PRINCIPLES AND DEVICES FOR CONTROLLING THE DRYING OF LUMBER

Stewart Holmes
Drying Solutions[1]
Corvallis, Oregon

It seems like almost everyone either has a new controller for their lumber-drying operations or is thinking about getting one. In the July 1988 Forest Industries, in "A shoppers' guide to electronic kiln controls," I described some of the benefits likely to accrue to users of these machines. Those benefits include improved grade recovery, greater kiln productivity, better use of limited steam supplies, and improved management and control of all aspects of lumber production. All of these lead to a better competitive position in the industry. In the companion article "Kiln drying advances in Western Canada," Graham Mackay talked about similar advances in electronic kiln controllers in Canada.

In those articles we wrote in general about the principles, and about the characteristics of the controllers. We didn't describe them in detail.

In this article I'll describe those principles in detail and I'll describe how the controllers work that use those principles. I think this is important because only by understanding those principles and controllers will you be able to optimize your lumber-drying operations.

While this article was written with steam-heated kilns in mind, many of the principles still hold for direct-fired and dehumidification kilns.

Before starting I want to make clear an important distinction between controlling the drying of lumber in a dry kiln, and controlling conditions in a dry kiln. Until recently, when we talked about kiln control what we meant was control of kiln conditions, i.e., the temperature, humidity, and rate and direction of air flow. We monitored AND controlled the temperature and moisture content (MC) of the air in the kiln. We did NOT measure and control the temperature and MC of the lumber in the kiln. We might have guessed at those conditions but we had no way to measure them and to base control of drying o them.

That's changed recently, however, with the development of devices that allow you either to measure directly or to infer the MC of lumber during drying. That is in distinction to devices that only allow you to measure the condition of the kiln atmosphere. I'll reiterate that distinction in the discussion.

I'll describe the more common principles of control in use today as well as some others that appear promising. For each principle I'll describe what's involved, the advantages and disadvantages, and where the principle is or might be used.

DIRECT MEASUREMENT OF LUMBER MOISTURE CONTENT

These principles and devices measure the MC of lumber directly, based on the electrical or physical properties of the lumber.

Lumber MC Using Kiln Samples

Principle.--Ideally you want to subject lumber to different combinations

---

of temperature, humidity and air flow when the lumber is at different MCs. That's exactly what this principle allows you to do.

Moisture content is usually expressed as the (percentage) weight of water in lumber compared to the weight of the lumber without any water (the oven-dry weight). For example, 50% MC means that the weight of water in the lumber is 50% of the weight of the oven-dry wood. At 50% MC, a 15 pound board would have 5 pounds of water and 10 pounds of oven-dry wood. By knowing the weight of the lumber, and by being able to calculate the (approximate) weight of the oven-dry wood (which you can do using published specific gravity data) you can calculate the MC of that lumber.

To use this method you measure the MC of specially-prepared sample boards and use that information as the basis on which to manipulate kiln conditions. The sample boards are removed from the kiln periodically and weighed. When one or more of the samples reaches the next MC range, you change kiln conditions.

Advantages and disadvantages.--The main advantage is that kiln conditions are based on (the changing) lumber MC, which is what conditions should be based on. If the lumber has a low green MC you might start drying at a more advanced stage in the schedule. If the lumber has a high green MC you might adjust conditions so as not to subject the lumber to too severe conditions that might cause defects to occur. Or, if the lumber dries fast you can advance the kiln schedule sooner to take advantage of that, and vice versa.

You can use zone control with this method. If you know the MC of lumber in different zones or areas in the kiln, you can adjust conditions in the different zones to suit the drying needs of the lumber in those zones.

Another advantage is that kiln-sample MC usually determined by weight, which is a much more reliable measure than others, like electronic MC meters.

One disadvantage is that since you probably would only want to measure the MC of 10 or 15 samples in a load of perhaps 5000 to 10,000, your choice of samples could have very significant effects on the way the entire load of lumber was dried. If you happened to pick some pieces that had MCs greatly different from the average of the rest of the lumber, you could end up drying some of the lumber either too fast or too slow with potentially disastrous consequences.

Another disadvantage is that since this technique requires you to enter the kiln to remove, weigh and replace samples, it's not practical to use in high-temperature or high-production kilns.

