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ELECTRONIC CONTROLLER for an Automatic Feed Grinder

By H. B. Puckett

Bulletin 615

An electronic controller on a 5-horsepower electric hammermill for ear-corn grinding.

UNIVERSITY OF ILLINOIS
AGRICULTURAL EXPERIMENT STATION
In Cooperation with the
U. S. Department of Agriculture
TO PERFORM AUTOMATICALLY without human attention, a feed-grinding mill must have some form of automatic load regulation that will keep the grinding unit properly supplied with feed. For some feeds, such as small grains, which flow easily and smoothly, a fixed rate of induction into the mill is suitable for automatic operation. If, however, the feed cannot be induced in a smooth flow, some method of control that can be regulated by the mill-motor load must be provided for the feeding mechanism.

The 5-horsepower automatic ear-corn grinder is one such mill. One ear of corn can make the difference between overload and underload. It is imperative that quick-acting overload controls be able to stop the flow of feed into the hammermill or the unit may become clogged. The success of the small electric hammermill in grinding irregular feeds is determined, to a large extent, by the control unit.

A magnetic controller for an automatic 5-horsepower hammermill was developed by R. W. Mowery. The motor current is utilized directly to operate an overload relay controlling the feeders. This magnetic controller contains all the necessary control functions for completely automatic operation of a 5-horsepower mill. It has been accepted by two motor-control manufacturers and is being marketed. Many units are now in use.

**Aim of This Study**

The magnetic control, as now manufactured, represents a very large investment for the user. The cost has doubtless discouraged many prospective buyers who would otherwise have installed automatic feed-grinding systems. This study was undertaken to find ways of simplifying the controller and reducing its cost without lessening its sensitivity or sacrificing any of its desirable automatic operations.

**Procedure**

Mowery studied magnetic controls and selected those best suited for fully automatic control of an electric feed-grinding mill. Some device using controls other than straight magnetic ones offered the best possibility for reducing costs without sacrificing performance. Attention was directed to electronic controls that had good possibilities through the use of smaller detecting equipment. An electronic control could easily be added to the magnetic starter-switch for the mill motor.

1 Results were reported in Ill. Agr. Exp. Sta. Bul. 555.
Most important, the value and amount of special purpose equipment required would be less.

Two methods for developing an electronic controller could be undertaken: (1) the use of a vacuum-tube circuit; and (2) a thyratron circuit. The circuit developed had to provide the following control functions:

1. An overload current detector to control feed meters
2. An underload timer to stop the mill within a reasonable time when it was underloaded
3. A device to control total grinding time
4. A delay shutdown to clear mill and pipes at end of grinding period
5. A device to control power for mill motor
6. A means to protect the mill motor against overload

**Results**

Tests of the vacuum-tube overload detector demonstrated that adequate sensitivity could not be built into a unit at a lower cost than the cost of the present magnetic controller. For this reason, no further work was carried on with the vacuum-tube overload detector.

The use of thyratrons in the overload detector provided a one-tube relay with adequate sensitivity and power amplification to operate a relay that could control the feed meters and do it with only a slight change in mill-motor current. With a high-impedance current transformer, the change in mill-motor current between off-on positions of the feed-control relay was only 0.25 ampere. The unit was capable of very fast operation, being limited only by the speed of response of the power relay controlling the feed meters. A thyratron was also selected for the underload timer because of its high power amplification and because a very good time-delay circuit had been developed using the thyratron. This time-delay circuit required but a fraction of a second to reset. The opening of the meter relay recharged the timing circuit of the underload timer.

The other components were built into the system much as they were in the magnetic controller. An electric clock-type interval timer to control grinding time was installed in the mill-motor control circuit and equipped with a single-pole double-throw switch. The normally closed position of the switch was used to operate a normally closed

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Standard 5-horsepower magnetic starter switch. Arrow indicates the current transformer that detects the motor load and controls the feed meters.

(Fig. 1)

thermal time-delay relay that provided for delayed shutdown of the mill. A standard magnetic starter was used to control the motor power and modified to the extent that a small high-impedance current trans-
Output voltage of current transformer versus output voltage of primary current.

(Fig. 2)

former was added to the box. This provided the signal for the feed-meter control circuit.

Power for the control unit was connected only while the main motor starter was energized. A normally open thermal time-delay relay prevented operation of the feed-meter relay until the tubes were warm and the underload-timing condenser was charged. A mercury-plunger
relay was used to switch the meter circuit. This simple control circuit and the motor starter were separated to reduce the cost of the special purpose items. Also if the motor starter were provided with its own case, a less expensive enclosure could be used.

(For the parts list, see page 9. See the Figs. specified for the following illustrations: small current transformer installed in the motor starter switch, Fig. 1; current transformer output, Fig. 2; circuit for the electronic controller, Fig. 3; electronic controller installed on a 5-horsepower ear-corn grinding mill, front cover; and rear view of electronic controller, Fig. 7.)

Laboratory tests were conducted to compare the control functions of the magnetic- and electronic-control units and to determine if more feed could be ground for less power with one method than with the other. The results and the statistical analyses are given in Table 1.

The laboratory tests indicated that there were no significant differences in the operation of either controller. It was observed, however, that if the meters were set to feed a large oversupply of feed, the electronic controller could handle the overload better with its faster switching rate. Whenever the feeding rate of the feed meters approached the capacity of the mill, there was little difference in the grinding capacity of the mill or power consumption per pound of feed ground with either controller. The faster switching of the electronic controller reduced the peak currents of the mill motor and increased the frequency with which the mill was charged with feed (Figs. 4 and 5).

