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Operation of a Feedback Control, Communications Between Controls

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This essay is presented to give the designer and installer a better understanding of electronic feedback controls and their application. We will discuss the operation and logic of each control method and detail the requirements necessary for accurate and reliable control function.

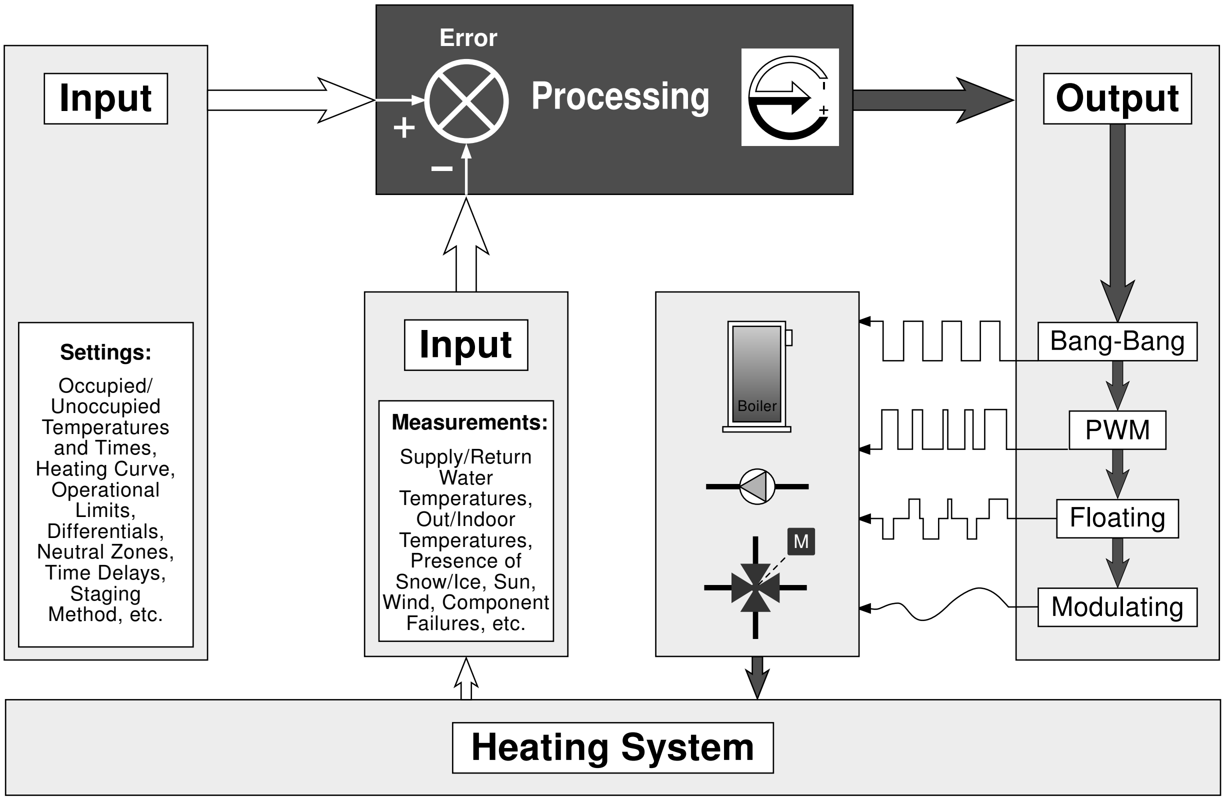

Fig. 1 **A block diagram of an electronic feedback control**

The operation of a typical electronic feedback control for an hydronic heating system is shown in figure 1. Initially, settings (inputs) are made to the control to allow it to calculate the desired temperature and to match its functions to the specific application chosen. The control reads the measurement (input) of the actual temperature, and calculates (processing) how much difference there is from the desired temperature. When the temperature is cooler than the desired temperature, this difference (error) tells the control to send a signal (output) which increases the heat delivered. This added heat makes the temperature being measured (feedback) warmer. As the temperature becomes warmer, the control continues to process the feedback information (input) until the error is so small (close to the desired temperature) that it becomes insignificant. When the control recognizes (processing) that this point has been reached, it sends a signal to reduce the heat delivered.

Inputs – *Settings*

Control settings are considered inputs because they determine what the desired temperature is to be, and how the control will operate a given number of measured inputs. The variety of possible control settings is almost endless, but the most common ones that are used in hydronic heating systems determine the desired temperature and include; the heating curve, domestic hot water setpoint and indoor air temperature settings. Other settings define control operation, such as time delays, occupied/unoccupied schedules, staging methods, zoning priorities, etc. Most control settings depend on the application being chosen and must be carefully selected before the control can properly operate a system. Careful consideration must be taken right from the start in the selection of a control to ensure that it will have all of the features and functions necessary to do the intended job.

