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# The Effective Billet Heating Method for Ultimate Seamless Tube Size Control

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## ABSTRACT

In the competitive seamless tubing market a tight tolerance with a high yield can be achieved by starting with a uniformly heated billet. This paper presents a new method to control furnace temperature in order to produce billets with a uniform temperature distribution. The result is optimal control over tube size at no added cost.

## INTRODUCTION

The seamless tube making process consists of heating billets to a temperature of about 2000 $^0$F and then piercing them to create a seamless tube. In the piercing process the billet is pushed against a set of rotating piercing mill rolls. As soon as the rolls grip the billet, it is extruded over a fixed plug. The hot metal flows in the direction of least resistance. If the billet temperature is uniform, the tube is concentric. Alternatively, if the billet temperature is not uniform, the tube is eccentric. Eccentric tubes often result in an out-of-tolerance wall size. This paper explains a statistical technique to produce uniformly heated billets while controlling size and reducing mill tolerance at no extra cost.

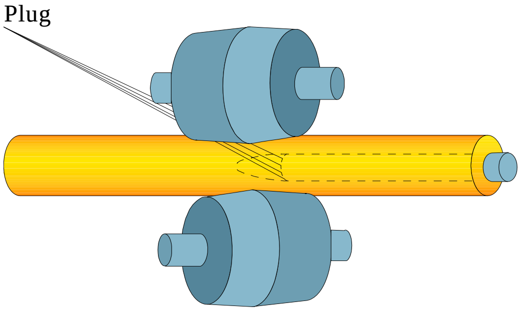


*Figure 1 2-Roll Piercing mill*

## CONVENTIONAL BILLET HEATING

Round billets are charged into one end of a continuous gas fired furnace and discharged from the other end after reaching aim temperature. The heating cycle can take anywhere from one hour to several hours depending mainly on the billet size and downstream delays. The furnace is divided into several heating zones. Each zone has an enthalpy target. For example, zone #1 enthalpy target of 50% is 1000 $^0$F when billet aim temperature is 2000 $^0$F. The last zone usually has an enthalpy of 100%.

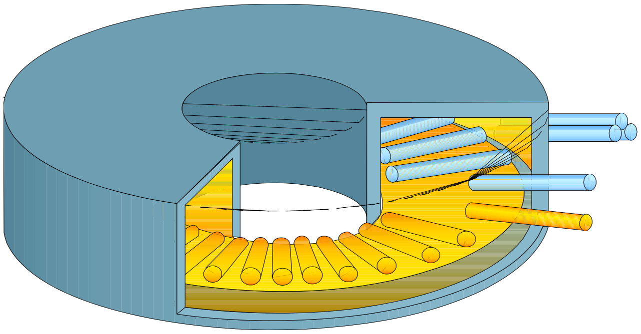


*Figure 2  Rotary billet heating furnace*

An online finite element (FE) heating model controls gas firing rates in each zone. The model tracks zone temperature where each billet sits as well as elapsed time under that temperature in order to compute billet temperature. The FE model also accounts for the space between billets and billet size. The billet's calculated temperature is compared to the target zone enthalpy. If billet temperature is below zone enthalpy, the model increases firing rate without overheating the billets. Consequently, if billet temperature is greater than zone enthalpy, the model reduces firing rate to avoid wasting energy and overheating billets.

Furnaces are slightly pressurized in order to reduce cold air infiltration. Cold air infiltration negatively affects billet temperature uniformity. Dampers are supposed to close as soon as furnace pressure drops to maintain a constant positive pressure. However, the short time it takes for dampers to close is significant enough to negatively impact temperature uniformity. Negative pressure occurs each time the charge or discharge door is opened, as well as when the furnace firing rate is low. FE models can not accurately account for furnace pressure dynamics. Therefore, the result is an unevenly heated billet. Piercing non-uniformly heated billets results in eccentric tubes. Eccentricity is measured using a gage in the downstream operation. If eccentricity is severe, the tube wall size can be out of tolerance. Out of tolerance tubes are often scrapped thus, resulting in the delay of customer orders.

## THE EFFECTIVE BILLET HEATING METHOD

A resolution 5 fractional factorial design of experiment with center points was conducted using JMP to understand the effect of furnace factors on eccentricity as measured in the post-piercing operation. The furnace factors were as follows...

1. Billet spacing (S): Billet spacing as measured at the smallest distance can be .25D where D is billet diameter. For example, S for an order of 10 inch billet size is 2.5 inches. High S reduces billet

shadowing that can improve uniformity. If S is too great, fewer billets can fit in the furnace and furnace heating time is reduced and heating uniformity deteriorates.

2. Zone #4 excess air (Z4 Air): Most gas fired zones are supposed to fire with about 5% of excess air for safety reasons. Excess air can reduce furnace pressure fluctuations and improve uniformity. Too much excess air can cause flame flickering and turbulence.

