The Cumulative Sum Chart for Moisture Control in Lumber Drying

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Abstract

Monitoring the moisture content of lumber is an important part of the manufacturing process. Lumber that is too wet or too dry will have a lower value than properly dried lumber. The cumulative sum (CUSUM) chart is proposed as an alternative to traditional control charts for detecting small sustained changes in the mean charge moisture content of kiln-dried lumber. Charts are presented and interpreted for two kilns. The CUSUM chart readily detected changes in the mean moisture content that were not detected with an X-chart. For the CUSUM chart to work well, the process must be in a good state of control with the mill's average moisture content near the target moisture content.

Controlling the lumber drying process is important because overdrying results in increased warp, increased energy consumption, and less kiln throughput while underdrying results in lumber that does not meet grade requirements for moisture content.

Some mills use control charts to determine how consistent the drying is from batch to batch. These usually consist of a line of central tendency with upper and lower limits. An X-chart, for example, is designed to detect charges with mean moisture contents more than approximately 3 standard deviations (SD) from the mill's running average. When charge means are within the control limits, the process is in control. A charge mean outside the control limits indicates that the process is out of control and mill personnel should determine a cause. However, moisture content can drift seasonally or shift as new equipment or techniques are implemented. A small, sustained shift in moisture content might be far less than 3 SD and the process may appear to remain in control for a long time based only on the X-chart control limits. Run rules (Grant and Leavenworth 1988) can be applied to detect mean shifts, but these are more difficult for the operator to identify. Examples of run rules include a certain number of consecutive points above or below the mean and a trend of consecutively increasing or decreasing points.

The cumulative sum (CUSUM) chart is designed to better detect small, sustained changes in the process mean than an X-chart. The CUSUM chart can be set up to indicate when the mean charge moisture content is trending above or below the target moisture content or the average charge moisture content. In this article we have used the target moisture content. The difference between the charge and target moisture contents is converted to a z statistic and added to a total and plotted. The total starts at zero. If the lumber moisture content varies randomly around the target, then the total remains near zero. If the values are consistently above the target, the total gradually becomes more positive. Conversely, if the values are consistently low, the total becomes more negative. A control limit is exceeded if the total is far enough from zero.

The chart utilizes the z statistic:

$$z = \frac{(x - \bar{x})}{\sigma} \qquad (1)$$

where the target value is used instead of $\bar{x}$. Two lines are used in practice, one to detect mean increases (S_H) and the other for mean decreases (S_L):

$$S_{H_i} = \max[0, (z_i - k) + S_{H_{i-1}}] \qquad (2)$$

$$S_{L_i} = \min[0, (z_i - k) + S_{L_{i-1}}] \qquad (3)$$

where i is a sample and k is one-half of the mean shift that one wishes to detect (Ryan 2000). Typically k is chosen to be 0.5 (a unitless z value) to detect a 1 SD shift. A greater value of k is not used because an X-chart is capable of detecting large shifts in a process, whereas the CUSUM chart is used to detect small shifts. S_{H_i} and S_{L_i} are reset to zero after an out-of-control situation occurs and, presumably, corrective action has been taken. The control limits for the cumulative sum of the deviations from the target moisture content value are typically set to ±4 or ±5. Ryan (2000) presents a table indicating that a 1 SD shift in the process mean would typically be detected after eight to nine samples for control limits set at ±4 and after 17 samples for limits at ±5 (with $k = 0.5$). One does need to know the

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Forest Prod. J. 59(11/12):24–26.

charge-to-charge standard deviation of moisture content which may take 20 charges to determine or will already be known if X-charts are used.

Procedure

Data from a kiln drying western hemlock (*Tsuga heterophylla*) lumber (Mill 1) and a kiln drying southern pine (*Pinus* spp.) dimension lumber (Mill 2) are presented. The hemlock was 2 by 4 and 2 by 6 and the southern pine was 2 by 4 to 2 by 12. Units of lumber were identified at the kiln with either a barcode or an alphanumeric tag. This tag was read at the planer, the moisture content of each board in the unit was measured using an Apex in-line moisture meter (Wagner Electronic Products, Rogue River, Oregon) and the mean moisture content for each charge was calculated from the moisture content of each unit in the charge.

X-charts were constructed with the center line and control limits at 3 SD calculated based on the first 20 data points. An X-chart is used instead of an X-bar chart because of the large sample size (a 100% sample; Wadsworth et al. 2002).

The CUSUM charts are set to detect a 0.5 percent moisture content shift in the mean in each case. This means $k = 0.36$ for Mill 1 and $k = 0.56$ for Mill 2. These are in z units and calculated by dividing 0.5 percent by the process standard deviation. The charge-to-charge standard deviations were 1.4 and 0.9 percent, respectively. The control limits were selected to be ± 4.

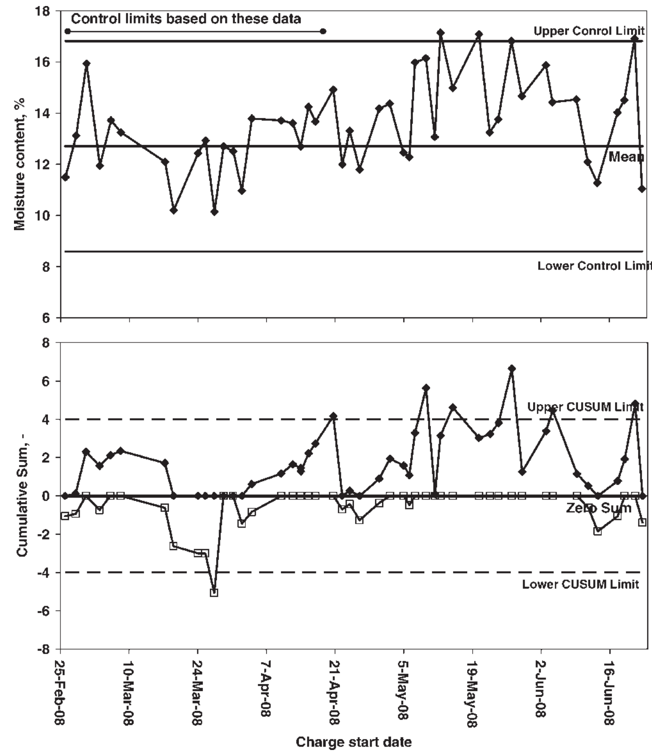

Figure 1.—X-chart (upper) and CUSUM chart (lower) for Mill 1.

