# MODEL-BASED COATING WEIGHT CONTROL SYSTEMS FOR GALVANIZING

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*ABSTRACT*

Model-based closed loop coat weight control systems have emerged over the last 30 years as a reliable and stable means of controlling the coating process and producing uniform product.

The author describes the development, design and application of a model-based coat weight control system that has been installed on two lines at a hot dip plant in the United States. Using object-oriented design and the flexibility of OPC to link the elements of the system, it provides a user-friendly interface through which operators can interact with and direct the system and set boundaries on the control envelope.

The system has proved itself in its ability to respond to large speed changes, reduce coat weight variance, increase accuracy in coat weight transitions, and cut coating weight diversions.

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## INTRODUCTION

Hot dip galvanizing operators want to control the process such that coat weight uniformity is maintained from side-to-side and from end-to-end for the coil. More uniform material generates savings for the producer and minimizes the production problems of the end customer.

Hot dip galvanizing control is not simple due to the physics of the jet-stripping process and the mechanical requirements of line layout. The jet-stripping process is highly non-linear. The coat weight response surface in Figure 1 shows the high degree of non-linearity with respect to pressure. The ratio of maximum slope to minimum slope for the pressure surface may exceed 50:1. Not only is the weight response to pressure non-linear with respect to pressure, but the response is also affected by knife distance and line speed in a non-linear manner. The latter characteristic is also shared by the relationships of coat weight to knife distance and line speed. The second major problem with a galvanizing closed loop control system is the long delay between the process at the air knives and measurement at the coat weight gauge. In some systems, this can be greater than three minutes.

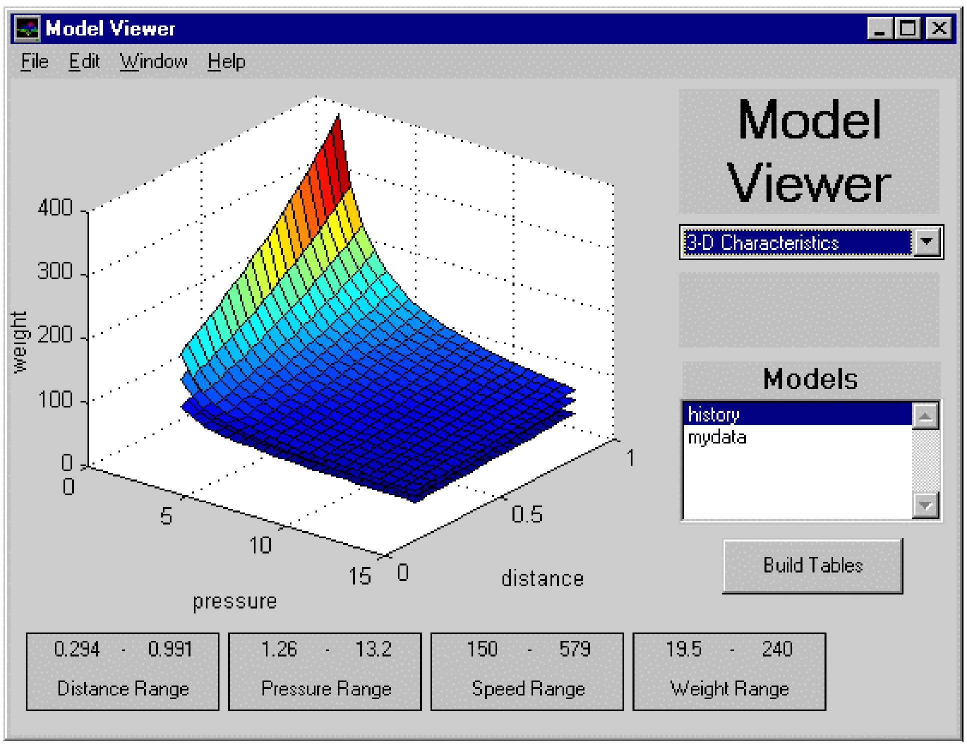


**Figure 1 – Coating Weight Response Surface for Knife Pressure, Knife Distance, and Line Speed**

In order to make reasonable control changes through such events as process variation, target changes, and critical circumstances requiring large changes in line speed, the control system needs some means to know how the process will behave at the current time and under current conditions. This is the purpose of the model – a mathematical representation of the zinc pick-up and jet stripping process – which is used to predict process behavior. There have been many attempts to build such models, some very successful, and others not.