3. Zone #5 excess air (Z5 Air): same as above.

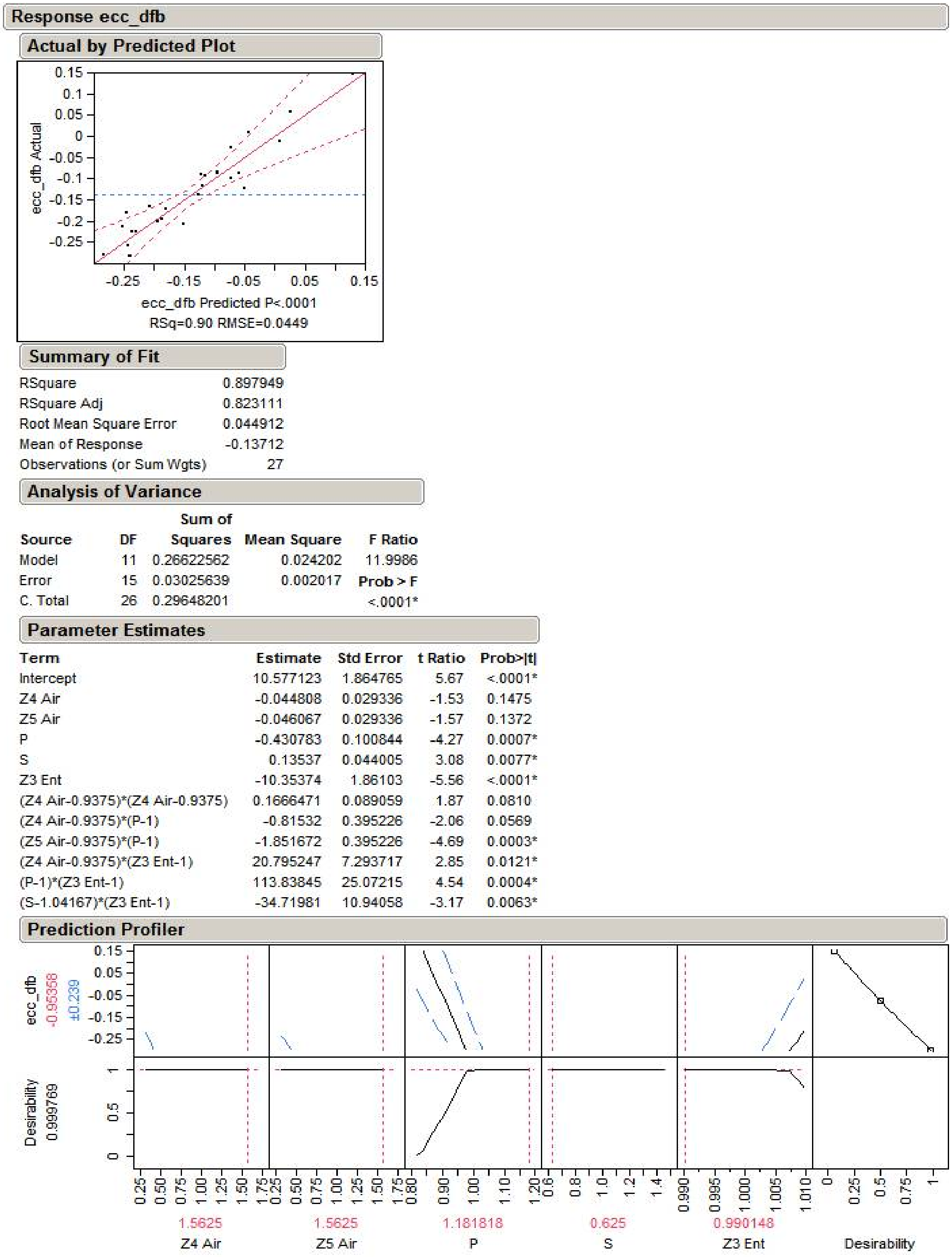
4. Zone #3 enthalpy (Z3 Ent): Z3 Ent is usually set at 100% to allow billets to soak in the last couple zones. However, since all burners are located above the billets, the top part of the billet is often discharged hotter than the bottom.

5. Furnace pressure (P): P is usually maintained thru a PLC controlled damper. Setting furnace pressure higher can cause high pressure fluctuations. A lower pressure setting can cause cold air infiltration.

The design region chosen was slightly above and below normal settings. The response variable was eccentricity deviation from before (ecc_dfb) for the same order. Several orders were processed at each design setting. The response was the difference between the new eccentricity for that order as compared to the tradiotional eccentricity for the same order heated under the conventional settings.

The first order model was significant. Model results show that lower eccentricity can be achieved with high S, high Z4 Air, high Z5 Air, high Z3 Ent and high P. However, since there was no evidence of Lack of Fit, the region did not contain an optimum.

