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Process control variables, instrumentation and automation of pelleting lines

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Many years ago, it was thought that running a pellet mill without human intervention was impossible. The proponents of this belief stated that a human needed to be at the pellet mill to hear and see the equipment run, as well as feel the product being made, in order to verify that it was properly conditioned. In the years since, much advancement has been made in monitoring the required conditions and controlling pellet mills with little human intervention. In fact, it has been shown that running a pellet mill automatically is more productive and energy efficient than manually via an operator.

The following chapter will provide the basis to understand and apply pellet mill automation. The many parameters that govern the operation of a pellet mill will be discussed first. After that, the instrumentation required to electrically sense and monitor the process variables will be introduced. With an understanding of the control parameters and how they are monitored electronically, the basic methods used to apply this instrumentation to automatically control a pellet mill will then be discussed. Finally, emerging trends and technology that will determine the direction of future systems will be shown.

Control variables

Pellet mills use a combination of compression, the heat generated by friction and the physical characteristics of the product being processed to form pellets. The variables monitored and processes controlled in the pellet mill have two purposes. The first purpose is to properly condition the incoming product to form a pellet with the desired characteristics. The second purpose is to properly control the pelleting equipment to enforce the interlocks between the related pieces of equipment, to maximize throughput and to prevent equipment damage.

Steam is the primary variable controlled to properly condition the incoming product. Steam adds heat and moisture. Heat and moisture activate the starches and other adhesives in the ingredients in the feed to bind the pellet together as it passes through the compression of the pellet mill die. The process holds or binds the ingredients together, and as the feed is cooled and dried, the softened materials harden in the pellet.

The amount of steam added to the feed is typically controlled by monitoring the temperature of the conditioned mash just before it enters the pellet mill die. A temperature set point is determined for each feed, and the steam valve is controlled by determining the difference between the set point and actual temperature and opening or closing the steam valve to maintain the desired temperature. The steam valve position is often monitored by the control system and used to set an initial valve position at the start of a production run.
The other primary control loop is the control of the

load on the pellet mill drive motor. This is controlled by monitoring the motor load, comparing it to a desired load and changing the pellet mill feeder speed to maintain the desired load. This motor load is also used to ensure the motor is not overloaded and to monitor for feed backing up in the die resulting in a plug condition.

The feeder speed is often monitored to determine the dry flow rate through the pellet mill. By determining the volume delivered by the feeder with each revolution, and knowing the density of the feed, the feed rate through the mill can be calculated. This is used to calculate the tonnes per hour (TPH) production rate. It is also used to control the addition of any liquids in the conditioner or at the die.

Various interlock devices are typically monitored by the control system. Devices such as the shear pin switch, door-closed switch, oil pressure, oil temperature and oil cooling fan are used to protect the mill from damage or premature wear. If the pellet mill is equipped with a die force feeder, the motor load on the force feeder is often monitored for a plug forming in the die. As feed backs up in the die, it causes an increase in the force feeder motor load. Often a die plug can be sensed and avoided before it requires the mill to be shut down and manually cleaned out.

The pellet mill cooler is also monitored to ensure it is properly cooling the pellets. It does no good to pellet a product if it is not being properly cooled. Typically, the temperature of the pellets exiting the cooler is measured and compared to the ambient air temperature around the cooler. The pellets are normally a little warmer than the ambient air, but if the temperature difference becomes too great, corrective measures must be made at the pellet mill.

Instrumentation

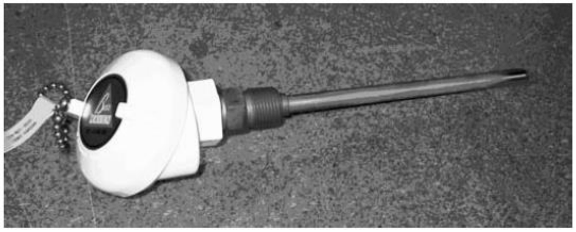
One of the key parameters measured in the pelleting process is temperature. Mash temperature entering the die, ambient air temperature and pellet temperature at the cooler discharge are just three examples. There are two common devices used to measure temperature electronically to produce a signal compatible with typical programmable logic controller (PLC) control systems.