A well-formulated model that uses knife pressure, knife distance, and line speed to predict coat weight is relatively easy to build and to put into operation. Figure 2 shows the results of an automated test coil run used to determine the basic parameters of such a model. These parameters are different for every line and knife set. However, it is possible to use a model from one line to start control on another with a similar knife set. The test coil for the second line can be run later to refine the model. The test coil for this model was run through seventy-five different combinations of pressure, distance, speed, and knife height throughout the normal operating range of the line over a period of less than 45 minutes. The system determines the model parameters using these raw data and updates the control package just moments after the test.

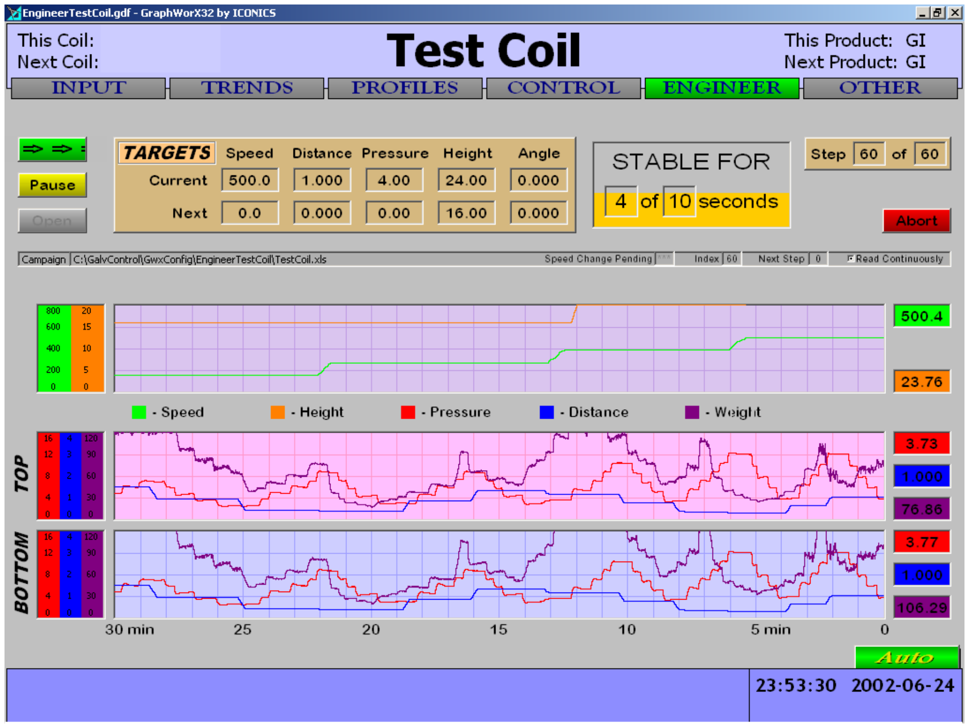


**Figure 2 – Process Trends for an Automated Test Coil Campaign**

## *HISTORY*

Since the time of the first model-based closed loop coat weight control system for galvanizing developed in 1971 by Industrial Nucleonics, many hot dip galvanizing coat weight control systems have been created and/or marketed throughout the world. Most customers want a control system to be bundled with the air knives or the gauge. Gauge manufacturers have answered by offering add-on packages that perform some sort of control.

Trends in recent years have had gauge manufacturers getting out of the control business or offering low cost simple systems to stay in the business. ABB, following its heritage from Industrial Nucleonics, offered a true model-based system in the early 1990’s. When the ABB Metals group was bought out in the late 1990’s, the buyer’s strategic plans did not include continuing a coat weight control offering. Since then, there have been few new systems which have been commercially successful and there are very few independent coating weight control system suppliers.