Additional experimentation was conducted in order to determine the optimal settings for this process. The new design region chosen was in a higher setting. This time, the model had significant evidence of Lack of Fit in a region possibly containing an optimum. The second design was then augmented in an effort to estimate a second-order response surface. The augmented design is a Central Composite Design. The second-order response surface had no Lack of Fit. JMP estimated both the optimal eccentricity and the factor settings.



**Response ecc_dfb**

**Actual by Predicted Plot**

**Summary of Fit**

| | |
|---|---|
| RSquare | 0.897949 |
| RSquare Adj | 0.823111 |
| Root Mean Square Error | 0.044912 |
| Mean of Response | -0.13712 |
| Observations (or Sum Wgts) | 27 |

**Analysis of Variance**

| Source | DF | Sum of Squares | Mean Square | F Ratio |
|---|---|---|---|---|
| Model | 11 | 0.26622562 | 0.024202 | 11.9986 |
| Error | 15 | 0.03025639 | 0.002017 | Prob > F |
| C. Total | 26 | 0.29648201 | | <.0001* |

**Parameter Estimates**

| Term | Estimate | Std Error | t Ratio | Prob>\|t\| |
|---|---|---|---|---|
| Intercept | 10.577123 | 1.864765 | 5.67 | <.0001* |
| Z4 Air | -0.044808 | 0.029336 | -1.53 | 0.1475 |
| Z5 Air | -0.046067 | 0.029336 | -1.57 | 0.1372 |
| P | -0.430783 | 0.100844 | -4.27 | 0.0007* |
| S | 0.13537 | 0.044005 | 3.08 | 0.0077* |
| Z3 Ent | -10.35374 | 1.86103 | -5.56 | <.0001* |
| (Z4 Air-0.9375)*(Z4 Air-0.9375) | 0.1666471 | 0.089059 | 1.87 | 0.0810 |
| (Z4 Air-0.9375)*(P-1) | -0.81532 | 0.395226 | -2.06 | 0.0569 |
| (Z5 Air-0.9375)*(P-1) | -1.851672 | 0.395226 | -4.69 | 0.0003* |
| (Z4 Air-0.9375)*(Z3 Ent-1) | 20.795247 | 7.293717 | 2.85 | 0.0121* |
| (P-1)*(Z3 Ent-1) | 113.83845 | 25.07215 | 4.54 | 0.0004* |
| (S-1.04167)*(Z3 Ent-1) | -34.71981 | 10.94058 | -3.17 | 0.0063* |

**Prediction Profiler**

*Figure 3 Statistical analysis using JMP*

The new furnace settings were put into place as a 3-months temporary operating practice. Eccentricity was significantly reduced, but maintenance problems increased due to the higher furnace pressure setting. As a result, furnace pressure (P) was locked to 1 in the prediction profiler and new furnace settings were used.

**Prediction Profiler**

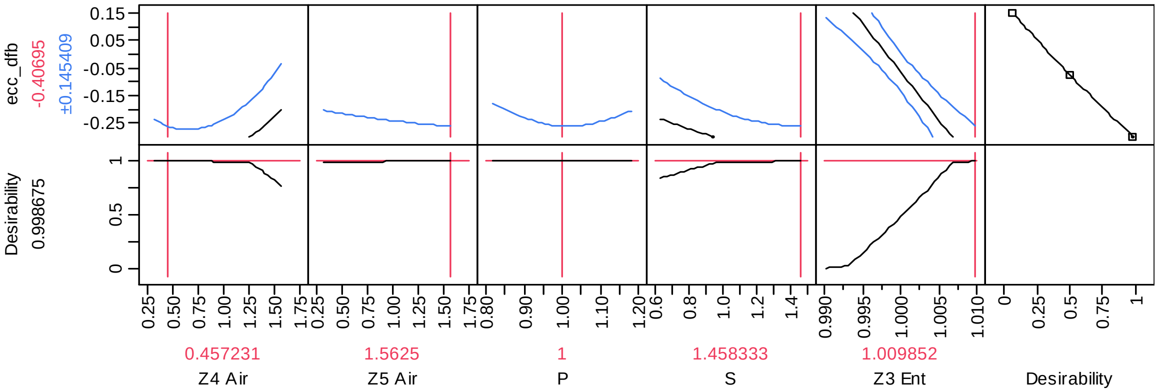


*Figure4 New furnace settings after locking pressure to 1*

Since the last furnace settings were changed, eccentricity has been at a record low. Tubes scrapped for wall size have been reduced by 45%. New orders with a tighter wall size tolerance were processed with success.

## CONCLUSION

A design of experiment using JMP was conducted to optimize furnace settings and achieve uniformly heated billets. Tube eccentricity was minimized, wall scarp was reduced and tubes with a tighter tolerance were successfully manufactured.