Where used.--This principle has been in use longer than any of the others. It's the principle of choice for controlling the drying of high-valued lumber, especially lumber that has been air dried. You might use this method to dry a species or dimension with which you had little or no experience. This is the method used to develop most of the schedules you'll find in such books as the **Dry Kiln Operators' Manual** and **Dry Kiln Schedules for Commercial Woods**.

Lumber Weight

Principle.--This principle, like the kiln-sample one just described, also is based on weighing lumber. the difference is that you weigh a large part or all of the lumber continuously and without stopping the drying process. The weighing device can be located outside or inside the kiln. Lumber MC, as calculated from weight, would be used for real-time control of kiln conditions from the start to the finish of drying.

Advantages and disadvantages.--The main advantage is that weight is the most reliable and widely used basis for MC calculations. If you can weigh lumber you can calculate reliably its MC. If you can weigh most or all of the lumber you

can base control on most or all of the lumber.

This principle allows taking advantage of differences both in green lumber MCs and in drying rates. Regarding green lumber MCs: most of you may be aware of the differences in green lumber MCs that can result both from the logs (when they were cut and how and how long they were stored) to differences in the lengths of time the lumber was stickered and left to air dry before being charged into the kiln. These differences can be significant with regard to kiln conditions that should or could be used at startup.

Regarding different drying rates: every piece of lumber dries at a different rate. These differences could be detected if the lumber could be weighed continuously. If you (or an automatic controller) could know how fast the lumber was drying, you could change the conditions accordingly and thereby optimize control of drying. You could prevent slow drying pieces from drying too fast and you could cause fast-drying pieces to dry as fast as possible. The results would be high grade recovery and faster kiln throughput.

The disadvantage is that if you calculate MC based on the weight of all or a large part of the load, you will know only the average MC of all the pieces weighed. Most pieces will have a MC higher or lower than the average. Because of this, drying conditions for those pieces might be faster or slower than desireable. If there were large variations you would want to be careful when establishing schedules for that lumber.

Where used.--Weight was first used as the basis for automatic kiln control in the 1930's. More recently, at least two companies and several researchers have developed devices to be used in commercial kilns. None are currently in commercial use.

Despite that, many researchers and manufacturers agree that weight-based control is the one that holds the greatest promise for the industry. Weight could be the basis for single- or multiple-zone control and weight-based control could be used in new or old kilns in any state of repair.

Lumber MC Using a Capacitive-admittance Meter

Principle.--These devices measure the capacitive-admittance (electrical-energy storing) properties of the lumber load in the few courses above, to about two feet on either side of, and down to the tracks under the load. Sensors are thin strips of bare aluminum inserted like a sticker in a lumber load at about chest height. The amount of electrical energy stored in and passing through the lumber and stickers is different at different MCs and temperatures.

The sensors are connected to a meter in the kiln control room via an electrical cable. the meter provides an output that, with some experience, you can interpret in terms of MC. The meter provides an electrical signal that can be used to close steam valves and shut off the fans.

Advantages and disadvantages.--The advantages are that the aluminum strips are durable and only require cleaning of the electrical-lead contact area. The electrical signal can correlate closely to the MC especially at lower levels.

The disadvantages are that the electrodes measure not only the capacitive-admittance of the lumber load but also the stray capacitance ground return of everything else in the area. For that reason these meters have to be calibrated for each kiln, each location in the kiln, each species, each thickness, etc., and the aluminum strips should be placed in the same place every time to get reproducible results.

Also, it takes experience to learn to how to interpret the meter readings. The meters are accurate to about 1% MC in the range of 30% (the average fibers'

saturation point (FSP)) to 7% MC. They are not calibrated to read in MC. These devices can't presently be used for realtime (ongoing) kiln control.

Where used.--These meters are used widely by hardwood, and by some softwood, lumber producers.

Lumber MC Using an Electrical Conductance Meter

Principle.--You can determine the MC of lumber by trying to pass an electrical current between electrodes stuck in the lumber and measuring the flow. Free ions in lumber conduct electricity. Because these ions are usually found in water, wet lumber will conduct electricity better than dry lumber.