Inputs – *Measurements*

It is necessary to have a method of measurement with a fine degree of resolution to accurately control temperatures in the comfort range. Better quality electronic controls and temperature sensors make this possible, and as these controls become more and more precise, it is very important that they receive the most accurate input information possible. This means that the control should be supplied with a very accurate thermistor or other measuring device, and the placement of that sensor should be in the location most closely representing the temperature that needs to be measured. Actual measured temperature inputs for a hydronic heating system may include the following: the supply water (supply sensor), the return water (return sensor), the outdoor air temperature (outdoor sensor), the indoor temperature (indoor sensor), and the domestic hot water temperature (DHW sensor). Other measured inputs for hydronic heating systems can include inputs from snow/ice sensors, wind sensors and sun sensors, and internal checks that detect faults like broken or shorted sensor wires within the control circuit itself. An electronic control constantly monitors these measurements and processes the information in reference to the settings that were made by the user.

Processing

As soon as the necessary measured inputs are given to the control, and the proper control setting inputs have been made, the processing of the information can begin. An example of a simple boiler reset control is used to illustrate this function.
Figure 2 shows how the desired supply water temperature is calculated for outdoor reset using a 1.0 heating curve. At an outdoor temperature of 10°F (-12°C), the desired supply water temperature will be 130°F (54°C). This calculation can be done using a graphic representation of a heating curve, as shown in figure 2, or electronically by the reset control.

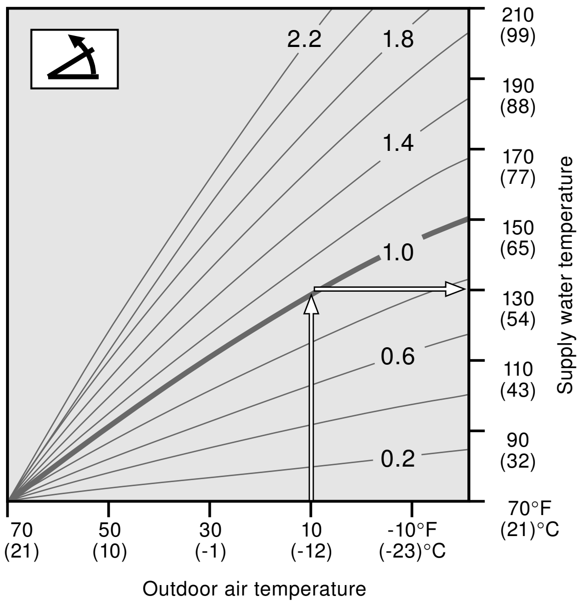

Fig. 2 **Heating Curve**

As the control processes the outdoor temperature measurement into a desired temperature, it also measures the actual temperature of the supply water and processes this information to make a comparison. The control determines whether the actual temperature is above or below the desired temperature, and then generates an output signal in an effort to reduce the error to zero. If, for example, our desired supply water temperature was 130°F (54°C), and our actual measured temperature was only 120°F (50°C), the control would recognize an error of 10°F (5°C). To bring that error back to zero, the control generates an output signal, increasing the heat delivered until the temperature rises to 130°F (54°C).

A simple setpoint control works in the same manner as a reset control, but having a single setpoint temperature eliminates the need to calculate the desired temperature. Because of this, the only measured input needed is the actual temperature, which makes the setpoint control the simplest type of feedback control.

Once the error from the desired temperature has been calculated, the information must be processed by the control. Proportional, Proportional + Integral and Proportional + Integral + Derivative processing are the three most common methods used.

Proportional (P) processing causes the actual controlled temperature to overshoot, undershoot and finally end up offset from the desired temperature, as shown in figure 3. For indoor temperatures, this poor control action usually results in inaccurate, fluctuating temperatures which can cause discomfort and inefficient system operation. Most mechanical thermostats in use today are P type controls.

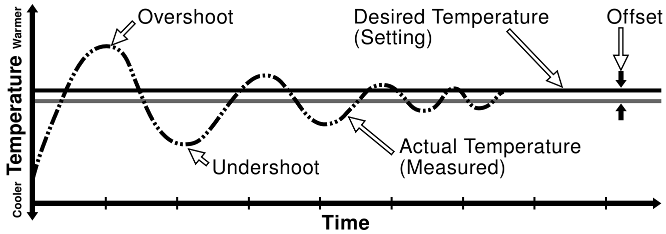

Fig. 3 **Proportional function**

Proportional + Integral (PI) processing can identify the amount of offset there is between the actual temperature and the desired temperature and adjust the control action to compensate. Figure 4 shows how this extra processing step results in more accurate temperature control. Most electronic controls are PI controls.

