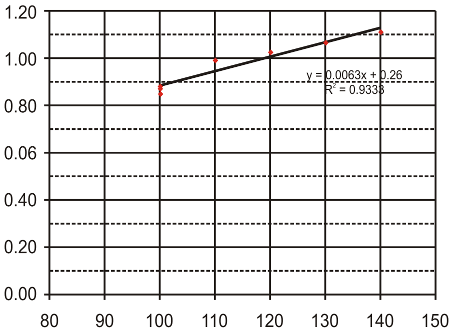


Tests confirmed that the correlation between coating rolls speed and coating thickness is also linear (Figure 5): higher rolls speed provides a higher coating thickness.

To a much less extent also the pick-up rolls speed affects the coating thickness: with the applicator rolls speed constant, the coating thickness tends to increase with the pickup rolls speed.

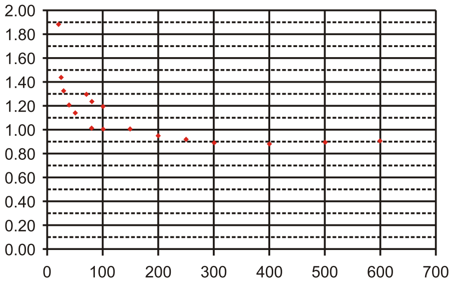
The steepness of the correlation between coating rolls speed and coating thickness depends on the varnish viscosity. For instance, viscosities in the range of 20-25 s (Ford 4 cup) a speed increase of approx. 1% for the applicator rolls provides a coating thickness increase of about 1%.

FIG. 5 : DRY COATING THICKNESS (ONE SIDE ONLY) VERSUS COATING ROLLS SPEED



The correlation between NIP pressure and coating thickness deserves a deeper analysis instead (Figure 6).

FIG. 6 : DRY COATING THICKNESS VERSUS NIP PRESSURE



The measurement chart recorded using low viscosity varnishes (up to 35 s Ford 4 cup) presents two areas.

For moderate NIP pressure values (more than 100 kg) the correlation is rather weak: any NIP pressure increase does not provide significant coating thickness changes.

For lower NIP pressure values the correlation becomes more significant (Figure 7) and coating thickness increases rapidly. But this holds up to a threshold value, that was found for our project being approx. 40 kg (Figure 7).

Below this threshold such correlation cannot be modelled easily and the quality of the coating worsens significantly: the uniformity cross wise the applicator rolls starts to deteriorate dramatically (Figure 8).

FIG. 7 : DRY COATING THICKNESS VERSUS NIP PRESSURE FOR LOW PRESSURE VALUES

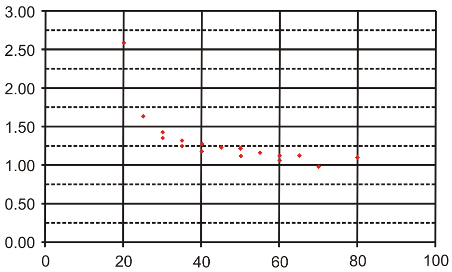
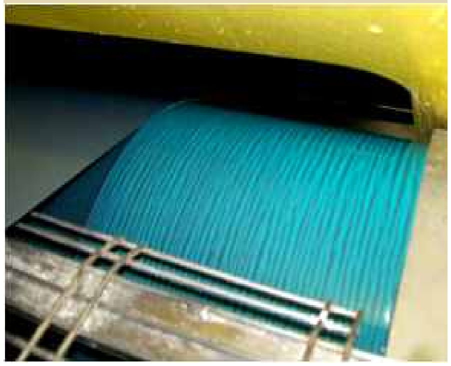


FIG. 8 : NOT-UNIFORM VARNISH DISTRIBUTION STARTS ON THE APPLICATOR ROLLS WITH VERY LOW NIP PESSURE



Coating Process Control

The commissioning is concluded with the tuning of the coating process control software.

During coaters normal operations both transient and steady states are common.

Scheduled transients come with production changes for different requirements on coating thicknesses and\or coating products. In other cases process parameters may change unpredictably. For example the drift of the coating varnish characteristics explained before. Another possibility is that as the coating solution is prepared in batches, from time to time the empty barrel is changed with a new one that may have a different dry residual.

This control software was developed for dealing with both the transient states and the steady state conditions.

Let's see how it works

The control model acquires the dry thickness value measured by the in-line gauges and compares it with the target value.