Results

Examples of the CUSUM chart are shown in Figures 1 and 2 with the corresponding X-charts for the two mills.

For Mill 1, the mean of the first 20 points in Figure 1 is 12.7 percent. For convenience in interpreting the charts, the CUSUM target moisture content for this mill was also set to 12.7 percent even though the mill's desired moisture content is higher than this. The X-chart indicates that the kiln is in control from February to early May based on the control limits. Using run rules, seven consecutive points above or below the mean would indicate a likely shift in the mean using the X-chart. This does not occur prior to May. The CUSUM chart, in Figure 1, on the other hand, indicates a shift in the process mean by more than 0.5 percent moisture content in late March. Observation of the X-chart might suggest this will occur, but the X-chart does not alert the mill that the mean moisture content has shifted based on the associated statistically based rules. Similarly, the run of points above the mean from April 1 to 20 is in control on the X-chart, but the CUSUM chart readily detects the higher moisture content. In May, the CUSUM chart is continually going out of control and being reset because the charge moisture contents are much higher than the target. The CUSUM chart is redundant to the X-chart when this occurs.

For Mill 2, the mean of the first 20 points in Figure 1 is 17.3 percent. This is higher than what the mill wants, so the CUSUM target moisture content was set to 16.5 percent. This makes the two charts more difficult to compare. For example, the first point (17.1%) is below the mean (17.3%) on the X-chart, but the CUSUM ($0.32 = 0.88 - 0.56$) is greater than zero because the z statistic [$(17.3 - 16.5)/0.9 = 0.88$] is greater than k (0.56). For this mill the CUSUM chart indicates an out-of-control situation within the first five charges. The mean of these charges is 17.8 percent, 1.4 SD above the target. This is consistent with Ryan (2000) indicating that eight to nine samples are required for limits at ± 4 to detect a 1 SD shift. This also illustrates an advantage of using the process target rather than the process mean to develop the CUSUM chart. Use of the latter would

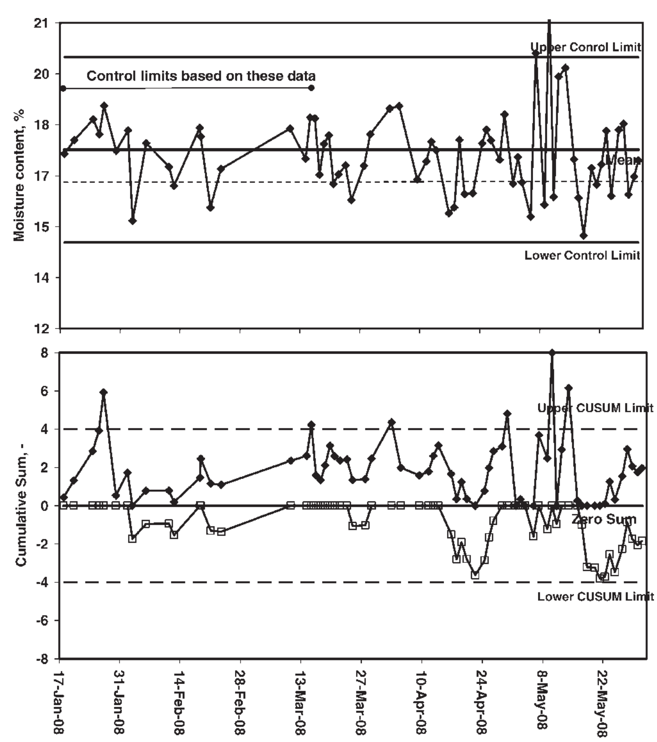

Figure 2.—X-chart (upper) and CUSUM chart (lower) for Mill 2. Dashed line on X-chart is desired moisture content.

have given a chart that was in control (the average of the process did not shift) even though the lumber was higher in moisture content than desired. In mid-March the mill's moisture content is again consistently high and triggers an out-of-control situation on the CUSUM chart that would be difficult to discern from the X-chart. Later, in May something changed in the process as readily detected by both charts.

Data were collected for other kilns but are not shown. In some cases, the mean moisture content at the other mills was not as stable as for the mills shown. This caused the CUSUM charts to be difficult to interpret. The X-chart is very satisfactory in these situations. The CUSUM chart should be thought of as a more advanced tool that can supplement the X-chart after a mill has fairly consistent final moisture contents from charge to charge.

Conclusions

The CUSUM chart is a good tool for detecting small changes in the mean moisture content of kiln-dried lumber that would take many charges to cause an X-chart to go out of control.

For the CUSUM chart to work well, the process must be in a good state of control with the mill's average moisture content near the target moisture content and only rare points outside the control limits. The CUSUM chart is difficult to interpret during periods when very wet or dry charges occur frequently. If a mill is drying to a consistent average moisture content based on an X-chart, a CUSUM chart is a tool that can help improve their consistency further due to its increased sensitivity to small but sustained shifts in mean moisture content.

Literature Cited

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