Evaluating Air Knife Adjustments with the Aid of a Coating Weight Model

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Abstract

Air knife parameters that normally remain fixed or are only infrequently adjusted may have a significant impact on coating uniformity, line operability, and throughput. Empirical evaluation of knife setup is essential, but is also very expensive in terms of time, materials, manpower, and loss of production. It is also difficult to directly compare data collected between knife changes because so many other variables affect coating weight.

Pro-Tec Coating Co. recently conducted a small number of tests to evaluate the potential for changes in knife gap and angle to improve throughput. The data evaluation procedure made use of the same coating weight model as is used in the plant's process control system. In this paper we discuss the objectives of the tests, the testing methodology, the role of the mathematical coating weight model in the evaluation, and the results obtained. The results obtained from the tests described here are tentative. We discuss the reasons for this and why we consider the use of the coating weight model to be a critical component in planning and analyzing the results of our future testing.

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1. Introduction

Pro-Tec Coating Company is a joint venture Continuous hot dip Galvanizing Line (CGL) located in Northwestern Ohio. Pro-Tec's customer base is primarily the automotive industry who use Pro-Tec's galvanized and galvannealed steel to make automotive body parts ranging from under-body to exposed-surface body parts. The diverse product mix at Pro-Tec creates the need for wide ranges in substrate sizes and grades, pot chemistry, annealing temperatures, and surface treatments. With the increasing ranges of these process conditions, we were finding that the ability to wipe the zinc down to an acceptable coating weight was becoming a limiting factor for production on certain steel grades. It was our desire to relieve this constraint that prompted the study of ways to increase wiping efficiency.

To approach this problem we formed a task force that included engineering and production management, process techs, mechanical maintenance, and operators to in an effort to identify the significant factors affecting zinc coating weight. Everyone in the galvanizing business knows "the big three" process variables: The speed of the strip moving past the air knife, the distance of the knife from the strip, and the pressure of the jet of air wiping the strip. Under normal operating conditions, these are the dominant variables in zinc coating weight on a steel strip. We wanted to identify better ways to use the known variables of pressure and distance, with speed effectively set to line design speed. We also wanted to identify other variables that were most likely affecting coating weight and to quantify their effect.

We would like to state right up front that we consider the conclusions we have drawn from this work to be tentative, and that we intend to corroborate or refute them with further testing. Most importantly, we hope to show why these ambiguities exist and why the ambiguities themselves are valuable lessons.

2. Design of Experiments

The first approach we agreed upon was to vary the opening of the air knife and the angle of the knife to strip. It was our belief that a wider knife opening would result in better wiping of the zinc coating. The assumption was that if we could maintain the same pressure at the wider gap, the increased quantity and a wider jet of air would produce a wider area where thinning of the zinc coating could occur, wiping more of the zinc off of the strip. These actions, we theorized, would give us an increase in speed. We also decided to try a slight angle downward, this again in hopes of increasing wiping efficiency. We also assumed that the slight pitch downward would increase the shear forces pushing the excess zinc downward and back into the pot.

In the first series of tests we decided to modify the knife gap from the current 1.5mm bow-tie configuration to a 1.7mm flat profile. A series of test coils all being the same width, thickness and surface roughness were assembled. The test consisted of three parts:

1. Run the test sequence with the original 1.5 mm bow-tie gap
2. Stop the line, change air knives to the 1.7 mm flat gap and repeat the test sequence
3. Stop the line, adjust the 1.7 mm set of air knifes to a negative (down) 1.5 degrees and repeat the test sequence.

These tests were carried out when the process line is stable at the end of a normal production run just prior to a downturn. The knife height remained at a constant 20 inches throughout the tests. The coating weight gauge was placed in single point mode over the centerline of the strip. The historical trending function of the gauging system was used to collect the test data. The test data were later transferred to a development computer for analysis.

Choosing Test Coordinates

Since we wanted to determine how wiping efficiency was affected by the changes in knife gap and angle over the entire range of operation, an important aspect of planning for the tests was to select the ranges of the operating parameters to be varied during the tests (line speed, knife distance, and knife pressure). We have conducted similar tests in the past to determine the parameters of a coating weight model used in our closed loop coating weight control system [Corson, 1994], and have found a “factorial design” approach for those tests to yield good results from a relatively small number of data points. A pure factorial design experiment chooses a set of values for each of the independent variables, takes one sample of the dependent variable (in this case, coating weight) at each of the possible combinations of the independent variables. Given the nonlinearity and highly interactive relationships between coating weight and these independent variables, a minimum of three values for each variable is desirable, thus suggesting a minimum of 27 data points.

Experience with the aforementioned model-building tests has also demonstrated the obvious fact that some of the extreme combinations of pressure, distance, and speed are so far from normal operating conditions that they provide little useful information and often cause operating problems, such as knife plugging, as side-effects. Since we had a model for the knives currently in use, we decided to use a modified factorial experiment, and to use the our existing coating weight model to determine the combinations of values of speed, pressure, and distance that would be most effective for our analysis.

Figure 1 gives a graphical view of the test plan. Because of the high degree of nonlinearity in the relationship between coating weight and knife pressure, and because we were particularly interested in how the knife parameters would affect line throughput, we elected to use four values of pressure for each combination of speed and knife distance, and four values of speed for each combination of knife pressure and knife distance. In Fig. 1, each of the four three-dimensional surfaces represents the coating weight predicted by the model as a function of knife pressure and knife distance at a fixed line speed. The lowest surface represents the lowest line speed to be tested, and the highest surface the highest line speed to be tested.

The points shown as black dots in Fig. 1 are located at the coordinates of the specific knife pressures and knife distances to be tested, 12 pressure/distance combinations for each of four line speeds. The height of each point represents the coating weight predicted by the model for that combination of parameters.[1] For each line speed, although we used the same three distance values, we chose a different sequence of four pressure values to reflect the most extreme conditions likely ever to be encountered during operation. This is readily visible from Fig. 1, and detailed by Table 1 in the Appendix.

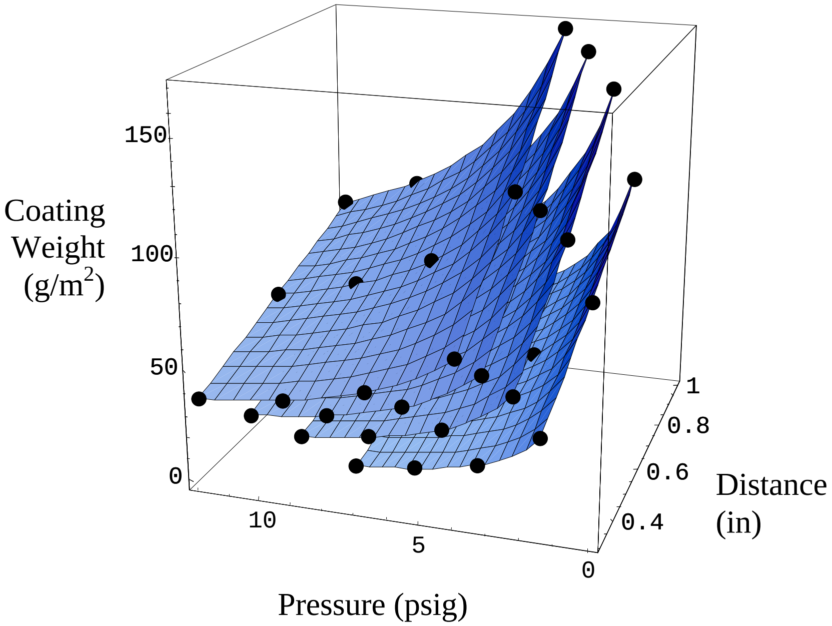

Fig. 1 – Test Plan: Sample Points and Model-Predicted Coating Weight Characteristics.