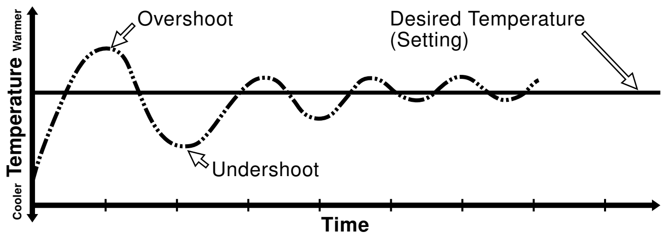

Fig. 4 **Proportional + Integral function**

Proportional + Integral + Derivative (PID) processing goes one step further than PI processing and minimizes the fluctuations above and below the desired temperature as well as the offset. Temperature swings above and below the desired temperature are most often a result of slow equipment response times. For example, when a control signals to a boiler that heat is needed, there is a delay and further water temperature drop before the boiler gets hot enough to heat the water. When the water finally gets hot enough, there is another delay while the boiler cools down, causing the water to overheat. As we can see in figure 5, the PID control action helps to compensate for delays, and the actual temperature is controlled more precisely. For most applications, PID processing gives better control than P or PI.

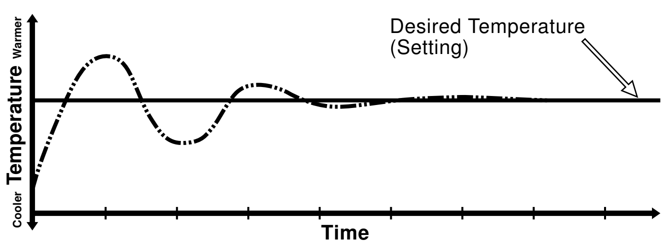

Fig. 5 **Proportional + Integral + Derivative function**

After the control has processed the error, an output signal is generated to operate the device that will change the temperature.

Outputs

There are four basic types of output signals commonly used in feedback controls.

- Bang-Bang (On/Off)
- Pulse Width Modulation, PWM (On/Off)
- Floating Action (On/Off)
- Modulating

Bang-Bang control outputs turn equipment on when there is a demand for heating or cooling, and then shut it completely off when the demand is satisfied.

In figure 6, we are representing the control action one would encounter in a typical gas fired boiler.

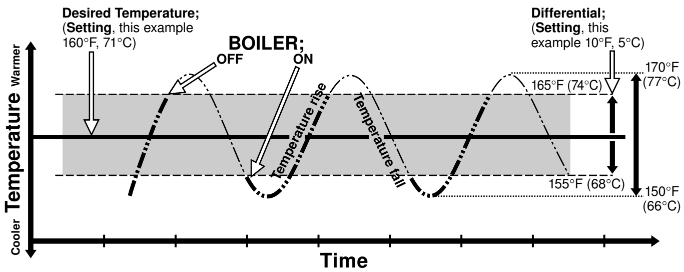

Fig. 6 **Bang-Bang (On/Off) function**

- The control fires the boiler at the desired temperature minus ½ the differential setting, and turns the boiler off at the setpoint plus ½ the differential setting.
- In this example, the setpoint is 160°F (71°C), and the differential is 10°F (6°C). The boiler will fire when the temperature drops to 155°F (68°C) and turn off when it rises to 165°F (74°C).

A common problem with bang-bang output control occurs when the temperature reaches the point where the boiler shuts off, but the water continues to be heated by the hot heat exchanger surface, refractory, residual products of combustion, etc. This extra heating causes the water temperature to overshoot the desired temperature as shown in figure 6. When the boiler turns off, the opposite happens, causing the water temperature to undershoot before the boiler can complete its startup sequence and come up to operating temperature.

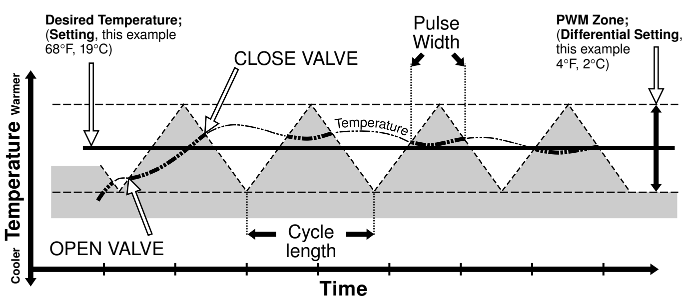

Fig. 7 **Pulse Width Modulation function**

The Pulse Width Modulation (PWM) control output is an on/off action, but differs from the simple bang-bang signal by changing the length of the "on" time based on how much the actual temperature differs from the desired temperature (size of the error). With the advance to PWM output, overshoot and undershoot is reduced by adding a quantity based function. The heating device is not simply operated "when" heat is needed but the operation is varied depending on "how much" heat is needed.