Conductance meters use nail-like electrodes usually inserted in the flat surface of specially selected boards about 1-1/4 inches apart. The boards are placed in the charge as it's being made up. After the load is charged into the kiln, the electrical leads are connected to the monitor via a junction box on the kiln wall. A voltage is established between the electrodes and the current is measured. This measure of MC is used as the basis for manipulating kiln conditions.

Advantages and disadvantages.--The main advantage is that these devices are accurate to about 1% MC in the range of 30% to 7% MC.

The main disadvantage is that conductance meters are limited to the 30% to 7% MC range. Since most lumber enters the dry kiln with a MC much greater than 30%, other provisions have to be made for control down to 30% MC. Above 30%, conductance meters may be able to provide a qualitative (for example, it's above 30% but less than 50% MC) measure of MC.

Another disadvantage is that the electrodes must be installed as a lumber package is being made up and removed before planing. During that time the electrode's leads are left inside the package. An electrode left in a board sent through a planer probably would do serious damage to the blades.

Measurements are species (different concentrations of ions) and temperature dependent so correction factors must be applied to all readings. This can either be done by the machine automatically or manually by the user with a lookup table.

Finally, because controllers allow measuring the MC of at most 16 boards in a kiln load that might contain 500 to 1000 times that many, you have to do a good job of picking the sample boards.

Where used.--These controllers have been used in Europe for decades, and in Eastern U.S. hardwood installations more recently, primarily for controlling the drying of air-dried and high-value lumber. With increasing frequency, conductance-based controllers are being installed in Western U.S., high-production softwood mills.

INDIRECT MEASUREMENT OF LUMBER MOISTURE CONTENT

These principles and devices infer the MC of lumber based on the physical properties of the kiln atmosphere.

Steam Flow to the Kiln

Principle.--Steam provides the heat and humidity needed to dry lumber. In most situations a lot of steam is required at the start to evaporate free water and water on or near the lumber's surface, to heat up the lumber and kiln building, and to heat up fresh, relatively cool air coming into the kiln to replace the hot, humid air being vented out. Smaller amounts of steam are required as drying proceeds since the lumber and kiln are hot and less air needs to be vented.

Steam use can be measured by various means (flow meters). For example, a number representing the amount of steam needed to evaporate a given quantity of water from a particular species and dimension, from one MC to another, in a particular kiln, at different times of the year, could be arrived at with experience. Given that information, it would be possible to match your knowledge of steam flow and kiln conditions to come up with an estimate of the current lumber's MC. In this way steam flow could be used as part of a real-time kiln control system.

Advantages and disadvantages.--The main advantage is that this principle is probably valid over almost the entire range of MC, that is, from the start to the finish of drying. Also, since steam flow could be measured either for the total system or for individual zones, multiple-zone control would be possible.

There are several disadvantages. First, while the physical principles are well understood, the variability in steam-use efficiency that exists among dry kilns in the real world would make kiln-to-kiln comparisons difficult or impossible in a practical sense. You would have to "calibrate" the use of steam by each of your kilns separately and use that information to program each kiln's controller separately.

Since only the total amount of steam flow to the kiln or to a zone would be known, control would be based on the average condition of the entire load, not individual boards. As with the lumber weight principle, pieces that dried significantly faster or slower than the average would represent potential inefficiencies or difficulties.

Since a large part of the steam used at the start of each drying run goes to heat the kiln building, evaporate surface moisture from rain or snow, heat frozen lumber, etc., corrections would have to be made for those factors.

Where used.--The number of mills in the Western U.S. using steam flow as part of their kiln control system is increasing. Although data are still scarce, measurements of steam flow show promise as a means of helping the operator determine such things as when the average fibers' saturation point and the desired final MC have been reached.

Temperature Drop Across the Load

Principle.--As air circulates through a load of lumber it gives up heat to the lumber. As a result, the temperature of the air leaving the load is lower than that entering the load. This difference is called the temperature drop across the load, TDAL or Delta T. Since wetter lumber will absorb more heat than drier, wetter lumber will produce greater Delta Ts. This relationship can be used to infer the lumber's MC. Delta T can be used in real-time control of kiln conditions from the start to the finish of drying.

Advantages and disadvantages.--The primary advantage is that Delta T is an inferential measure of the MC of a large part of the drying lumber load, not just a few pieces. That is, air-temperature sensors on the entering- and leaving-air sides of the load record the conditions in the large mass of air entering and leaving the load, not just the conditions around or in a few boards.