3. Data Collection

During the tests, the coating weight gauge was positioned at a fixed point near the center of the strip. The coating weight control system was placed in manual mode, but continued to record the knife pressure, knife distance, line speed, and measure the coating weight as usual, saving its samples in a history database. For purposes of these tests, the values stored in the history database are a sequence of consecutive 5-second averages of the independent variables of knife pressure and knife distance for each (top and bottom) air knife, line speed, and top and bottom coating weight. Since these samples are recorded simultaneously for all variables, the data must be manipulated to align the coating weight measurements with the other data, taking into account the distance between the air knives and coating weight gauges (approximately 470 ft.) and the line speed.

The data collected for the “reference test” (the first test sequence run on the reference knives) is typical, but took nearly twice as long (and included nearly twice as many samples, all redundant) as the subsequent tests, since the team became more efficient with experience and wanted to minimize the time and material costs. The aligned data are shown in Figs. 2a – 2d, with the top side and bottom side data shown as though they were consecutive sequences rather than in their true (parallel) form. Each sequence included 399 samples.

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[1] The coating weight model used in our coating weight control system does not predict a specific coating weight, as coating weight is affected by many other variables. It predicts only the change in coating weight that will result from a specified change in one or more variables. However, the model does have the *capability* to predict absolute coating weight provided that extraneous variables are held constant, and it is this capability that we employed for the purposes of these tests.

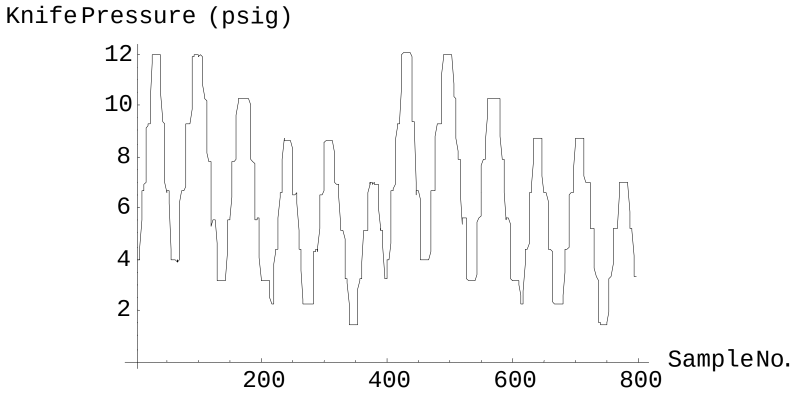

Fig. 2a – Knife Pressure Test Sequence (Top followed by Bottom)

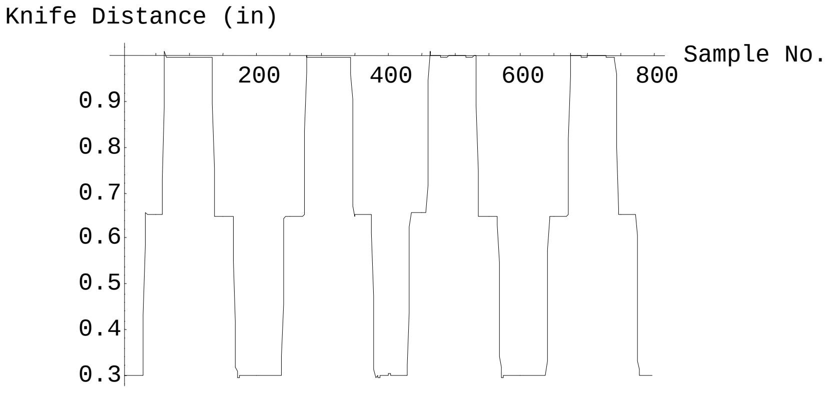

Fig. 2b – Knife Distance Test Sequence (Top followed by Bottom)

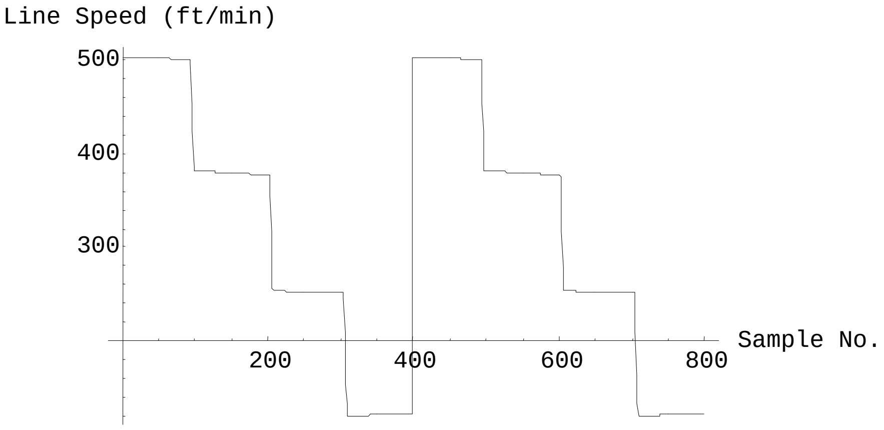

Fig. 2c – Line Speed Test Sequence (Shown repeated for top and bottom)

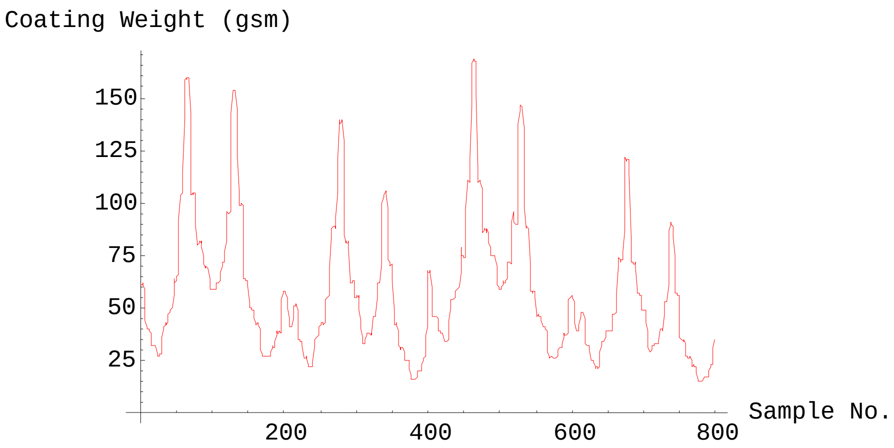

Fig. 2d – Coating Weight Measurements (Top followed by Bottom)

4. Analysis of the Data

Our coating weight control system has provisions to upload data from this history database to a PC-based *Galvanize Modeling Toolkit*[2] that we use to build the coating weight model used during normal operations. The model is built offline, then uploaded back to the coating weight control system for use during normal operation. This model-building procedure is rarely performed – in general only when we modify the air knives – but has also proven valuable for special tests such as the ones being described here. The model we used to plan the tests was one we had constructed for the reference knives (those with a 1.5 mm gap and in regular production use) over two years earlier, and which has been in constant use in the coating weight control system since that time.