The first device is a thermocouple. Thermocouples are simple devices that change their electrical resistance in direct proportion to the temperature of the sensor. Most PLC manufacturers make a thermocouple input module that accepts the signal generated by these devices and converts the signal to a temperature reading. Thermocouples have been in use for some time and are readily available. Since their resistance change with temperature is small, special thermocouple wire must be used to connect these devices with the wire being matched to the thermocouple.

The other method of measuring temperature electronically is with a resistance temperature detector (RTD) sensor. Like the thermocouple, the RTD changes resistance with temperature, but it does not require special wire to be used to connect it. RTD input modules are also readily available from PLC manufacturers. Any good-quality three-conductor shielded signal cable can be used to connect the RTD. The design of the RTD and devices that read its signal compensate for any resistance in the wire connecting the RTD.

Both thermocouples and RTDs are very small devices that are physically frail. In order to be inserted into a flow of mash or pellets, the devices must be protected physically. This is normally done by housing the sensor within a steel probe. The device is mounted inside the end of a small thin closed tube where it will sense the temperature of the tube wall. The material moving past the tube will cause the tube to reach the same temperature as the material. The sensor can then determine, though somewhat indirectly, the temperature of the material moving past the probe. The tube is mounted to a junction box where the probe leads are terminated for connection to the plant system. The probe typically has a threaded pipe concentrically mounted near the junction box to allow the whole device to be mounted in the proper position to be exposed to the material being monitored. A typical temperature probe is shown in **Figure 14-1**.

Figure 14-1. A typical temperature probe.



Temperature probes are normally tip sensitive because the actual sensor is mounted at the end of the probe. Proper positioning of the probe is necessary to ensure accurate readings are obtained. The tip of the probe should be in the center of the material flow being measured. The probe must also be rated for the area where it is used. Normally, feed mills are rated Class II Division II Group G areas. Therefore, temperature probes and other electrical devices should be rated NEMA 12 or NEMA 9 to meet the rating of the area.

Measuring motor loads

A common way of monitoring the pellet mill motor load is through a current transformer (CT), measuring the current flowing through one of the motor leads. Measuring the current in only one phase of the motor is usually an acceptable practice because in a typical three-phase system, the current is almost the same in all three phases of the motor. There are two fallacies with this method.

First, if the three-phase voltage becomes unbalanced, the current in each phase of the motor will also be unbalanced. This can cause an artificially high or low current in the monitored phase of the motor. The second fallacy with this method is that three-phase voltage fluctuations will cause current fluctuations in the motor. A motor consumes power, which is the product of voltage multiplied by current. If the voltage decreases, the current will increase to maintain the same power. Both of these situations can cause a current transformer monitoring a three-phase motor to produce false readings which the control system will interpret as a false change in motor load. A typical current transformer is shown in **Figure 14-2**.

Figure 14-2. A typical current transformer.

A better method of monitoring the pellet mill motor load is to use a three-phase power monitor. These devices monitor the current in all three motor leads and the voltage to the motor. It internally calculates the power consumption of the motor and outputs a signal to the control system that is a true representation of the motor load. These devices are not “fooled” by voltage fluctuations or unbalanced voltages.

Price often drives the choices made in a control system. Current transformers are inexpensive devices that provide a satisfactory signal under ideal circumstances. In other situations, a power monitor may be required to provide a reliable signal to the control system.

Controlling motor speeds

Controlling and determining feeder speed has been implemented many various ways in the past. The most common methodology used today to control speed is a variable frequency drive (VFD). A VFD takes the place of the feeder motor starter and changes speed by changing the frequency of the voltage going to the motor (see **Figure 14-3**). Despite early problems, VFD technology has become very stable and reliable for industrial users. VFDs commonly accept a variable voltage or variable current signal generated by most PLCs. This allows PLC-based control systems to control the speed of a motor quite easily.