Figure 7 shows the PWM function operating a two way zone valve.

- The control generates a triangle wave (shaded area) centered on the desired temperature, and the actual temperature is compared against it.
- The width of the triangle wave determines the cycle length, and the valve will open and close once during each cycle length.
- When the indoor temperature (actual temperature) crosses the rising slope of the triangle wave, the valve is opened.
- When the actual temperature crosses the falling slope of the wave, the zone valve closes.
- The pulse width (total time the valve is open) is modulated depending on how far the actual indoor temperature deviates from the desired indoor temperature setting.
- If the actual indoor temperature equals the desired indoor temperature, the pulse width will be 50% of the cycle length.
- If the actual indoor temperature is above the desired temperature setting, the pulse width gives the valve a shorter period of on time, allowing the room to cool until it re-balances at the correct temperature.
- If the indoor temperature is cooler than the desired temperature setting, the pulse width will be wider, causing a longer cycle and more heat to be added to the system until it warms up the room.
- If the indoor temperature is so high or low that it goes past the boundaries of the triangle wave, the valve will be held open or shut all the time until the indoor temperature again approaches the range where the pulse width modulation occurs.

The PWM function is an excellent way to control indoor temperature since it is clear that PWM can control it with very little deviation, operating the valve on a regular duty cycle rather than waiting for the indoor temperature to drop down far enough for a simple bang-bang control to call for heat.

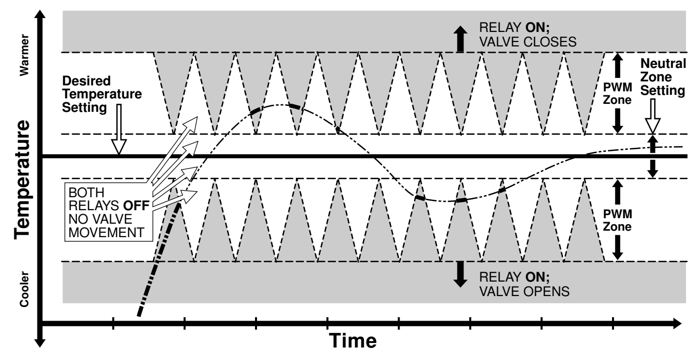

Fig. 8 **Floating function**

Floating action, using two PWM ranges to operate a mixing valve, is shown in figure 8.

- The control generates two triangle waves positioned equally on both sides of the desired temperature.
- The distance between the two waves is called the neutral zone and if the actual temperature is within this range, no relay is energized and the valve remains stationary.
- If the temperature increases enough to be affected by the top triangle wave, the pulse width signals will cause the valve to pulse closed until the temperature falls into the neutral zone.
- If the temperature falls far enough to be affected by the bottom triangle wave, the pulse width signals will cause the valve to pulse open until the heat increases enough to bring the temperature back into the range of the neutral zone once again.

With the use of floating output, we can virtually eliminate temperature swings because a steady amount of heat can be delivered under all load conditions.

Modulating output provides a signal which is directly proportional to the valve position required by the control. Since the valve position directly corresponds to the output signal, modulating output is in many ways the easiest control action to understand.

Figure 9 on the next page, illustrates the action of a modulating mixing valve controlling water temperature.