We made use of the existing capabilities of both the coating weight control system (for data gathering) and the PC-based *Galvanize Modeling Toolkit* for modeling, planning the experiment, and analyzing the data. Objective Control Ltd. assisted with the experimental work and analysis, supplementing these tools with additional software written in *Mathematica*.

We planned from the beginning to employ the model in the data analysis as well. It is both difficult and risky to draw conclusions from a direct comparison of data taken at different times on a galvanizing line. It is easy to change knife pressure, knife distance and line speed quickly, so that it is fairly safe to assume that other conditions, such as bath temperature and composition, strip surface roughness, and strip temperature remain constant. Comparing two sets of air knives, however, is another story entirely. Direct comparisons are only likely to be valid if based on large volumes of data gathered from many production runs so that other variables can be averaged out or carefully controlled. Indeed, it is often the

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[2] The *Galvanize Modeling Toolkit* was originally designed by Objective Control Ltd. for ABB Industrial Systems Inc., and was included in the scope of supply for the coating weight control system installed when PRO-TEC's coating lines were built. The *Toolkit* is written in *Matlab* and features a graphical user interface.

case that even the settings for knife pressure, knife distance, and line speed may differ slightly (unintentionally) from test to test. The model can easily compensate for such small differences.

5. The Reference Test

The set of experimental data in this series, as outlined previously, was gathered using the reference knives (1.5 mm bowtie gap, set at 0° from horizontal). The first thing we did was to construct a new model from this data – actually three models: one from top side data only, one from bottom side data only, and an aggregrate model from top and bottom side data. The results are shown in Figs. 3a – 3c in the form of scatter diagrams, with the model-predicted coating weight plotted against measured coating weight for each sample. Most of the outlier points are due to the inclusion of samples taken during the transient conditions and the relative imprecision of the algorithm used to time-align the measurement data with knife conditions. Although we have sometimes employed certain filters and sieves to exclude such data, experience has shown that the resulting improvements are very small given the relatively large number of samples available and relatively small amount of scatter.

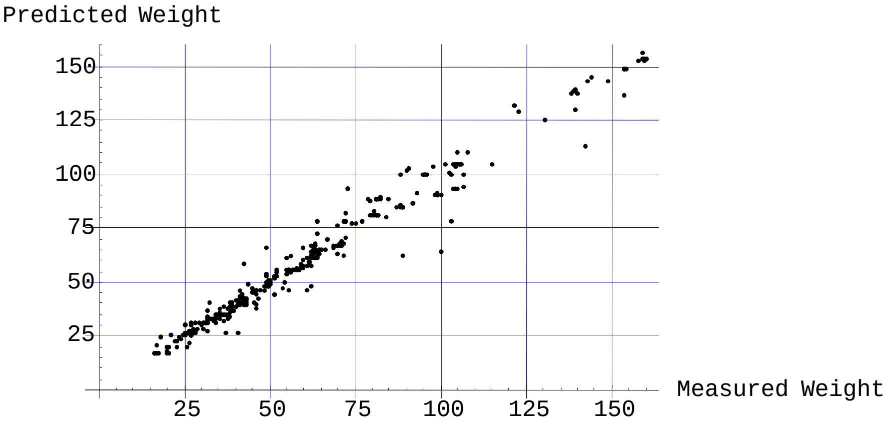

Fig. 3a – Scatter Diagram for Top Side Data vs. Model-Predicted Weight

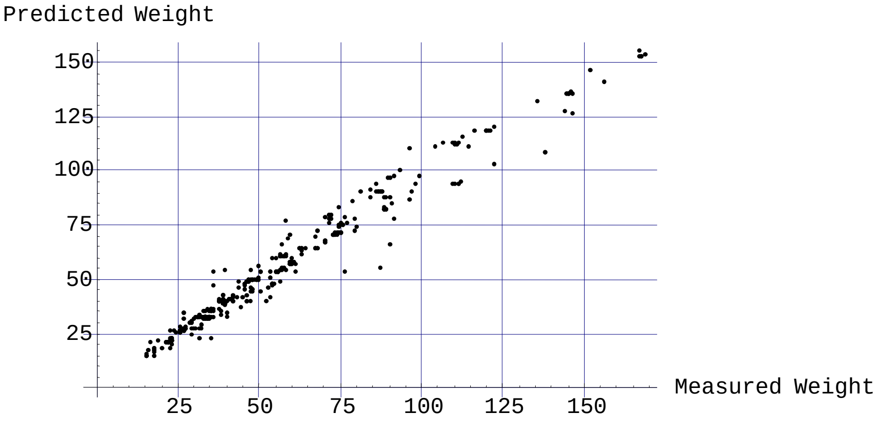

Fig. 3b – Scatter Diagram for Bottom Side Data vs. Model-Predicted Weight

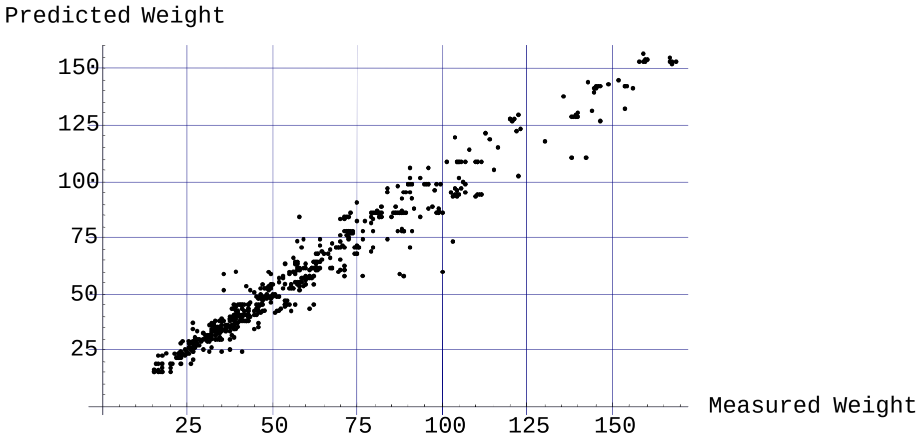

Fig. 3c – Scatter Diagram for All Data vs. Model-Predicted Weight

Comparing the Reference Test with the Plan

It is of interest and somewhat relevant to compare the measured values from the reference test to those predicted by the 1998 model used in planning. Figure 4 shows the raw comparison. The black dots represent the values predicted for our tests by the 1998 model, while the surfaces represent the model developed from our newly acquired data. Though the predictions are reasonably good overall, we note that the deviation is most significant for at the lowest knife pressure and highest knife distance at all but the lowest line speed. These are the conditions where the knives have least effect, but also the conditions under which coating weight is most sensitive to any change in conditions. Given that there have been no intentional changes to the knives during this time and that the instrumentation and equipment are well-maintained, such a difference suggests that other factors could be causing the strip to inherently pick up significantly less Zinc during this test than when the model was developed 2 years earlier. Indeed, this is the reason why models that predict absolute coating weight are poorly suited for use in closed loop coating weight control.