CMC and Objective Control have developed a new PC-resident, model-based, closed loop control system for hot dip galvanizing. This system and its designers continue the succession of galvanizing control systems from Industrial Nucleonics and ABB.

In the early 1990's, when processors were much slower, it took too much clock time to use the model equation in real time for control. The ABB system used partial-derivative gain tables, which gave the change in weight for a change in the process variable over a range of pressures, speeds and distances. This model would calculate the change in coat weight due to a change in a process variable and would then calculate the necessary change in pressure to compensate.

With faster processors, the new control system uses the model equations to predict the coat weight given a set of process variables and the parameters generated from the test coil data. When the process is in operation, control system feedback is used to modify the prediction to account for unmeasured or unmodeled sources of variation, which almost always vary more slowly than the primary modeled variables.

## *PHILOSOPHY*

We believe that outstanding product requires outstanding control. Outstanding control is both the immediate control of knife pressures, distances, and roll positions; and the overall determination of control strategies for different classes of coating weight variations. The control strategy for thicker material will differ from thinner substrate; the strategy for thin annealed coatings differs from thicker galvanized coatings; and the strategy for well-rolled, flat substrate differs from substrate with significant shape variations. By employing several strategies for coating, the system assures the operator that coat weight uniformity is paramount.

While uniformity is paramount, a control system must also be able to make clean, sharp, and accurate transitions and compensate for large speed and distance changes with minimum effect on coat weight. Any zinc savings generated by more uniform product will be lost if transitions are missed. Therefore, it is critical that model on-line adaptation be accurate so as to change targets precisely and repeatably.

## *NEW SYSTEM*

The newest-generation control system takes advantage of gains in processor power, process understanding, programming concepts, and years of experience working with operators in galvanizing plants. In addition to a new model, the new system uses an object oriented design for its software architecture – utilizing the flexibility of industry-standard OPC to link the control package with process I/O and the HMI, and refining the philosophy of interaction between the operator and the control system.

The system controls knife pressure, knife carriage position, knife distance, knife height, and correcting roll position. The primary variables for normal operation are knife pressure, knife carriage position, and knife height. Pressure control to maintains the coating weight on the strip side. Knife carriage position control keeps pressures in balance by keeping the strip centered between the knives. Knife height control is a function of line speed. Knife distance is adjusted to new preset values as needed when product specifications change. Changes in all of these variables are fully coordinated to eliminate or minimize disturbances to coating weight. Figure 3 shows the screen that lets the operator define the knife height operating practice for a given product.

