Before I describe in more detail the functioning of an automatic electronic kiln controller I would like to briefly recap some of the basic physical principles about lumber drying.

Since wood is a hygroscopic material it is necessary to apply energy in order to drive the water out of a board, to evaporate into the surrounding air and to carry this water vapor away and to the atmosphere.

Two factors are determining the rate of how fast the lumber will give up the water or in other words, how fast it will dry. One is the dry bulb temperature and the other one is the climate condition in the kiln.

To determine or to measure the climate condition in a kiln we have different possibilities.

One would be to measure the climate by a thermometer and hygrometer which indicates directly the relative humidity, and the other would be to measure the dry and wet bulb temperature which in turn could be translated into a certain relative humidity.

A third possibility would be, and this is the most practical for us lumber dryers, is to express the climate in the kiln in terms of equilibrium moisture content which is the wood moisture content a given piece of wood will achieve when it is exposed to a climate condition for a certain length of time.

A psychrometric chart shows the relation between dry and wet bulb temperatures, relative humidity, and EMC.

Using this known EMC we can define now the ratio between a piece of wood at a given moisture content and the moisture content it wants to achieve according to the climate condition.

This ratio MC/EMC is called the drying gradient. The larger the ratio will be the more severe the drying conditions are and the faster the lumber will dry if the drying process is supported by enough energy to evaporate the water, or in other words a high enough dry bulb temperature is maintained.

If this would be all that lumber drying is about I don't think we would be sitting here today because all that would mean is to crank the temperature up as high as possible and to open the vents up as much as possible.

The result of such a drying practice would certainly not please the management.

We all know that a charge of lumber will have to be dried according to a specific drying schedule.

A drying schedule shows the relationship between the moisture content of the lumber and the respective EMC and dry bulb temperature this specific wood could be dried at without causing any drying defects like case hardening, checking, discoloration and honeycombing.
The kiln operators have to determine the moisture content of the lumber in the kiln and set the controller according to the applicable drying schedule. Table 1 shows a typical drying schedule in a tabulated form.

| Moisture of Lumber, % | Dry Bulb °F | Wet Bulb °F | E.M.C. °C | E.M.C. % |
|----------------------|-------------|-------------|-----------|
| >40                  | 110         | 106         | 41        | 17.8     |
| 40                   | 110         | 105         | 40        | 15       |
| 35                   | 110         | 102         | 39        | 13.5     |
| 30                   | 120         | 109         | 41        | 9.5      |
| 25                   | 130         | 100         | 38        | 6        |
| 20                   | 140         | 90          | 32        | 2.5      |
| 15                   | 180         | 110         | 43        | 2        |

For maintaining the desired dry bulb temperature and climate condition a dry kiln is equipped with heat regulators, vent and spray regulators. They are controlled by a controller which is manually set according to a drying schedule and which receives the actual values for dry and wet bulb temperature by the means of dry and wet bulb sensors inside the kilns.

Depending on the type of controller the regulation of the actuators could be done in an on-off mode or modulating mode.

During drying the EMC is going down and the temperature is going up depending on the actual moisture content of the lumber in the kiln which is determined by oven-dry tests of sample boards.

Another type of controller is doing the changes of dry and wet bulb temperature through a set of camplates. This controller does not take into consideration the actual moisture content of the lumber in the kiln and is based only on a time-relation in which way the dry and wet bulb temperature will be changed depending on the specific lumber in the kiln.

The most significant difference between these described controllers and the Hildebrand 4006R controller lies in the fact that, by measuring continuously the moisture content of the wood inside the kiln, the lumber itself tells the controller which changes in dry bulb and EMC have to be made or in other words, which regulators have to be activated to follow a predetermined schedule to dry the lumber. Doing so, the EMC and dry bulb temperature are continuously changed by the rate the lumber is drying and the step curve for dry bulb temperature and EMC is changed into a continuous line, Figure 1.
In order to describe the functioning of the controller I am going to describe the measuring part, the programming and the regulating of the control separately before we follow through a complete drying cycle with this controller.

The controller receives three different signals from inside the kiln which are the dry bulb temperature, the EMC and the moisture content of the lumber.

All the sensors are located at one or two boxes which are fastened inside the kiln, and, in turn, are connected with the controller cabinet by the means of an armored cable and a plug.