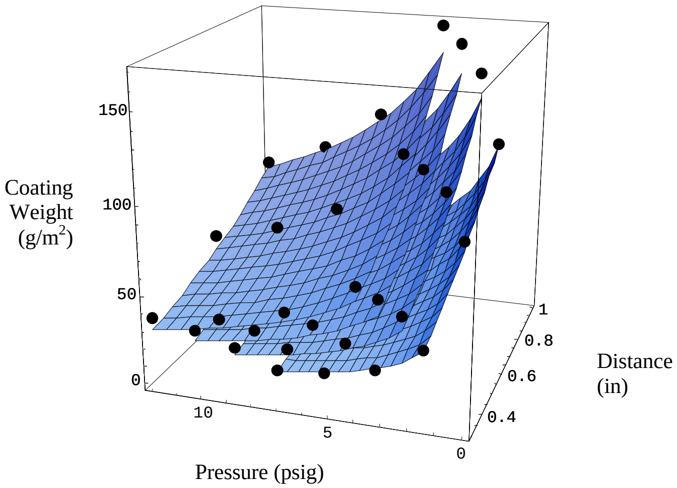

Fig. 4 – Predicted Testpoint Values Compared to New Model (Surfaces).

Although we have no data reflecting the raw withdrawal flux (Zinc pickup in the absence of air wiping), the data collected where the knives have their least impact can be used to suggest how withdrawal flux varies with speed, as shown in Fig. 5.

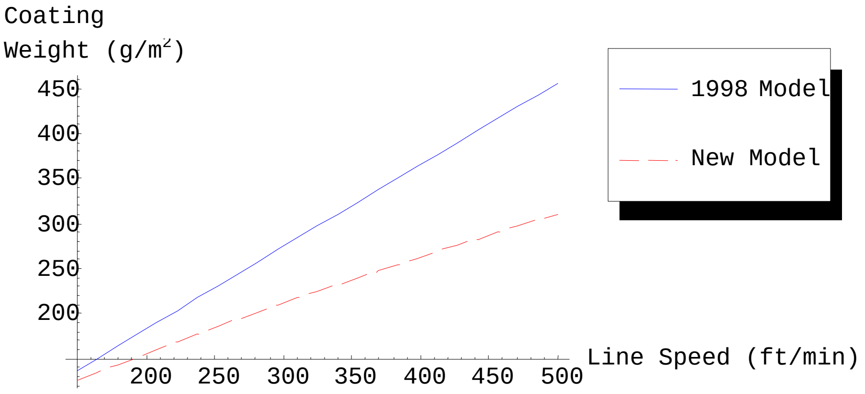

Fig. 5 – Difference in Coating Weight at Least Knife Effect.

Correcting for Differences in Operating Conditions

As we mentioned earlier, although our model is *capable* of predicting absolute coating weight, that is not the form in which it is used for control. On the other hand, our model is also capable of normalizing itself to compensate for the effects of unmeasured extraneous variables on coating weight. Applying such a normalization function yields the comparison in Fig. 6 between the new model and the experimental points predicted by the model derived two years earlier. Points not visible along the rear edge are just very slightly below the top surface. The model appears to be a stable and accurate predictor of wiping behavior.

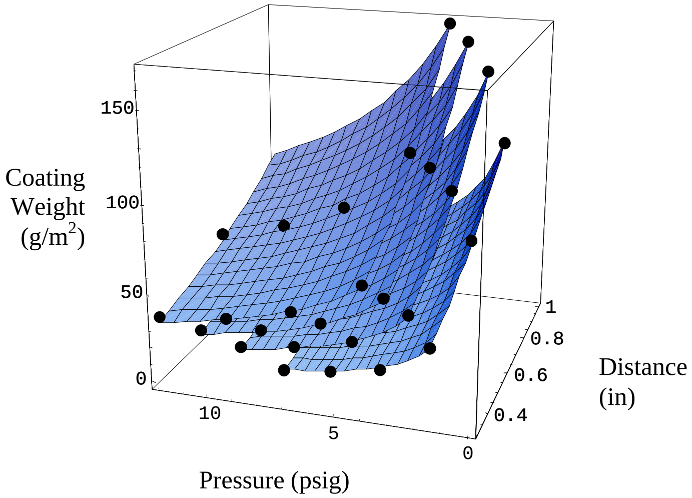

Fig. 6 – Points predicted with 1998 model compared to new model (surfaces) after normalization for unmeasured influences.

6. Evaluating the Effect of Knife Gap

Immediately after the reference test, the existing air knives with the 1.5mm bowtie gap were replaced with a set with a 1.7mm flat gap. The knives were set to 0° from horizontal (jet normal to strip, as were the 1.5mm knives). The line was then restarted and the test sequence was repeated.

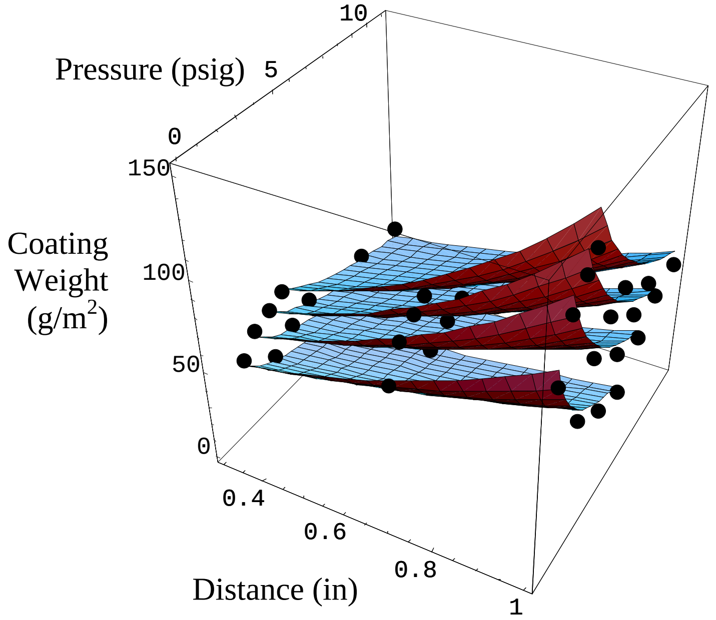

Fig. 7 – Coating Weights Measured for 1.7mm Flat Gap Knives (black dots) Compared to Characteristics of 1.5mm Bowtie Gap Knives (surfaces).

Figure 7 compares the coating weights measured for the 1.7mm flat gap knives (shown as the black dots) and the characteristics of the 1.5mm bowties gap knives (shown as surfaces). This direct comparison would appear to indicate that the 1.7mm knives yield lower coating weights under most circumstances, but slightly higher at the lowest knife distances. Careful consideration, however, suggests another possibility. We note that the difference between coating weights is largest at the lowest pressures and highest knife distances – the region in which the knives exert the least stripping force. It seems possible, therefore, that these differences represent the influence of other variables (such as strip temperature) on the withdrawal flux (Zinc being pulled out of the pot by the strip) rather than changes in stripping efficiency.

There are several possibilities to consider here:

Possibility 1. The changes in coating weight from test to test could be explained completely in terms of the changes in stripping efficiency due to the changes in knife parameters.

Possibility 2. The changes in coating weight from test to test could be influenced in part by changes in unmeasured parameters, such as strip temperature, surface roughness, bath conditions, etc.

Possibility 3. The changes in coating weight within a single test could be affected by changes in unmeasured variables during that test, such as strip temperature.