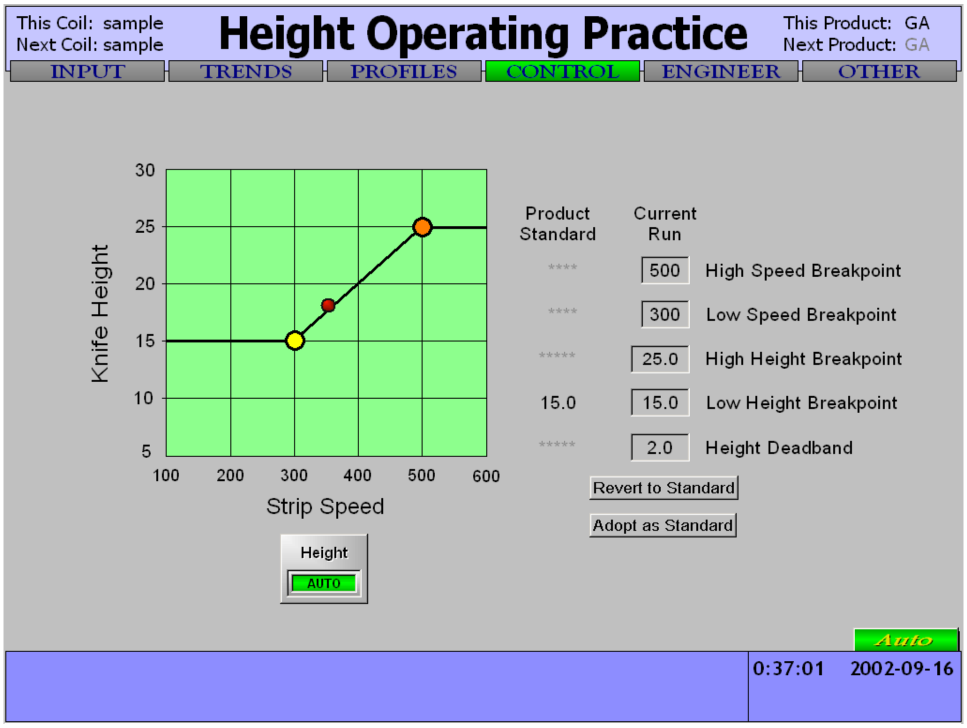


**Figure 3 – Knife Height Operating Practice Screen**

The philosophy of the control system is to use the operator as a sensor. When the operator makes a change in a system variable, he is not doing it to fight the control system, but to add some information, such as appearance, that the control system cannot measure. With this in mind, it is not necessary for the operator to "take it out of control" to make a change. All switches on the operator panel are active when control is running. If the system is controlling pressure, knife distance, height and knife carriage position and the operator wishes to change height, he simply changes the height from the panel. The system will automatically begin tracking the operator.

Under some circumstances, manual adjustments by the operator do not cause the associated control loop to drop to manual, but are utilized by the control system to refine its operation. For example, if the operator adjusts the knife carriage position near the time a weld is passing the knives, he is most likely correcting for a passline change, so the system simply updates its current estimate for strip passline, then continues to track it automatically as inferred by the model and available measurements.

The system provides the operator with screens by which he can set the limits and parameters of operation for the given product. The operator can monitor the process from the Control Overview screen, shown in Figure 4, which displays the measurement trend, the profiles, and the predicted value of the coat weight at the knives.

The closed loop coat weight control system uses "envelopes" to define the range of process parameters. On the pressure control screen shown in Figure 5, the appropriate top/bottom pressure ratio is automatically computed based upon knife distance settings and coating weight targets, allowing for either equal or differential coatings. The operator defines the maximum amount the ratio can deviate from normal and the absolute maximum difference between top and bottom pressures. While the control system maintains the process inside this envelope, it will take no action other than controlling pressure.

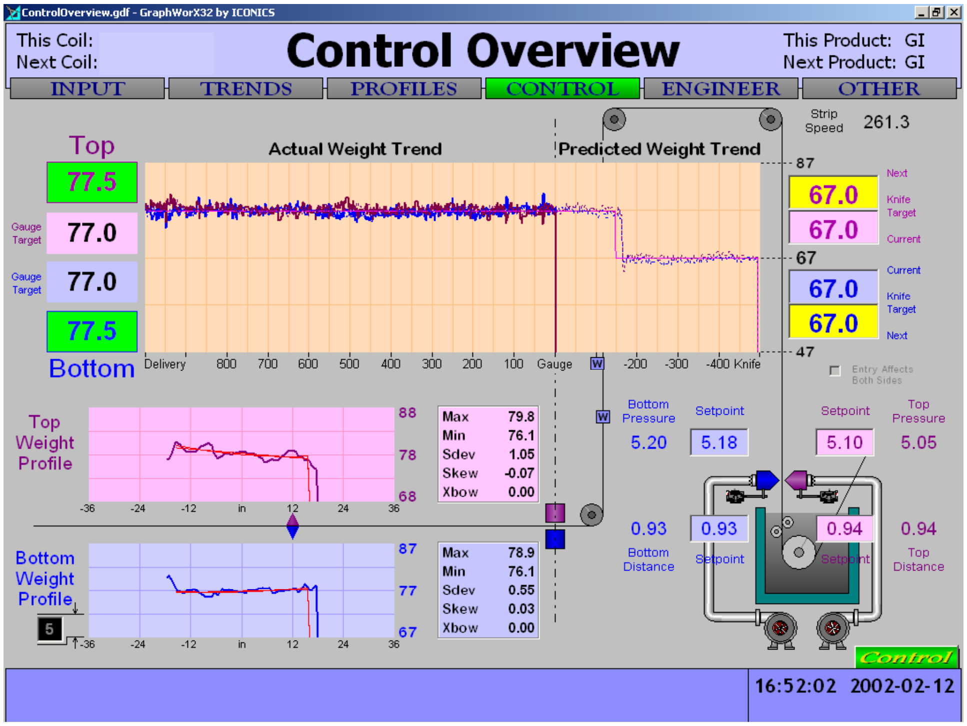


**Figure 4 – Control Overview Screen**

When the ratio reaches a boundary, the system will move the knife carriage to keep the strip centered between the knives. If the system has not been given control of the carriage, it will maintain the limit by lowering one of the pressures and overcoating one side.