The disadvantage is that for Delta T to be a consistently valid basis for control, everything in and about the kiln has to be the same in every run. The control system's software is based on parameters like temperature, humidity, and the rate and direction of air flow, that have to be precisely and accurately measured and controlled at all times. That's probably only possible in a new or completely rebuilt kiln that's maintained in excellent working condition.

Where used.--Delta T has been used since the 1930's for lumber-drying and kiln control. In the past few years, several of the controller manufacturers have started using Delta T as their principle of control in both conventional- and high-temperature kilns. Delta T can be used for multiple-zone control because conditions in the separate zones can be detected separately.

MEASUREMENT OF KILN CONDITIONS

Time Versus Kiln Conditions

Principle.--This principle involves changing kiln conditions at given times usually regardless of the actual MC of the lumber. Every species, dimension and grade might have its own time-based schedule. Those schedules might differ from season to season, from one logging site to another, or for other reasons affecting log and lumber quality.

Advantages and disadvantages.--The main advantage is that "in principle" time-based schedules should be easy to use and to teach others to use. What could be easier than to run the kiln for 24 hours at one set of conditions, change to another set for another 24 hours, etc.?

The main disadvantage is that, in practice, it takes a lot of experience to use a time-based schedule effectively. This is because almost invariably something happens during a kiln run that forces you to alter the schedule at least a little. It's for that reason that you can't expect to be able to use someone else's schedule in your kilns without at least some experimentation.

Another disadvantage is that if you misjudge a kiln charge completely, perhaps because it's from an area very different from the ones your company has been buying logs from, you could ruin the entire charge by drying it too fast. Conversely, you could lose time and money by drying the lumber too slowly. Finally, if you have to dry a species and dimension with which you have no experience, for example, if the lumber is imported, you might not have a time-based schedule to use as a guide.

Where used.--There are time-based segments in almost every schedule, particularly if there are equalizing and conditioning periods. In general, however, this principle is used by operators:

A. Who are just learning and only have the time-based schedules left behind by the last operator, or

B. Who have enough experience with a particular species and dimension that they can estimate how long the lumber should dry at each of the schedule steps or conditions, or

C. Who are working with a species and dimension that's so easy to dry that it almost doesn't matter what conditions are used.

Probably most of you who dry lumber have or now use this control principle. You can get away with it because the drying character of most lumber is either so well known, or the lumber dries so easily, that this principle works just fine. But I think most of you could dry lumber faster and with a higher grade recovery if you switched to one of the other lumber-drying-control principles and strategies.

Air MC Using (Equilibrium) EMC Wafers

Principle.--Lumber, and other materials composed of wood fibers, will pick up or lose moisture to the surrounding air until the lumber's MC is in equilibrium with the air. The MC of the lumber in that state of equilibrium is called the equilibrium MC (EMC). [NOTE: The EMC is not equal to the relative humidity of the air.]

An EMC-wafer meter consists of a cellulose-fiber pad (like a piece of thick blotter paper) held between two aluminum electrodes. A voltage is established between the electrodes and the current through the pad is measured. As the kiln air MC increases, the fiber pad picks up moisture from the air, which increases the

conductance, and vice versa. The changing electrical output from these devices is used for real-time kiln control.

Advantages and disadvantages.--One objective of kiln control might be to regulate the MC of air surrounding the lumber so as to control surface drying to prevent undesirable stresses and defects from forming. EMC wafers measure air MC and thereby allow that sort of control.

One disadvantage is that the wafers may not respond quickly enough to drastic changes in kiln conditions that might occur if a piece of equipment malfunctions. That could allow lumber defects to occur before corrective action could be taken. Another is that, because the wafers and their electrical connections are exposed in the kiln, they are susceptible to all the corrosive and other electro-chemical effects that can take place leading to false indications of conditions. Finally, because the wafers are only about 1-inch square, they sense conditions in a very small part of the total kiln atmosphere. (This is a disadvantage shared with most electronic temperature sensors.)

Where used.--EMC-wafer meters are used with some of the conductance-MC-meter based kiln controllers.