Possibility 4. The observed changes in coating weight either during a test or between tests could be due in part to measurement errors induced by sensor instability or sensitivity to strip temperature or other parameters.

We can make the following observations:

Observation 1. We ruled out consideration of possibility 4 above, based upon our experience and previous testing of the coating weight gauge.
Observation 2. It is clear that possibility 1 above does not completely explain the differences, particularly between the reference test and the 1998 test data taken with the same knives.
Observation 3. For the present set of tests, the test coils had been carefully selected to have similar surface characteristics, so we rule that out as a source of variation between tests taken at this time, but not between the reference test and the 1998 tests.
Observation 4. Stripping theory indicates that for the relatively small changes in knife gap and angle chosen for these tests, we should expect a consistent increase or decrease in stripping efficiency over the entire range of operation we tested. We should not expect these parameter changes to produce an increase in one part of the range and a decrease in another [Ellen, 1983], [Thornton, 1976].
Observation 5. If a systematic drift or trend in an unmeasured variable were affecting coating weight significantly during a test, we would expect to see some unusual patterns of variation due to the nature of our test sequence (see Fig. 2a-d above and Table 1 in the Appendix). Since we see no such anomalies, we conclude it is unlikely that systematic or random variations due to exogenous variables are significant in any one test.

Given the success of the model normalization at reconciling stripping behavior between data sets taken on the 1.5mm knives two years apart, we decided to apply the same sort of compensation on the data sets collected in the current experiments. We want to take pains here to point out several important points with respect to this decision:

1. Because we did not collect data on withdrawal flux with no stripping action, we have no basis for an *absolute* comparison between experiments.
2. However, by forcing two models to yield the same coating under common pressure and distance conditions of minimal wiping, we clarify the comparison of the *rates of change* of wiping efficiency as pressure is increased and distance decreased at a given speed.
3. Taking into account Observation 4 above, such a comparison is likely to more accurately reflect the underlying performance difference between knife configurations.
4. The most important remaining *caveat* is the possibility that unmeasured variations *during* a single test sufficiently distort the data to invalidate the comparison. We shall have more to say about this shortly.

Normalizing the 1.5mm and 1.7mm knife models to yield identical weights under minimal wiping conditions leads us to an entirely different conclusion than does the raw data, as illustrated by Fig. 8. Now we see that the coating weights produced by the 1.7 mm knives are generally higher than those which would have been produced by the 1.5 mm knives at the same pressure, distance, and line speed, and that the differences are particularly marked at the high pressure, low knife distance settings where we most need additional wiping capacity.

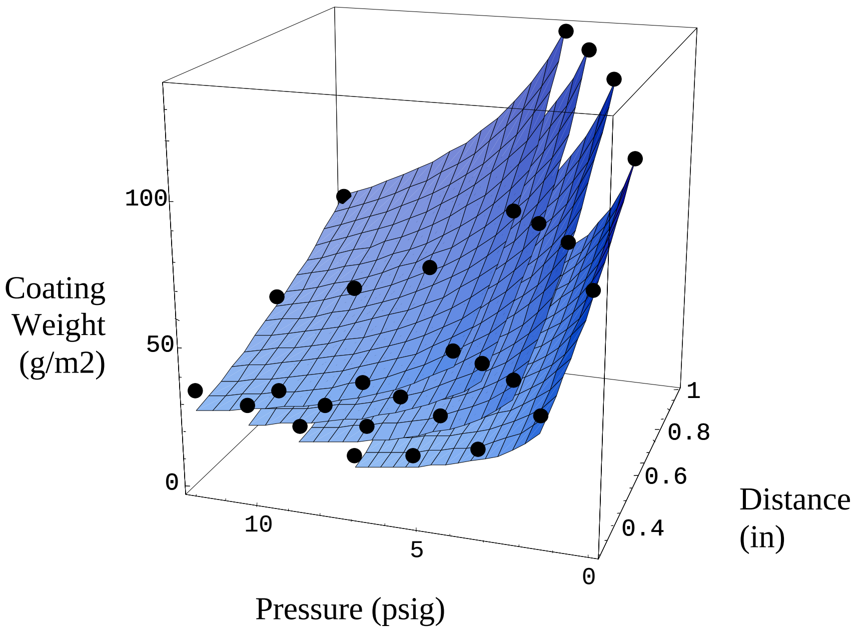

Fig. 8 – Coating Weights Measured with 1.7mm Flat Gap Knives (black dots)
Compared to Normalized Characteristics of 1.5mm Bowtie Gap Knives (surfaces)

<u>Strip Temperature: Adding to the Uncertainty</u>

The reference test with the 1.5mm knives was run according to the plan outlined in sections 2 and 3 and detailed in Table 1 in the Appendix. However, the test of the 1.7mm knives was run in the reverse order, proceeding from lowest speed to highest speed. Because the line had been stopped while the knives were changed, annealing furnace temperatures were noted to be unusually high at the beginning of this test, and during the test we observed that temperatures came down very slowly due to the slow strip speed and, therefore, low rate of thermal mass transfer on the front end of the test. Given this experience, we decided to run all remaining tests in the original order.

In comparisons of the models generated from the raw data from all experiments and their normalized versions, this particular set (the 1.7mm knives at 0° from horizontal) presents the greatest problems of interpretation. We believe that at least part of the difficulty may be due to an inconsistent progression of strip temperatures during this run when compared with other runs. In addition to convincing us that we must strive for greater consistency by running all tests in the same order, we have also come to the realization that we should strive for consistency in the timing between pressure, distance, and speed changes, and that we should monitor and record annealing furnace and/or strip temperatures during the test campaigns.

7. Evaluating the Effect of Knife Angle

Our test plan only had provisions for one change in angle. The 1.7mm knives were tested at 0° and at 1.5° from horizontal. As with the other tests, this involved a temporary shutdown to manually adjust the knife angle. Figure 9 compares the test point values for the 1.7mm knives set at –1.5° with the characteristic surfaces derived from the data taken from the same 1.7mm knives set at 0°.

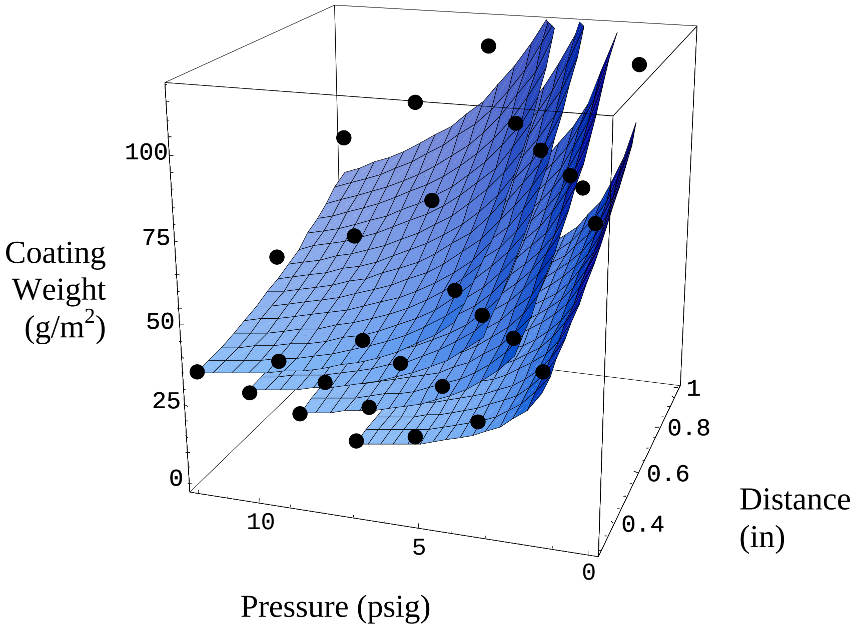

Fig. 9 – Test points (black dots) for 1.7mm knives at –1.5° angle compared to characteristic surfaces for the same knives at 0°.