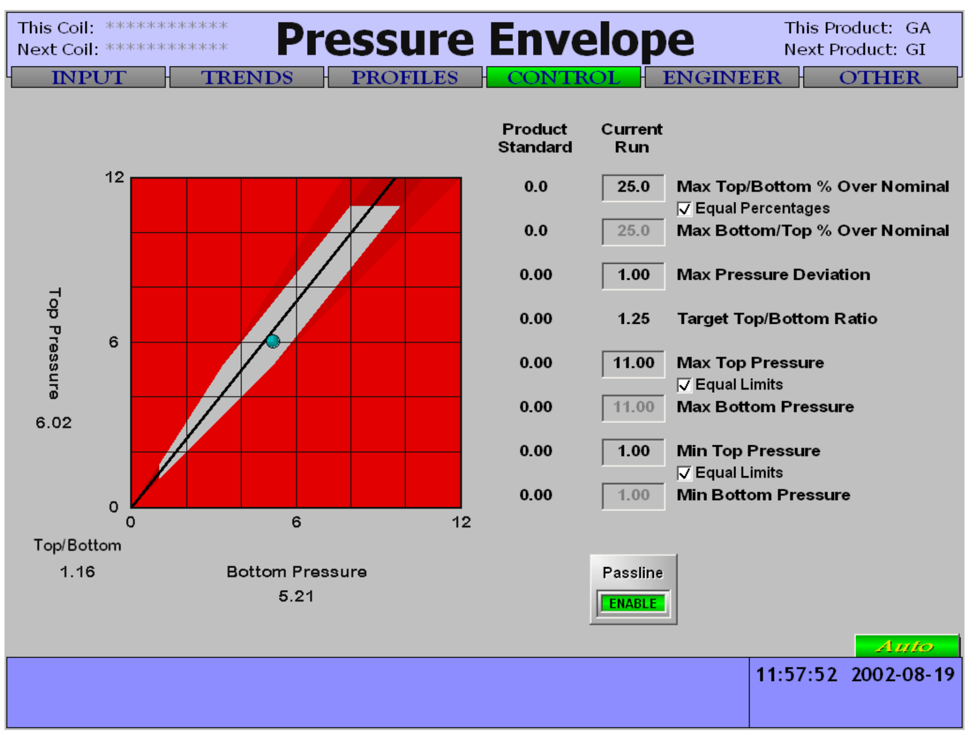


**Figure 5 – Pressure Control Envelope Screen**

## *DESIGN*

The object-oriented design of the control software creates a computational analog object for each of the main portions of the actual process. The object overview drawing in Figure 6 shows the line being divided into entry, coating, and exit sections. Each section has the procedures to handle coil tracking through the section. The coating section is further broken down to include objects for the air knives and the coat weight measurement gauge.