The measuring of the dry bulb temperature is done by using a bi-metal thermocouple and the values are indicated at the controller.

The climate in the kiln is measured, and this is different from all other controllers, directly by the means of an EMC wafer. This is a little cellulose wafer which changes its electrical resistance very quickly according to different relative humidities inside the kiln. At the controller which could be up to 400' away, the measuring current is amplified and indicated in terms of EMC% at the respective instrument.

To measure the moisture content the controller can be equipped to read up to 10 probes located in the lumber and distributed throughout the kiln.

The moisture content is determined by measuring the electrical resistance between two brass or stainless steel pins inside the board. The readouts at the control panel are displayed at one meter which switches automatically from one probe to another. The readings are of course all temperature compensated and are automatically adjusted for different wood species.

Figure 2 shows the face of the controller 4004R and the meters I mentioned before are located here. The fourth indicator displays the drying gradient throughout the drying process.

As long as we have the picture of the controller, let me explain the other dials on the face plate.

- Heating up climate - 23
- Drying TG - 24
- Acceleration - 25
- Final moisture content - 29
- T₁ - 27
- T₂ - 28
- Conditioning - 26
- Clock - 12
- Selector switch for wood species - 5
- Timer - 11
- Selector switches for probes - 6
- Adjustment dial for EMC & MC - 7 and 8
- Manual switches for regulators - 19, 20, and 21

It consists basically of four integrated circuit plug in cards with 100% fully electronic components. Every card is kept as a spare part in our plant in Portland. Each card has defined responsibilities so it is possible to find out which card is wrong by the description of the malfunction over the telephone. In 90% of cases the problem can be solved by just exchanging one plug in card.
As we mentioned before the regulators could be operated in an on-off mode or as modulating control. With this controller the heat regulation as well as the vent regulation can be a fully proportional regulating system.

The position of the valve or vent is fed back to the controller by the means of a potentiometer which is located at the respective regulator.

Using this information together with the knowledge of how far the actual measured values in the kiln are off the desired set points at this specific point the controller computes the length of the impulses to either close or open the heat valve more or less or the vents respectively.

This feature proved to be a very efficient energy saver as a study, conducted by the University of Massachusetts, with several Hildebrand kilns located at the East Coast.

I think it is worthwhile to be mentioned that the regulators can be driven either electrically or pneumatically. In new installations we are using mostly electrically driven regulators but especially for refitting existing kilns with pneumatically driven regulators this additional possibility proved to be an advantage.

We are now in the position to start up our dry kiln. All of our probes are hooked up and we have made our settings for the drying schedule.

The controller divides the drying process into five different steps: heating up, warming through, drying, conditioning, and cooling.

During heating up the controller heats the kiln up to the preset temperature I. If this temperature is higher than 43°C (approximately 150°F), then the further heat-up will be done with heating and spraying interlocked. The controller gives priority to the desired EMC and opens the heat valve only when this EMC is reached in the kiln.

A clock is measuring the time the kiln stays at the wanted T₁ and heating up climate. When this time is over the controller switches over automatically into the drying stage.

The drying program is now determined by four settings:

1. TG
2. ΔTG
3. T₁
4. T₂

Above 34% MC a value of 34% MC is simulated, from 34%-27% TG and from 27%-8% TG plus ΔTG is effective by increasing the severity of the schedule. The temperature curve is determined by T₁-T₂.

The kiln operator has several options to interfere with the drying. With the selector switch he can decide if he wants to run the charge according to the wettest probe or if he wants to run according to the average of all probes. In addition to that he can select any one of the probes to be effective or not in computing the average.

The lumber is now drying down and eventually we are reaching the preset final moisture content.

The controller now switches over into conditioning for the predetermined length of time and will control the EMC which is wanted during this phase.
When the timer has timed out the cooling phase starts. The kiln will be gradually cooled down to approximately $2/3$ of $T_2$. Then everything will shut off automatically and the kiln is ready to be unloaded.

According to our experience with over 700 of these controllers in operation worldwide and 31 here in the United States, we would expect this lumber to come out of the kiln in a shorter time, with less energy being used to dry it and probably at a better quality.

Hoping that the last 30 minutes have explained to you the different ways and possibilities this new type of control equipment implies I would like to thank you very much for your attention.