Surprisingly, these results indicate that the coating weight increased nearly everwhere, though there appears to be little effect at high pressures and close knife distances where the knives should have maximum effect. Not only is this change in a counterintuitive direction, but the changes in coating weight seem unexpectedly large in regions where the knives should have least effect. One possible conclusion is that an extraneous variable, most likely strip temperature, could have affected either the withdrawal flux, the wiping efficiency, or both. Our normalization procedure could compensate for the former, but not the latter effect.

Figure 10 shows the results of applying the normalized model. Now the observed changes in coating weight are small over the entire range of operation, and the sign of these small changes is different in different regions. We believe that changes of this magnitude are as likely to have been due to other variables as they are to have been due to the angle change. Although the results did show a slight reduction in coating under maximum wiping conditions, we believe the results to be inconclusive and will reserve judgment until we can conduct additional tests including larger angles.

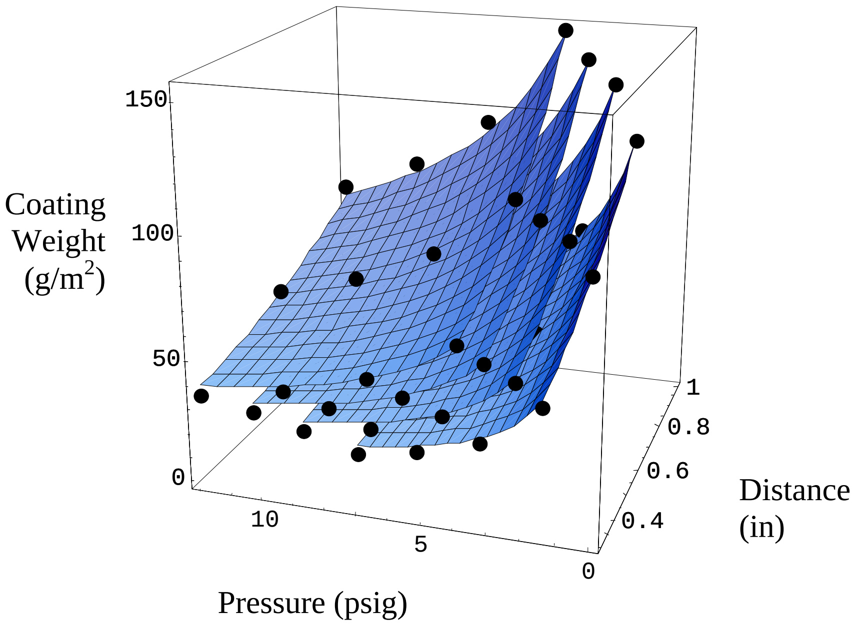

Fig. 10 – Test point coating weights for 1.7mm knives set at –1.5°, compared to normalized characteristic surfaces for the same knives at 0°.

8. Knife Gap Revisited

Because the increase in knife gap appeared to have had the opposite effect from that which was intended, we decided to schedule a second set of tests with a narrower gap to determine whether wiping efficiency would further increase and reinforce the results of the first test. We did not repeat a reference test on the 1.5mm knives, but to facilitate comparison to the previous run, we did test the 1.35mm gap at both 0° and –1.5° as before.

In the second series of tests the task force decided to modify the knife gap from the current 1.5mm bow-tie configuration to a 1.35mm flat profile. A series of test coils all being the same width, thickness and surface roughness were assembled. The test consisted of only two parts.

1. Change air knives to the 1.35 mm flat gap and run the test sequence.
2. Stop the line, adjust the 1.35 mm air knifes to a negative (down) 1.5 degrees and repeat the test sequence

Our experience from the first test also persuaded us that we needed to consistently change line speed in the originally prescribed sequence in an attempt to make strip temperature variations as consistent as possible from test to test.Figure 11 shows a comparison of the test results from the 1.35mm knives at a 0° angle to the characteristics of the original 1.5mm knives. In this raw comparison, the coating weight appears higher for low pressures and high knife distances, but unchanged or very slightly lower for close knife distances at lower line speeds. We reasoned that, once again, the differences at least knife effect could be due to other variables, and tried a comparison with normalized characteristics. In Fig. 12, we see that the normalized comparison indicates that the 1.35mm knives yield lower coating weights throughout the entire range of operation.

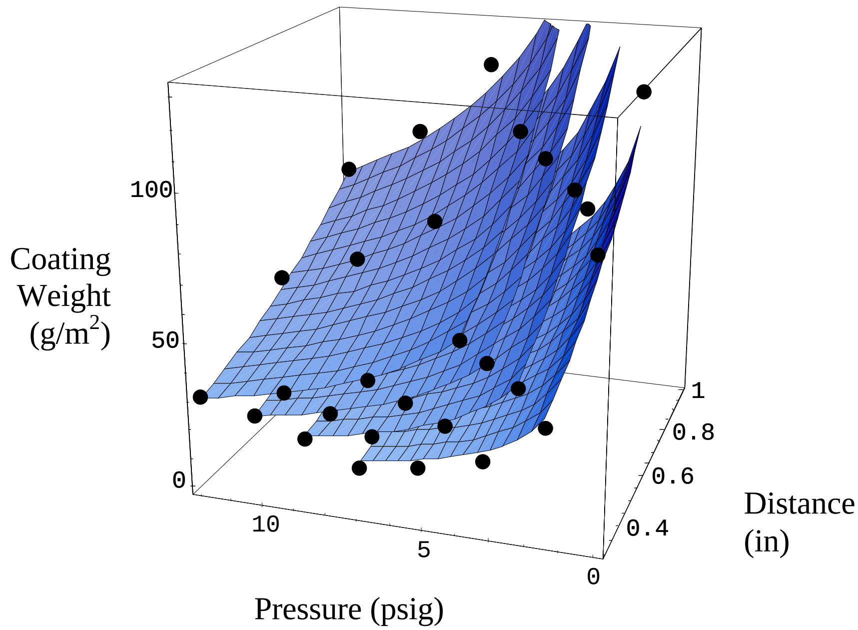

Fig. 11 – Raw comparison of test points (dots) for 1.35mm knives to characteristic surfaces for 1.5mm knives.