Figure 14-3. Face view of a variable frequency drive.

If a motor is controlled by a VFD, determining the speed is very easy. Some VFDs have an "at speed" output signal that indicates when the motor is running at the speed set by the VFD, or they have a variable voltage (0-10 volts direct current, or VDC) or current (4-20 mA DC) signal that will change with the speed of the motor.

In previous years, when feeder speed was changed mechanically, speed was monitored by mounting a tach generator or a pulser disk on the feeder drive shaft. A tach generator outputs a 0-10 VDC signal in relation to the speed of the shaft. A pulse disk outputs a series of electrical pulses. The frequency of the pulses indicates the speed of the shaft. These methods were often less reliable than required, but can still be found installed on some machines.

Control valves

Control valves are used on pellet mills to control steam and liquid flows. These valves come in many types and mechanical arrangements. From a control system aspect, the major considerations are the signals that control the valve and indicate its status and position and what its flow characteristics are. Valves used in the past often had bi-directional motors that either drove the valve open or closed. The control system would pulse, or jog, the valve open or closed to control the steam or liquid flow rate. These valves were sometimes equipped with a position feedback potentiometer that would provide a voltage relative to the valve's position.

Without a feedback potentiometer, the control system could only pulse the valve and watch the resultant variable such as a liquid flow or product temperature. This limited the control system's ability to make corrections quickly and accurately. The addition of a feedback potentiometer allowed the control system to determine position of the valve and then make faster, more accurate corrections.

Valves of newer design usually have a position control built into the valve. The control system outputs an analog signal (0-10 VDC, 4-20 mA, etc.) that represents the desired valve position. The control built into the valve will set the valve to that position and "follow" the signal from the PLC as it changes over time.

Some control valve designs, such as ball valves, are mechanically non-linear. This increases the difficulty for the control system to predict the required valve position. Valves that are linear allow the control system to provide more accurate control with a faster response time.

Other signals

The interlock signals from other devices on the pellet mill can either be discrete (on or off) or analog signals. The control system must have inputs matching their individual signal levels to read these devices. Shear pin and door switches are examples of discrete devices. For discrete devices, the device output voltage must match the PLC input voltage and type. Care must be taken not to mix direct current (DC) devices with alternating current (AC) devices.

Analog signals are continuous electrical signals that vary with time to represent current conditions. Analog signals that are compatible with most PLCs are 0-10 VDC, 1-5 VDC and 4-20 mA DC. As with discrete devices, the signal output by each device must be matched to the appropriate PLC input. Oil pressure, motor load and temperature are examples of analog signals.

Signal conversion

All of the sensors and controllers connected to the control system use electrical signals to represent a physical condition. As such, proper conversion of the electrical signals into the proper units representing these conditions is vital. For discrete (on or off) signals, the control system converts these signals to either a one or zero representing on or off. The control program uses the ones or zeros to represent the various states of these sensors in the program logic.

Converting analog signals for use in the control program is more complex. Analog signals represent some value, such as temperature or pressure that quantitatively changes with time. An analog signal representing a motor load may be generated by a device that generates a signal ranging from 0-10 VDC. As an example, from a specific sensor's characteristics, it may be known that 0 VDC represents 0 amps in the motor and a signal of 10 VDC represents 500 amps motor load. So the first consideration in selecting a sensor is to choose a device with the proper sensing range for what is being measured and an output signal that is compatible with the control system. The analog input on the control system will take the signal from the sensor and convert it to a number. The number of times per second that the conversion is made and the accuracy of the conversion are important considerations when matching sensors and control systems. The number generated by the analog to digital conversion process must then be scaled to another number representing the real value being measured.