Any deviation of the dry thickness value from the reference value is automatically compensated by changing the coating machine setup so that the set point thickness can be reached. The coater settings are remotely adjusted via a close loop based on a set recipes tailored to the producer.

The time for reaching the new target thickness value is limited by the line layout that commands the time spent by the strip travelling throughout the drying oven.

This physical parameter cannot be reduced, especially in existing lines, therefore accurate and extensive recipes built during commissioning are of primary importance.

To do this a campaign of tests is carried out for the various coating varnishes to be used and over the entire range of thicknesses. The recipes record the main coater process parameters (namely the NIP pressure and rolls speed).

These recipes can then be employed as starting point to feed the coating control model continuously, either when changing production schedule or during steady states – in order to reduce the time required for converging to the set point thickness value.

Trials have demonstrated that in case these recipes are excluded the system still converges to the set point but in a much longer time since it starts farther away from the proper machine set up.

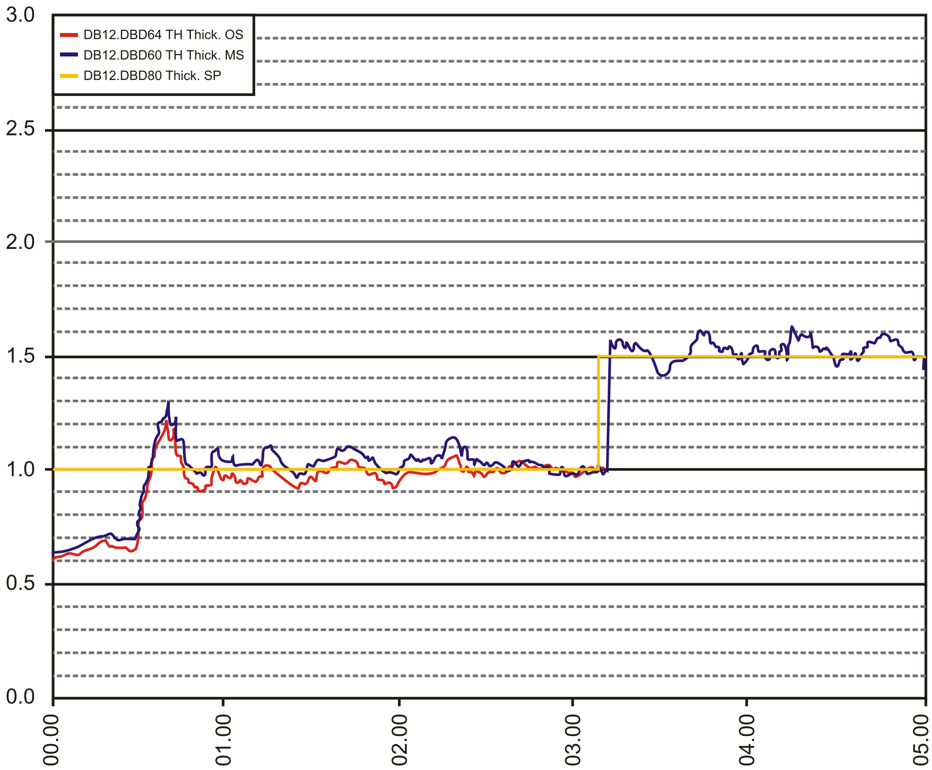
A key factor is the gain coefficient of the regulation loop.

Low gain coefficient help avoiding oscillating behaviours due to over-reactions, but on the other hands it tends to slow down the response time of the automatic system. High gain coefficient produces fast response times but brings along excessive oscillations.

During commissioning gain coefficient is initially kept low and steadily increased up to an optimum response time required for converging to the set point thickness.

Figure 9 shows the typical behaviour of the close loop system starting from the recipes built during commissioning: the corrections, commanded by the in-line gauges readings, pursue the coating thickness value with a good

FIG. 9 : RECORDING OF THE MEASURED DRY COATING THICKNESS IN-LINE DURING COATING THICKNESS TARGET CHANGES



- Faster program changing times (i.e. less material out of tolerance)
- Reduced need for off-line quality control checking (reduced laboratory costs) and to greater competitiveness coming from:
- Improved coating thickness uniformity and tolerance
- Stronger capability to meet reliably better tolerances for important products

The same approach and this control model can be applied also to 3-rolls coating machines, that on the other hands requires much longer commissioning time.