PRINCIPLES AND DEVICES IN DEVELOPMENT

While the ways these principles could be used to measure or infer the MC of drying lumber are fairly well understood, what's not so clear is how they can be used in a commercial lumber-drying operation. That is, devices are not yet available that would make these principles commercially applicable for lumber-drying or kiln-conditions control.

Lumber Temperature

Principle.--Lumber cools both on the surface and in the interior as water evaporates from it. The amount of cooling is directly proportional to the amount of evaporation. The amount of evaporation depends on many things including the temperature and MC of the lumber and air. As a result, the surface and interior temperature of lumber could be used as an indicator of its surface and interior MC. In general, a low temperature would indicate a high MC, and vice versa.

Because lumber's surface dries out early in the drying period, control would only be based on measurements of internal temperatures. Even then, lumber temperature might only be used for end-point-MC determination.

Advantages and disadvantages.--The advantage is that temperature is something everyone understands and it's easy and cheap to measure. Electronic thermometers (RTDs and thermocouples) can withstand the harsh conditions inside a dry kiln and lumber.

Temperatures sensors share all the disadvantages of the nail-type MC meters. You have to install the thermometers before drying and remove them after. Since you only would sense conditions in perhaps 10 or 20 pieces in a load of 5000 to 8000, you must chose the samples carefully.

Where used.--Researchers have measured surface and internal temperatures of several species under a wide range of conditions to determine intermediate and end-point MCs. They showed the feasibility of determining at least the end-point in drying. At the moment, however, it appears that the extra knowledge gained from this measurement doesn't justify the extra work involved.

Fibers' Saturation Point Calculator/Detector

Principle.--This method is built around two elements: a conductance-MC meter and a computerized MC-extrapolation scheme. The MC meter detects MCs

at two or more locations through the thickness (for example, at the surface, at one-quarter, and at one-half way through the thickness) of a board and sends that information to the computer. The computer uses that information, plus information about the electrical-conducting and drying character of the lumber gained from experience, to predict MCs at some future time using an extrapolation scheme. The most important objective is to predict when the average FSP will be reached. The average FSP, especially at the lumber's surface, is important since it's at that MC that most shrinkage and defects start to occur.

Automatic controllers can use this principle to manipulate kiln conditions from relatively high MCs to the end of drying as described in the discussion of conductance MC meters.

Advantages and disadvantages.--The advantages are the same as those for conductance MC meters. A major advantage would be the increased range of possible, though less reliable, MC measurement.

Another advantage is the computer's ability to predict when the FSP will be reached. With many species and dimensions it might be possible to subject the lumber to relatively severe drying conditions as long as the MC, particularly at or near the surface, was above the FSP. Once the FSP is reached and the lumber starts to shrink, conditions can be made less severe. A controller that can predict when the FSP will be reached might be able to dry the lumber faster at the outset thus saving valuable time in each kiln run.

The disadvantages are the same as those for the conductance MC meters. The main one is that you have to carefully select the sample boards in order to prevent any or much lumber from being dried too fast or too much.

Where used.--This principle is currently used in at least one commercial controller and continues to be developed.

Acoustic Emissions from Lumber

Principle.--When lumber dries it shrinks. This causes the wood cells to pull apart from each other, forming little checks or splits. When a check forms it makes a noise, an acoustic emission (AE), that can be detected electronically with a device that acts like a stethoscope.

When lumber dries fast it shrinks fast and gives off lots of AEs, and vice versa. The number of AEs depends in part on the MC of the shell and core of each piece. By sensing the AEs it should be possible to determine about how fast the lumber is drying.

Control could be effected by sensing the AEs and manipulating kiln conditions to maintain the AEs within certain desired limits. For example, the AEs might be controlled based on their rate of occurrence or on their severity. Though control might be possible over the entire MC range, AEs might not become very evident until the surface MC approached the FSP, which could take time.

Advantages and disadvantages.--The advantage is that AEs are good indicators of something important in the drying process, especially in drying high-valued and check- and honeycomb-prone woods like oak. If you could determine upper limits on the number and/or severity of AEs that could occur before severe defects would result, you could manipulate drying conditions so as to prevent those defects. Your schedule might call for relatively severe drying conditions but, in response to upper limits on AEs, would change to less severe conditions when the number of AEs approached and exceeded the limits.