As an example, a motor load sensor generates a 0-10 VDC signal in proportion to a motor load ranging from 0-500 amps. The control system analog input converts the 0-10 VDC signal into a number ranging from 0-10,000. A mathematical equation must be applied to this number to convert it to correspond to the true motor load. In this case, the number must be divided by 20 to convert it so that the value inside the control system corresponds to the real amperage of the motor. The accuracy and conversion rate will determine how closely the value inside the controller matches the real value. This process is commonly referred to as scaling or calibrating the control system.

These considerations must be applied to all analog signals used in a control system. The selection of sensors with the proper type, range and accuracy are vital parts of designing a control system. Proper conversion and scaling of values to represent the real world are the difference between a successful automation system and a disaster.

Automation methodology

Now that all of the field devices are connected to the control system, the control system can determine what is going on and control the equipment. The control system itself will be examined next.

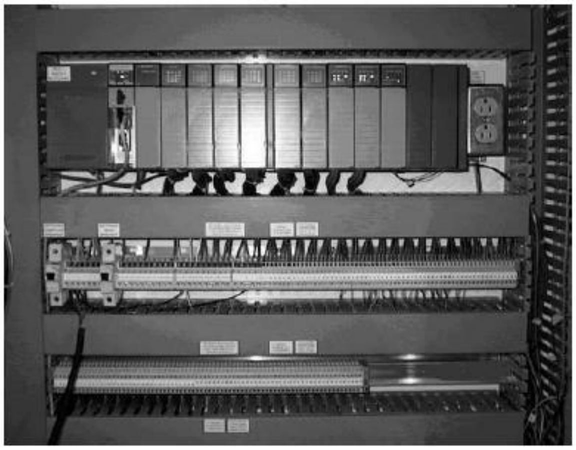
Control system technology has changed rapidly over the recent past. Originally, small computers were used and interfaced to the "real world" to control pellet systems. Cost, reliability and longevity were issues with these systems. Approximately thirty years ago, a new device called a programmable logic controller (PLC) came on the scene in the automotive industry. It solved most of the problems inherent to the computer-based systems. Even though a PLC is technically a computer, it has been designed from its very inception for control systems. PLCs are rugged enough to withstand the temperatures, dirt and electrical noise in a typical factory. Their internal operating system and programming methods are designed specifically for control systems. Instead of adapting a computer designed for computations to perform process control, the PLC is a computer designed for process control systems. It is no wonder that in the last thirty years the PLC has taken over as the overwhelmingly preferred choice for process control systems.

Because of its popularity and widespread use, only PLC-based pellet mill control systems will be discussed in this chapter. Control systems based on other technology are typically older systems nearing the end of their lifetime or are aberrations from the normal systems found today. The full scope of how a PLC-based control system is designed is a larger study and only the required basics relating to pellet mill control systems will be presented here.

A PLC is a modular system that can be assembled to meet the requirements of the equipment controlled. The most basic part of a PLC is the rack which holds the various modules and allows them to communicate with one another over a communications buss built into the rack. A power supply provides regulated, filtered DC power in the rack to power all the modules plugged into the rack. A central processor unit (CPU) contains the control program that governs system operations. The other modules that plug into the rack are typically either input or output modules. Input modules accept signals from field devices, convert the signals and pass them to the CPU. Output modules send signals to field devices to control the equipment connected to the PLC. Input and output modules are of two types—either digital or analog. The differences between digital and analog have been explained previously. In summary, the PLC CPU recognizes the conditions in the pellet mill system through input signals received through its input modules and controls the equipment through its output modules.

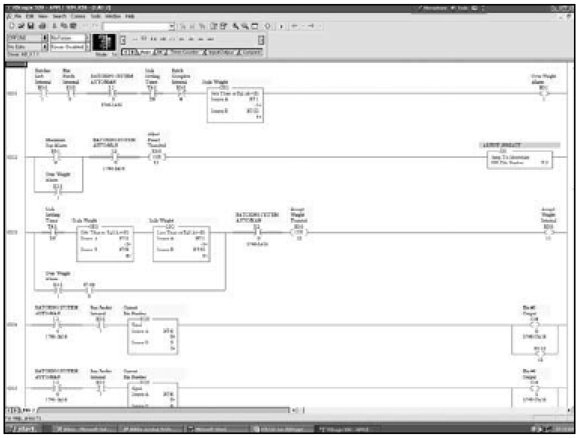
A typical PLC installed inside a control panel is shown in **Figure 14-4**. The CPU module is seen in the left-most slot with the various input and output modules shown to the right of the CPU. The input/output (IO) modules are pre-wired to terminal blocks mounted below the PLC for the connection of the field wiring.