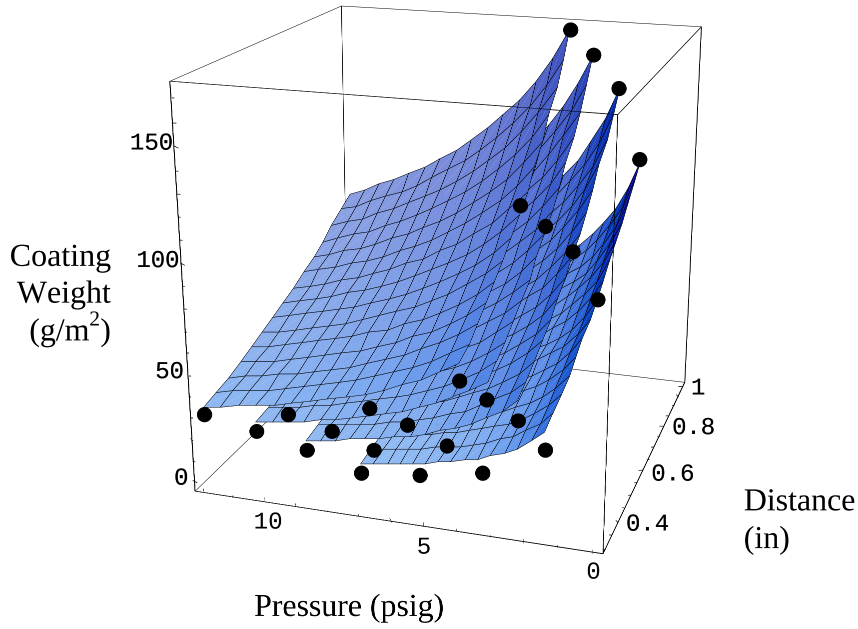

Fig. 12 – Test points for 1.35mm knives (dots) compared to Normalized characteristic surfaces for 1.5mm knives.

As we mentioned earlier, we also tested the 1.35mm knives at a –1.5° angle from horizontal. A raw comparison of the results from this test against the characteristics of the same knives set level is shown in Fig. 13. This comparison shows a large and counterintuitive increase in coating weight. Once again, we surmise that the difference is largely due to changes in raw withdrawal flux due to other factors. The normalized comparison is shown in Fig. 14. Although the coating weight still increases, the difference is slight, and, as with the 1.7mm knives we observe that such small differences could be due to many factors, and hold that these results are inconclusive.

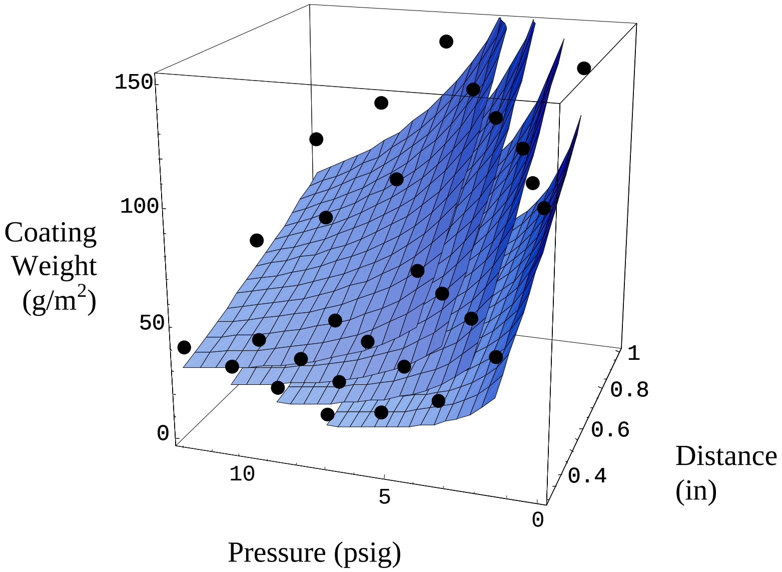

Fig. 13 –Test points for 1.35mm knives set at –1.5° compared to characteristic surfaces for the same knives at 0°.

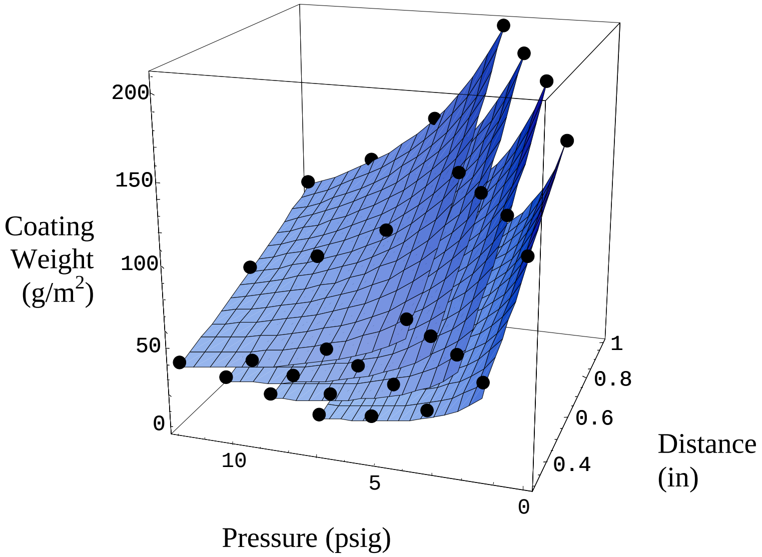

Fig. 14 – Test points for 1.35mm knives set at –1.5° compared to normalized characteristics of same knives at 0°.

9. Estimating the Benefits of Parameter Changes

Our objective was to determine whether production advantages could be gained by changing knife gap or angle without loss of quality and uniformity. In some cases, the limits imposed by wiping capacity are reflected in reduced line speeds. A useful way to look at the results, then, is to ask what increases in throughput could be expected to accompany a change in knife settings.

Once again, a coating weight model provides a valuable tool for making such projections. For example, if we wish to produce 40gsm coating on each side of the strip, and choose to operate the knives at a distance of 0.5 in from the strip and a pressure of 6 psig, we can use the models to derive operating curves for various knife settings at that pressure and distance. Figure 15 shows how coating weight is predicted to vary with line speed around this operating point for three of the knife settings we investigated.