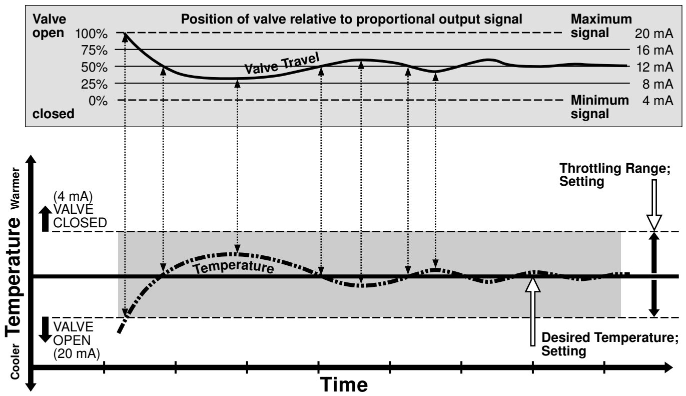

Fig. 9 **Modulating, 4 to 20 mA function**

- The control sends out a signal between 4 to 20 mA (milliamps).
- The amount of deviation from the desired temperature determines the signal strength, and the valve is positioned proportionally.
- The throttling range, is the amount of the temperature deviation needed to drive the valve from fully open to fully closed.
- The desired temperature is in the middle of the throttling range. When the actual temperature equals the desired temperature the control produces 12 mA which positions the valve 50% open.
- If the throttling range is set for 4°F (2°C) and the actual temperature drops 2°F (1°C) or more below the desired temperature, 20 mA is produced which positions the valve fully open.
- If the temperature rises, the signal from the control gradually becomes less making the valve gradually close until at 2°F (1°C) above the desired temperature, 4 mA is produced and the valve is positioned fully closed.

A modulating output results in a variable heat output and smooth response to a wide range of heating loads. Valve positions can be monitored by reading the mA output signal from the control.

Choosing the ideal control output depends on the equipment being operated and the application needs. PWM works well with zone control devices, but has limited use in boiler operation where short cycles can cause problems. Bang-Bang output may cause discomfort in indoor temperature control, but works well in boiler control where moderate temperature swings are not critical.

Communication between Feedback Controls

To obtain maximum energy savings and the most comfort from complex Heating/Cooling systems, it is important to use management controls that have the ability to communicate with each other.

Figure 10 shows stand-alone, separate function management controls that pass information back and forth to each other through a communication link. A communications center can add features like remote readouts, and external modem and communications connections. This is a very flexible system, allowing an almost unlimited combination of options. The primary management control functions are listed below the diagram.

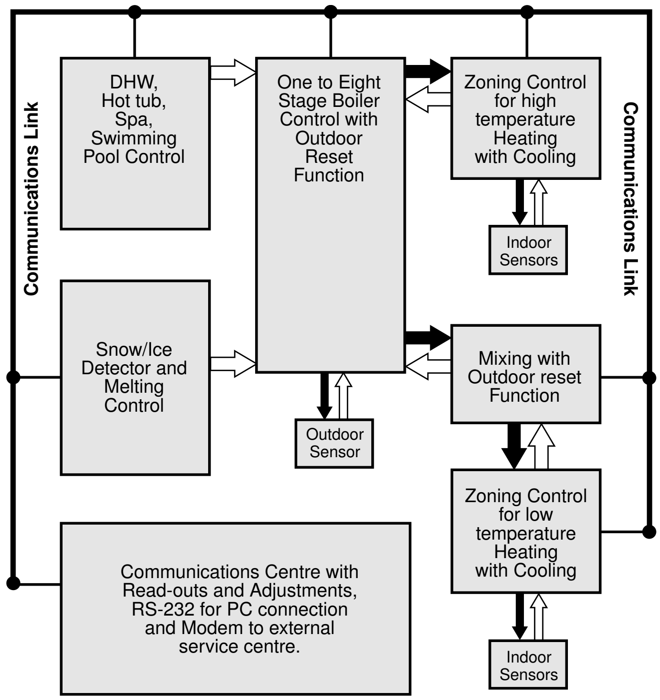

Fig. 10 **Communications between Management Controls**

- The Boiler control stages the boilers to maintain the supply water temperature required by the heating curve and/or feedback from other controls.
- The DHW control draws hot water from the system to heat the DHW, pool, spa, etc. to the setpoint temperatures.
- The Snow/Ice Melting control detects snow/ice and draws hot water from the system to provide heat for melting.
- The Mixing control mixes the high temperature system water down to low temperature requirements to maintain the supply temperature set on its heating curve or required by its zones.
- The Zoning control supplies heat to the high and low temperature zones on request from the individual zones. If a zone requests cooling, the heat for that zone is shut off and the cooling is switched on.
- The user has read-outs on the communication center to examine the operational status of the system, and can make minor adjustments on site or at a remote location.
- The total system is integrated to operate at peak efficiency and comfort levels. Conflicts between separate systems such as air conditioning and heating systems running simultaneously are eliminated.

For more information

The discussion of control operation and strategy in this essay can be a useful addition to the practical knowledge needed in the field, but cannot take the place of experience and practical training. For more information, refer to tekmar essay; E 002, Control Requirements of Hydronic Heating Systems.
Contact your tekmar agent or wholesaler.

tekmar® Control Systems

tekmar Control Systems Ltd., Canada
tekmar Control Systems, Inc., U.S.A.
Head Office: 5100 Silver Star Road
Vernon, B.C. Canada V1B 3K4
(250) 545-7749 Fax. (250) 545-0650
Web Site: www.tekmarcontrols.com