Figure 14-4. A typical PLC installed inside a control panel.



The control program in the PLC determines how the system operates. Typically, a PLC program is called relay ladder logic (RLL). RLL is a graphical language that looks like an electrical schematic. An example is shown in **Figure 14-5**. Like the PLC itself, RLL was designed specifically for machine control. The PLC solves the program from the first statement to the last in a cyclical pattern called a scan. The scan time is the time required for one complete pass through the program. As the program is executed, the CPU reads the inputs, solves the logic in each statement of the program and changes outputs in accordance with the program instructions or logic. The scan time determines the minimum response time the control system will have. The shorter the scan time, the faster the system will respond to changes and control the system.

Figure 14-5. An example of relay ladder logic in use.



While the PLC controls the pellet mill and handles the real-time process of running the equipment, there is still a need to display the status of the system, allow the operators to make changes, load set points into the process and record data from the pellet mill. All of these functions are best handled by a personal computer (PC) running software designed for this purpose. The most common way to display the status of the pellet mill is through a graphical representation of the pellet mill equipment on the PC screen. This provides the operator with an overall system status with one look at the screen. More information can be provided by allowing the operator to select a piece of equipment to display more details. This "drill down" methodology allows the operator to see the whole system at once or display any level of detail required.

The control parameters for each pellet run are typically stored in a database and organized by formula number. When the operator starts a pellet run, the formula to be pelleted is selected from the list of stored formulas. The PC software then downloads the parameters to the PLC to properly control the pelleting of that formula. The operator starts the run through the PC, which passes the run signal to the PLC. The PLC starts up the equipment per the control program and downloaded parameters. As the run progresses, the PLC controls the steam valve, feeder speed, etc., to pellet the feed. The PC monitors the PLC and displays the pertinent information on the screen. Various parameters are recorded as the run progresses and at the end of the run these values are written into a database to create a production record for that pellet run.

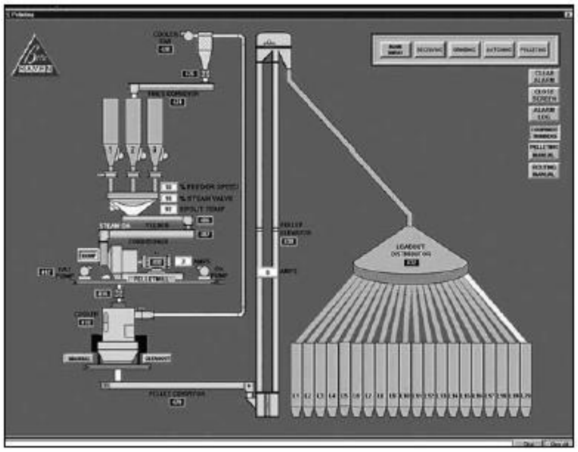
The automation system should be able to start up the pellet mill equipment at the beginning of a run, control the feeder speed and the steam valves to get the pellet mill to optimum production within a short time, and shut down the equipment at the end of the run. The system should monitor the pellet mill to determine when a die plug is forming and be able to take corrective measures automatically to clear the plug and get the mill back into production. The reaction time of a PLC-based system is often fast enough to avoid many plugs and keep the mill running at a higher production rate than a human operator could.