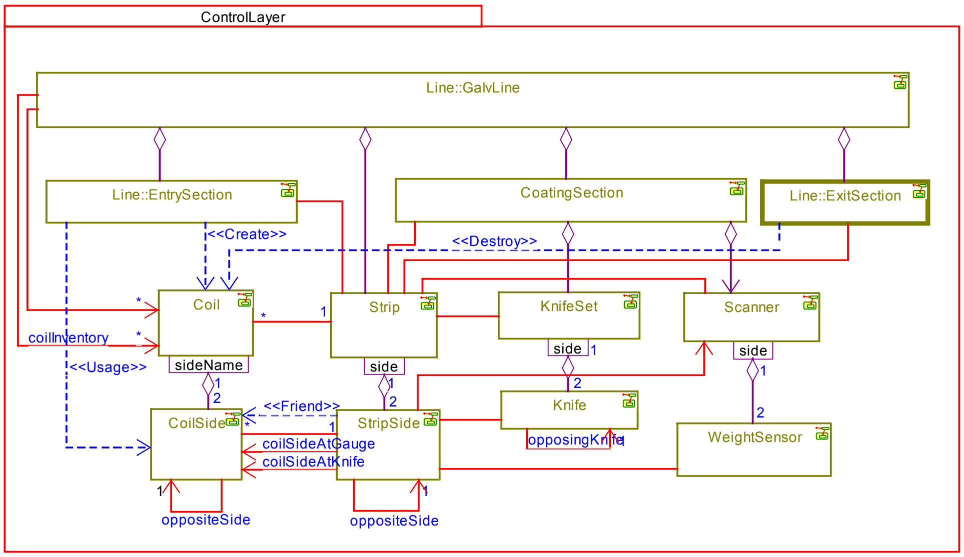


**Figure 6 – Object Overview for Galvanizing Line and its Components**

Each object contains the intelligence to perform the operations required on the corresponding physical equipment. Commands to move the knife carriage or adjust skew, for example, are translated into machine motion by the knife object. In addition, the objects communicate with each other to coordinate the operation of the entire coating system. Variations from line to line, such as different coating weight gauges or air knives, are easily accommodated by substituting a different "subclass" of the same general type of object. None of the other objects is affected by such a change.

The system has been developed using an object-oriented tool specifically designed for creating embedded real-time systems. This tool, Rhapsody® by I-Logix, has been successfully used in the design of communications, aerospace, and automotive systems. The design is expressed in the high-level, industry-standard graphical language, UML (Universal Modeling Language). The UML diagrams specify both structure and dynamic behavior.

Objective Control has enhanced the power of this approach by further integrating

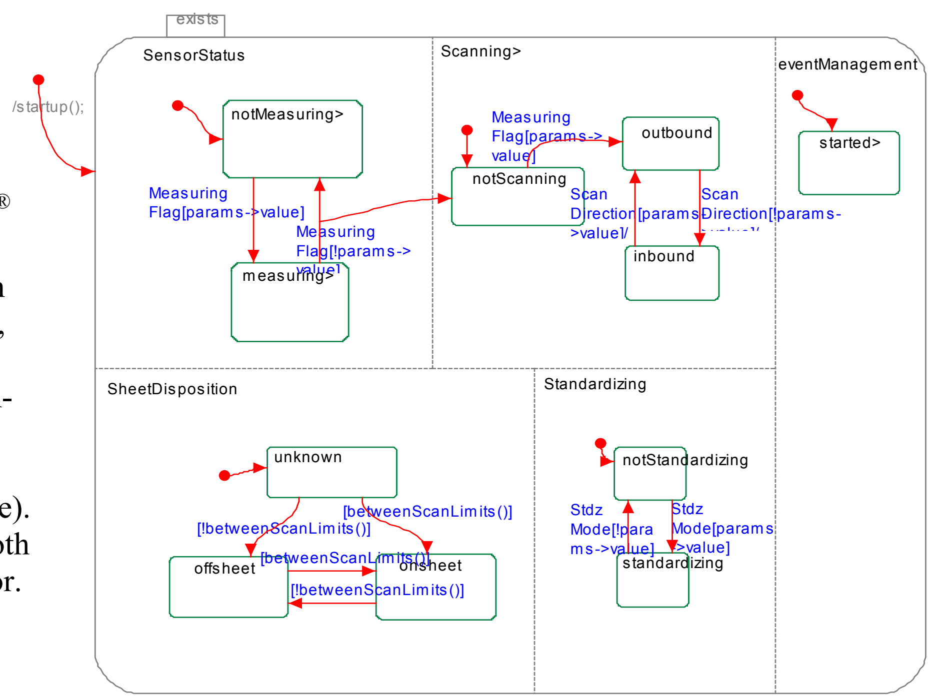


**Figure 7 – State Chart for Scanning Sensor**

the high-level Matlab® mathematical and graphical libraries with Rhapsody®. Rhapsody® then generates C++ code from state diagrams such as the one shown in Figure 7. The designer inserts detailed algorithms written in Matlab® and C++ into the appropriate elements. Objects in the control system programs correspond to actual objects in the line, (e.g. knife set, scanning gauge) so that the control system becomes an analog of the process.