The major disadvantage is that not only is the lumber making noises across a wide frequency range when it's shrinking, but the lumber makes noises when it's rubbing and scraping against the stickers and against the kiln truck, the kiln load

and baffles make noises when they're scraping around, etc. All these noises occur at different frequencies, which could be sorted out, but they're still there and have to be dealt with.

Knots, grain deviations, and other "defects" in the lumber will cause the AEs to attenuate and change in other ways. It's not yet clear where on a board the sensor would have to be located nor how many sensors might be needed for a good estimate of what was happening in the board.

As with several of the other systems, you can't measure AEs from all the lumber so you have to rely on AEs detected in a carefully selected few boards. You must chose those pieces well in order to do a good job of control.

Finally, there's almost no information regarding how many AEs are too many? That information could be acquired only after a long period of data collection and analysis with each species, dimension, combination of shell and core MCs, etc. The number of combinations of factors is enormous.

Where used.--This method has been tried only in a limited number of trials in experimental kilns, though the results with red oak were impressive.

Speed of Sound in Lumber

Principle.--The speed at which sound travels through lumber varies in a consistent way with MC when that lumber has a relatively uniform MC and is at room temperature. (Sound in this case refers to a stress wave that's not necessarily audible.)

Sound travels faster in drier lumber. Therefore, sound will travel fastest in the outer layers of lumber where, under most drying conditions, the wood is driest. The effects become exaggerated at higher temperatures.

The speed of ultrasonic sound pulses through lumber could be used to estimate MC, on the basis of which drying could be controlled. Control presumably could be effected over the entire MC range, that is, from the start to the finish of drying.

Advantages and disadvantages.--The main advantage is the apparent ability to determine MC over it's entire range by using a variety of frequencies. Also, since sound travels faster in the outer layers of the lumber (shell), speed of sound measurements would allow controlling kiln conditions based on what was happening in that part of the lumber most likely to form defects due to too harsh drying conditions. This method would work for hardwoods and softwoods.

There are several apparent disadvantages, which, however, might not prove to be serious given more research and development. The method of coupling the sending and receiving instruments to the lumber could prove troublesome since the ends now must be cut off and (probably) varnished. The sensors would have to be installed and removed by skilled operators.

Much calibration work would have to be done for each species, dimension, and schedule type. The effects of MC variability within the lumber samples would have to be taken into account somehow or those pieces would have to be chosen and prepared carefully before being inserted in the package at the sticker-stacker machine.

Where used.--This method has been tried only in a limited number of trials in experimental kilns.

Strains on Lumber's Surface

Principles.--There are several ways to detect strains in a board's surface that could be related back to MC. Electronic strain gauges could be attached to the lumber's surface to indicate changes in shape, due to shrinkage and warp, during drying.

Strain gauges produce electronic outputs.

Brittle coatings on a board's surface would crack as the surface shrank and swelled. The cracks could be detected optically.

Photoelastic coatings would warp producing optically-detectable Moire patterns.

Grids of lines (like those in graph paper) on a board's surface would change with respect to one another with changes in surface size and shape. These too could be detected optically.

Changes in the size and shape of a board's surface would indicate changes in MC, especially below the FSP.

Advantages and disadvantages.--The advantage is that these systems would allow you to measure something significant in the drying process, which is the change in shape of, and thereby the development of stresses in, the lumber's surface. Shrinkage and warping stresses and strains in the surface are potential defects and could lead to the development of more serious defects like checks and splits.

CONCLUSION

In this article I described a number of principles on the basis of which you can control lumber drying conditions. These principles are used by devices of two types: those that directly or indirectly monitor the condition of the lumber and control drying conditions based on that information, and those that monitor only the condition of the kiln atmosphere and control drying conditions based on that. I discussed the more common principles and devices as well as some others that appear promising.

I think that if you understand these principles you'll be ale to get the most out of the controller you now depend on, and you'll be able to decide if another type of controller would better meet your needs and abilities.

While I've referred mostly to steam-heated kilns, most of the principles also pertain to direct-fired and dehumidification kiln control.

Readers wishing information about optimizing grade recovery, and about how to develop and use different production and human strategies based on the control equipment I just talked about, should refer to the article "**Lumber-drying-control equipment and strategies to help you optimize grade recovery**" in the July 1989 **Forest Industries**.