Some systems have a challenge feature that allows the control system to find the maximum production rate automatically. A challenge feature will usually bring the mill to full production as specified by the preset parameters. After a set period of time running at a stable rate, the control system will increase the production rate and then monitor the reaction of the pellet mill. If the mill does not plug, the control system will again increase the production rate after a set time. Once the production rate increase causes a plug to start forming, the control system will reduce the rate and wait for a set period of time before challenging the mill again. Challenge features work best on smaller mills where reaction times are faster. The larger the pellet mill, the more problem is caused if a challenge step plugs the mill to the point where the operator must shut it down and clean it out.

The typical parameters recorded during a run are total tonnes produced, total liquids applied, total kilowatt hours of electricity consumed, average production rate and average temperature into the pellet mill die. Some systems will keep records of total production made through several dies to enable die life and costs to be determined. The automation system should also be able to control the application of fat at the die, liquids added into the conditioner and the pellet cooler control. Monitoring the pellet temperature at the discharge of the cooler and the ambient temperature at the cooler ensures that the pellets are being properly cooled.

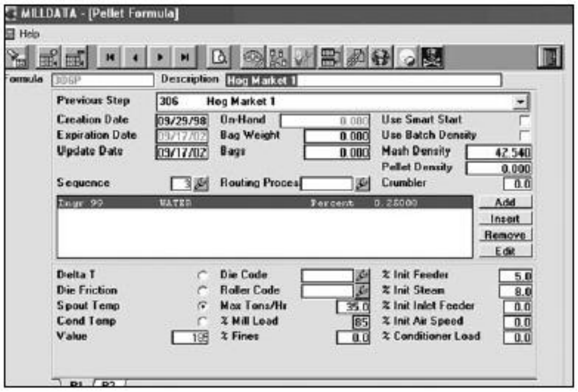
Often several of the pellet mill parameters are displayed on a trend graph on the operator's PC. Trend graphs enable the operator to not only see the current state of the pellet mill, but what has been happening during the time period displayed on the trend graph. This is quite helpful for pellet mill motor loads, temperatures and often liquid addition rates. A typical graphic screen of a pellet mill system is shown in **Figure 14-6**.

Figure 14-6. A typical graphic screen of a pellet mill system.



A typical pellet mill formula showing the various parameters stored in the system database is shown in **Figure 14-7**.

Figure 14-7. A typical pellet mill formula showing the various parameters stored in the system database.



Formula 306P
Description Hog Market 1
Previous Step 306 Hog Market 1
Creation Date 09/29/98
Expiration Date 09/17/02
Update Date 09/17/02
On-Hand 0.000
Bag Weight 0.000
Bags 0.000
Use Smart Start ☐
Use Batch Density ☐
Mash Density 42.540
Pellet Density 0.000
Sequence 3
Routing Process
Crumbler 0.0
Ingr 99 WATER Percent 0.25000
○ Delta T
○ Die Friction
● Spout Temp
○ Cond Temp
Value 195
Die Code
Roller Code
Max Tons/Hr 35.0
% Mill Load 85
% Fines 0.0
% Init Feeder 5.0
% Init Steam 8.0
% Init Inlet Feeder 0.0
% Init Air Speed 0.0
% Conditioner Load 0.0

Justification of automation

As with all automation, an investment in a pellet mill automation system should be justified based on the return on that investment. Typically, pellet mill automation systems have shown the following impacts on the pellet mill cost center:

- Capacity increase between 10-40%;
- Energy consumption decreased between 10-30%; and
- 10-30% reduction of wear on dies and rolls.

These factors can be used to calculate an expected return on an investment in automation based on the size and number of pellet mills in use and the number of operating hours per year.

Emerging technologies and trends

Pellet mill automation hardware has changed much in the last twenty years, but the basic program methods employed to control the mill have remained constant. This was due to the limitations of what parameters could be measured. Sensor technology has grown remarkably in recent years and has opened several possibilities for controlling pellet mills in newer, better ways.