Using the OPC-based HMI package Genesis32™, by Iconics, we are able to take advantage of OPC protocol in putting programs and packages together. Using an OPC server to collect data from the process PLC's, these data are passed to DataWorX™, a Genesis32™ component which serves as a bridge by being an OPC client to the I/O server and a server to the HMI and control clients. With this architecture, it is not necessary for the control programs to be modified for different I/O and customer equipment interfaces. When a different piece of equipment is encountered, a change in the I/O and DataWorX™ configuration handles the subtle differences.

In operation, the object oriented system acts, by design, much like the line itself. The entry section object uses physical data to classify the coil and to access set up conditions and strategies based on substrate, coating, and final specifications. Coils exist separate from the process and can archive data collected from entry and exit sections in addition to knife and gauge data. Data for each coil are archived when the weld crosses into the exit section. With this system it would be possible to send coil records automatically to the customer when the coil exits the line, though we know few operators who would consider this an advantage.

## *FEATURES*

Outside of the control itself, one of the major features of the system is its ability to show the predicted coat weight between the knives and the gauge. This gives the operator a visual representation in advance of coating weight variations between the knives and the coating weight gauge. In cases where the operator chooses to control the system manually, this predictor gives him immediate feedback for any changes to speed, knife pressure, knife distance and carriage position. If the strip is not centered, the operator can see the effect of carriage moves and bring the strip to center easily. Knife carriage moves consider the backlash in the mechanical equipment so the operator sees the actual effect of carriage moves, not simply the result of a change in the position reading.

There are many variables that affect the coat weight that are not currently predicted by the model. Changes in furnace exit temperature and their effect on galvanneal measurements are not compensated for. Similarly, changes in strip position, passline shifts at welds and strip roughness all cause weight changes that appear as deviations from the prediction when the coat weight is measured at the gauge. The system immediately compensates for these changes so their effect only persists for a single transport distance, from the knives to the gauge. We do have plans to incorporate strip passline sensors, when available, in order to eliminate the delay in response. We also plan to predict the effect of strip temperature on measured coating weight. Speed and distance changes may produce small bumps of less than three grams for the period of time that the change in the process variable leads the pressure response.

Passline centering has many benefits to product uniformity. By keeping the passline centered, the system keeps pressures more nearly equal and assures more uniform conditions for both sides of the strip. With greater uniformity of process conditions, small changes, such as passline flutter, will have a more nearly equal effect on both sides. By limiting pressure differentials, strip "pushing" by high-pressure differences is eliminated.

The system determines the amount of skew and crossbow in the profile by the same means used to determine strip position from coat weights and process conditions, whether produced by variations in actual strip position or by gradients in strip temperature or knife gap variations. The control system will minimize the effects of skew and crossbow, real or apparent.

The Analysis of Variance screen in Figure 8 gives the operator information regarding the magnitude of the variance in the single-side coat weights and helps identify the source of the variation. Cyclic analysis, planned for later this year, will tell operations the roll diameters associated with major cyclic passline flutter, which can pinpoint internal sources of error. If a process engineer thinks that eccentric or wobbly furnace rolls are simply mechanical problems, he can be assured that they are imprinting their "signature" on the product as shown in Figure 9.