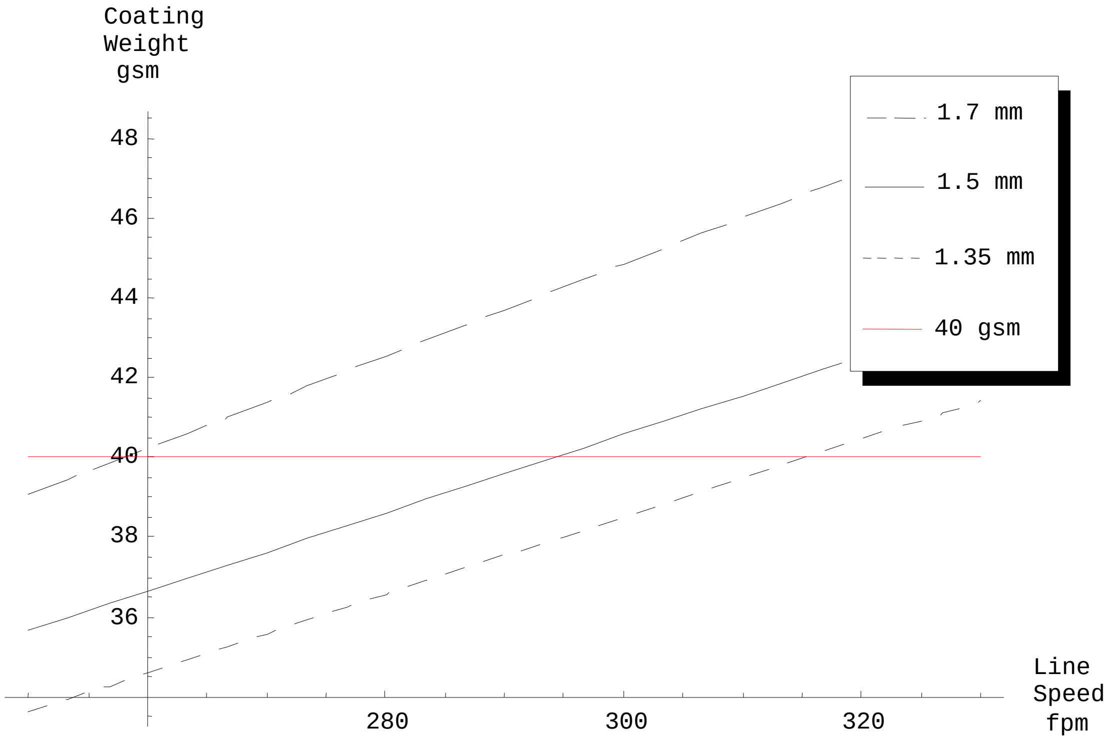

Fig. 15 – Coating Weight vs. Line Speed for three knife gaps at 6 psi pressure and 0.5 in distance.

According to this projection, the 1.7mm knives are would require running about 35 ft/min slower than the 1.5mm knives at this pressure and distance, whereas the 1.35mm knives would provide a 20 ft/min advantage. Of course, it is equally easy to project the necessary changes in pressure or knife distance to operate at a given line speed.

10. Conclusions

The results of these tests are far from conclusive. From what we have learned, we have been forced to view this as a work in progress. It is ironic that, in several cases, not only were the results counter to those expected from intuition, but applying normalization frequently reversed the conclusions. We believe that attempts to directly compare raw data from such tests without the insights provided by a model could easily lead to false conclusions.

Our normalization procedure involves adjusting the model derived from one experiment to match a model derived from another experiment at particular points – specifically the points of least knife effect as we used it in this paper. While we have demonstrated that this procedure is very effective in comparing results from experiments on the same knives taken at different times (and, most likely, different operating and strip conditions), and also (though not discussed here) that it is equally effective in resolving differences between the two sides of the strip due to, for example, passline offsets, it would be imprudent to conclude that the procedure is equally appropriate for comparisons between knife sets with different gaps or angle settings. Indeed, we recognize that small differences in wiping efficiency are quite likely have a large effect on the high coating weights experienced in the regions where the knives have minimum effect.

On the other hand, if we were able to sample raw withdrawal flux (at zero knife pressure) at one or more line speeds during each experiment, we believe we would be able to increase the reliability of the projections dramatically. As it stands, we consider our results to be tentative, but, nonetheless, to speak very favorably for the use of the coating weight model in this sort of experimental analysis.

We plan to conduct additional tests to clarify these results, and to take advantage of our improved knowledge by using it to continually refining our production quality and throughput.
One of the tangible benefits of this series of tests is that we were able to create a unique set of lookup tables for each set of test conditions. There are now five (5) separate tables for use with each corresponding knife configuration.

1. 1.5mm bowtie
2. 1.7mm flat
3. 1.7mm with -1.5 degree angle
4. 1.35mm flat
5. 1.35mm with -1.5 degree angle

As of the time of this writing we have not utilized any of the new knife configurations in production runs.

Some of the actions planned as a result of these tests are not directly related to the results of the air knife tests. Discussions with operators led us to look at the passline of the strip through the air knives. What we were able to determine is that the actual passline of the strip for certain steel grades is not as we would expect from theoretical calculations. On some thicker steel, especially at higher speeds, the bending forces in the strip overcome the applied tension and actually shift the passline through the air knives. This undetected shift causes a slight undercoat on one side of the strip and an overcoat on the other. A new coating weight control system scheduled for installation in the fall of 2001 will automatically adjust the air knives to compensate for such passline shifts by using the coating weight model to quantify their magnitude. In order to detect the changes before they reach the coating weight gauge, however, we also plan to measure this shift at the knife using CCD laser measurement technology. The detected shift will then be immediately compensated, thus increasing coating weight uniformity. Other actions will be to more closely watch the temperature of the strip coming into the pot. We have determined that strip temperature changes of only a few degrees can measurably change wiping characteristics. We have also noticed that different steel grades can react differently to temperature changes even when they have very similar strip roughness characteristics. We have, for instance, seen where increasing strip temperature increased wiping efficiency for some steel, while for some of our high strength products the opposite is true.

The irony here are that most of the changes that are being made or contemplated currently are not related to air knife gap or angle. This is primarily because of the conflicting indications given by the raw and normalized data and our desire to confirm our hypotheses with additional tests. Another factor was that we used a straight a straight knife to test, and we normally run a bowtie configuration. Because our tests measured only the center of the strip, we are not sure what effects this has on the edges.

Although the tests to date did not conclusively lead us one way or the other as far as knife angle or opening, this has been a valuable set of experiments for us. These tests made us aware of other issues involving our air knives, which were missed prior to the close scrutiny the air knives received during these tests. These tests also taught how to better conduct similar tests for future evaluation. Possibly the most valuable information from this work is that we now know what variables to address in future tests.

- Consider including at least one test point in each run with the blowers off so there is no wiping action.
- Perform all test sequences in the same order and with similar timing to help eliminate variation in (or at least duplicate) the furnace conditions.
- Make sure that the strip is centered in the knives using the coating weight feedback as the measure. Set the pressure and the distance equal and then move both knives in tandem to equalize the measured coating weights.
- Monitor strip temperature carefully and consider factoring it into the coating weight model.

We also recognize the need to develop tests to measure how coating weight is affected by surface roughness. We are particularly interested in how our coating weight models can employ roughness measurements to improve control accuracy and coating weight uniformity.

Perhaps what was most obvious is that gains in wiping efficiency will come in small increments from paying attention to small details that may have not gotten much attention in the past.

References

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APPENDIX

TABLE 1 - EXPANDED TEST COIL PROCEDURE

SAMPLE NUMBER	SPEED (FT/MIN)	DISTANCE (IN)	PRESSURE (PSIG)
1	500	0.3	4
2	500	0.3	6.7
3	500	0.3	9.3
4	500	0.3	12
5	500	0.65	12
6	500	0.65	9.3
7	500	0.65	6.7
8	500	0.65	4
9	500	1	4
10	500	1	6.7
11	500	1	9.3
12	500	1	12
13	375	1	10.3
14	375	1	7.9
15	375	1	5.6
16	375	1	3.2
17	375	0.65	3.2
18	375	0.65	5.6
19	375	0.65	7.9
20	375	0.65	10.3
21	375	0.3	10.3
22	375	0.3	7.9
23	375	0.3	5.6
24	375	0.3	3.2
25	250	0.3	2.3
26	250	0.3	4.4
27	250	0.3	6.6
28	250	0.3	8.9
29	250	0.65	8.7
30	250	0.65	6.6
31	250	0.65	4.4
32	250	0.65	2.3
33	250	1	2.3
34	250	1	4.4
35	250	1	6.6

36	250	1	8.7
37	125	1	7
38	125	1	5.2
39	125	1	3.3
40	125	1	1.5
41	125	0.65	1.5
42	125	0.65	3.3
43	125	0.65	5.2
44	125	0.65	7
45	125	0.3	7
46	125	0.3	5.2
47	125	0.3	3.3
48	125	0.3	1.5