Steam has always been used for proper conditioning of the feed before entering the pellet mill die. Steam supplies both heat and moisture to the feed. Problems arise if conditions require more moisture without more heat or more heat without more moisture. Many have thought it advantageous to add moisture and steam independently. While it has been easy to measure temperature with simple RTD probes, measuring moisture content inside the conditioner has not previously been practical. Now, several cost-effective moisture probes have been developed that can measure feed moisture inside the conditioner. This allows steam to be added to control the temperature of the feed and water to be added to control moisture content. There are still the practical limitations imposed by the moisture content inherent in the steam, but several have tried direct water addition with satisfactory results.

One of the duties of the pellet mill operator has always been to regularly grease the mill. This often requires shutting down the mill for several minutes. An auto-lubrication system for pellet mills has been developed that automatically pumps a measured amount of grease into the mill bearings on a regular interval. Auto-lube systems ensure that the mill gets greased when it should, with the proper amount of grease without shutting down the mill. The pellet mill automation system should include the controls for the auto-lube system so lubrication information can be added to the records kept for the pellet mill.

A feature that has been added to some pellet mill designs is a remote roll adjustment mechanism. This allows the gap between the rolls and the die to be adjusted while the mill is running without shutting down production. Roll adjustment systems allow the roll gap to be increased to start the mill with feed in the die, such as when clearing a plug, and then closed to normal after the mill is started. This feature also allows roll gap to be adjusted during a run to optimize production. Some work has been done that indicates higher production rates are possible on large mills when the roll gap is slightly increased. An automation system should be able to control the mill roll gap adjustment mechanism.

Determining if a quality pellet is being produced through the die has been difficult at best. One possible method is to measure the temperature that the feed gains going through the die. Since the temperature of the mash going into the die is commonly measured to control steam addition, the only missing parameter is to measure the temperature of the pellets exiting the die. This has been difficult and not accurate because of the conditions and the flow pattern of pellets exiting the die and the mill. With the infrared temperature probes currently available, pellet temperature can be measured at the die outlet. The rule of thumb is that the feed should gain between 10-20 degrees passing through the die. Temperature gains of less than 10 degrees indicate that there is not enough compression in the die to form a hard pellet. Temperature gains over 20 degrees indicate too much compression that can burn the pellet or shorten die life considerably.

Typically, the pellet mill drive motor load is monitored and used to control the production rate. Some die plugs can cause the main drive load to decrease rather than increase, making sensing a plug much more difficult. Some work has been done to monitor the rotational speed of each pellet mill roll. By monitoring the speed of each roll and comparing them, the maximum production rate can be determined given the current mash conditioning. This is a direct method of determining what is happening inside the pellet mill rather than making an educated guess based on the main drive amperage. Pellet mill designs must be modified to install the roll speed sensors in the correct positions and route the wires through the main shaft, but it can be done with current technology.

Another new option, though not directly mounted on the pellet mill, is an on-line pellet durability index (PDI) tester. This device is mounted after the cooler outlet adjacent to the pellet flow (see **Figure 14-8**). The device captures a sample from the pellet stream on a regular basis and performs a PDI test. After each test is complete, the unit transmits the test result to the pellet mill automation system for recording and corrective action in the control system, if necessary. These devices provide consistent feedback concerning pellet durability that will allow the automation system to adjust mash conditioning or the production rate to ensure a quality pellet is being made.

Figure 14-8. Example of a PDI tester.

Current control system technology combined with the emerging sensor and control technologies promises many changes in the future for better, more complete control of pellet mill systems. New methods of sensing conditions in the pellet mill mean that future control systems will be based on increased direct measurement and less inference of actual conditions from other parameters. Control systems of the future will not only control the pelleting process, but handle a variety of other tasks associated with the pellet mill such as its lubrication and managing the energy consumption of the mill.

This content was edited and reviewed by Dr. Adam Fahrenholz, Assistant Professor of Feed Milling at North Carolina State University, Dr. Charles Stark, Jim and Carol Brown Associate Professor of Feed Technology at Kansas State University, and Dr. Cassandra Jones, Assistant Professor of Feed Technology at Kansas State University.