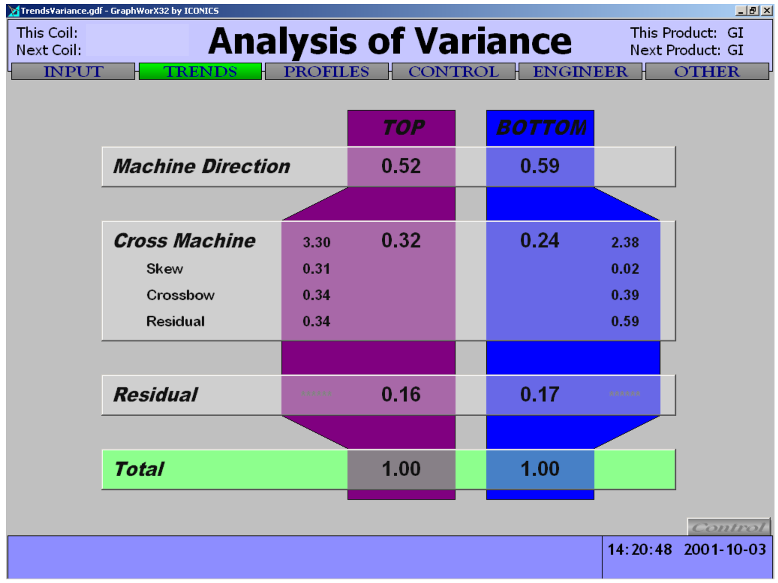


**Figure 8 – Analysis of Variance Screen**

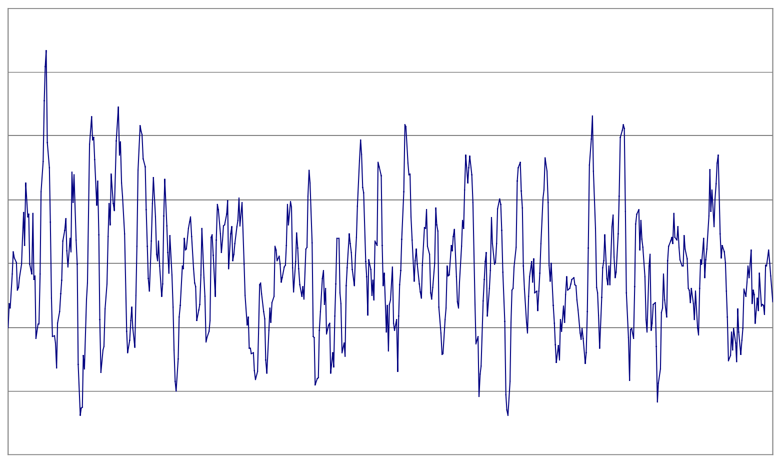

**Figure 9 – Passline Flutter Cyclic Component in Machine-Direction**

## *RESULTS*

Overall, the control system has produced significant results. Many coils have been produced with a standard deviation for an entire coil side of less than four grams. The control system has reduced overall variance for coils to less than one half that of previous product produced using an already effective control system. Coating weight diversions due to poor transitions between targets have been reduced.

## *FUTURE*

Although the system is already producing outstanding results, we have many plans for additional features. Immediate plans include development of algorithms for estimating coat weight changes due to changes in strip roughness, target optimization based on coating weight statistics, and compensation for furnace temperature variations.

## *ACKNOWLEDGEMENTS*

The author wishes to acknowledge Bob Wilhelm of Objective Control, his colleague and friend, for his work on the succession of model-based systems beginning with the first system in 1971; his son and colleague, Todd Corson, for his work on the control system and this presentation; and the late Paul Fontaine for his inspirational being and his contribution to the science of galvanizing.

## *REFERENCES*

Ellen, C.H., and C.V. Tu, *An Analysis of Jet Stripping of Molten Metallic Coatings*, Presented at the Eighth Australasian Fluid Mechanics Conference, University of Newcastle N.S.W., 28 November – 2 December 1983.

Thornton, John A., and Hart F. Graff, *An Analytical Description of the Jet Finishing Process for Hot-Dip Metallic Coatings on Strip*, Metallurgical Transactions, Volume 7B, December, 1976.

Corson, Richard C., and R.G. Wilhelm, Jr., *High Performance Coating Weight Control for Hot Dip Galvanizing Lines*, Proceedings of the 1994 Meeting of the Galvanizers Association. Dearborn, MI, 1994.

Corson, Richard C., *A Statistical Analysis Of Coat Weight Measurement*s, Proceedings of the 2000 Meeting of the Galvanizers Association. Toronto, Ont., 2000.

## *FIGURES*