Laboratory tests were conducted for several months without any serious defects showing up in the electronic controller. The unit was taken to a nearby farm having an automatic feed-grinding system that was used at least twice daily. It was installed on an under-fed hammer-mill that used vibrator meters to supply shelled corn and pelletized supplement to the mill. This unit has been in operation for 18 months without showing any serious defects in design. Some additional filtering was added to the current-transformer circuit, but no other changes were made in the controller. These changes are incorporated in the circuit diagram (Fig. 3). The motor-current chart (Fig. 6) shows the range and frequency of motor current changes on the field installation.

Advantages

This electronic controller has a number of advantages. It will be easy to repair because the parts most likely to fail, the tubes, plug in. It should cost less than other types, for the components are small and
Table 1. — Grinding Capacity of Automatic Electric Hammermill Equipped With Electronic Controller Compared With Capacity Equipped With Magnetic Controller

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Electronic controller</th>
<th>Magnetic controller</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pounds of ear corn ground</td>
<td>Watt-hours</td>
</tr>
<tr>
<td>Cut-out current 26 amperes, grinding time 1 minute</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>27</td>
<td>79.2</td>
</tr>
<tr>
<td>2</td>
<td>31</td>
<td>89.6</td>
</tr>
<tr>
<td>3</td>
<td>28</td>
<td>85.5</td>
</tr>
<tr>
<td>4</td>
<td>28</td>
<td>87.6</td>
</tr>
<tr>
<td>5</td>
<td>28</td>
<td>89.6</td>
</tr>
<tr>
<td>Total</td>
<td>142</td>
<td>431.5</td>
</tr>
<tr>
<td>Average</td>
<td>28.4</td>
<td>86.3</td>
</tr>
<tr>
<td>Cut-out current 30 amperes, grinding time 1 minute</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>37</td>
<td>112.5</td>
</tr>
<tr>
<td>7</td>
<td>37</td>
<td>102.1</td>
</tr>
<tr>
<td>8</td>
<td>36</td>
<td>104.2</td>
</tr>
<tr>
<td>9</td>
<td>39</td>
<td>104.2</td>
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<tr>
<td>10</td>
<td>36</td>
<td>104.2</td>
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</tr>
<tr>
<td>Average</td>
<td>37</td>
<td>105.4</td>
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Analysis of variance

<table>
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<tr>
<th>Item</th>
<th>Degrees of freedom</th>
<th>Sum squares</th>
<th>Mean square</th>
<th>Degrees of freedom</th>
<th>Sum squares</th>
<th>Mean square</th>
</tr>
</thead>
<tbody>
<tr>
<td>26 Amperes</td>
<td></td>
<td></td>
<td></td>
<td>30 Amperes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Individuals</td>
<td>9</td>
<td>.1407</td>
<td></td>
<td>9</td>
<td>.756</td>
<td></td>
</tr>
<tr>
<td>Controllers</td>
<td>1</td>
<td>.0449</td>
<td>.0449*</td>
<td>1</td>
<td>.041</td>
<td>.041*</td>
</tr>
<tr>
<td>Error</td>
<td>8</td>
<td>.0958</td>
<td>.0120</td>
<td>8</td>
<td>.7151</td>
<td>.089</td>
</tr>
</tbody>
</table>

* There was no significant difference between the performances of the magnetic and the electronic controllers.

are easy to install. It is flexible; the one controller can perform satisfactorily on a wide range of motor sizes. A simple adjustment adapts it to any motor having a line current of 5 to 50 amperes. The use of a different current transformer can change this range.

The electronic controller provides all control functions necessary for automatic operation of a grinding mill and can be attached to any magnetic starter-switch that provides over-current protection for the motor. The addition of the small current transformer to the magnetic motor starter-switch is all that is required to adapt the switch for the electronic controller.
Electronic controller circuit.  (Fig. 3)
Parts List

Case ........... 10" x 12" x 3" aluminum
Timer ......... electric 0-4 hour w/SPT contacts; Paragon Electric Co., Model 2408
M ............. relay, motor-starter switch
K ............. relay, DPDT; Potter and Brumfield, Type KCP11 with 2500-ohm coil
N ............. relay, SPST mercury plunger N/O contacts; Ebert, Type EM-1, rated 35 amperes at 115VAC
T₁ ............. current transformer (2 volts on secondary for 1 ampere on primary); Standard Electrical Products Co., Part No. 6383
T₂ ............. filament transformer; 115V primary; 6.3 volt at 1.2 ampere secondary; Thordarson, Type 26F65
V₁ + V₂ ... 2D21 thyratron
T/D₁ ........ time delay 30 seconds N/C contacts; Amperite, Type 115C30
T/D₂ ........ time delay 30 seconds N/O contacts; Amperite, Type 115N030
Rectifiers .... half wave, selenium; 20 ma, 130V RMs.; Federal, Type 1159
C₁ ........... .5 mfd 200 WVDC
C₂ ........... 1.0 mfd 200 WVDC
C₃ ........... .1 mfd 200 WVDC
C₄ ........... .25 mfd 200 WVDC
C₅ ........... .5 mfd 200 WVDC
C₆ ........... .5 mfd 200 WVDC
C₇ ........... 1.0 mfd 200 WVDC
C₈ ........... 1.0 mfd 200 WVDC
R₁ ........... 2500-ohm divide-ohm
R₂ ........... 68,000 ohm
R₃ ........... 100,000 ohm
R₄ ........... 9.0 mcg ohm
R₅ ........... 2500 ohm divide-ohm
R₆ ........... 47,000 ohm
R₇ ........... 50,000 ohm WW potentiometer
R₈ ........... 3,300 ohm
R₉ ........... 47,000 ohm
R₁₀ .......... 220,000 ohm
R₁₁ .......... 47 ohm
Mill motor current; A with electronic control, B with magnetic control. Feed meter control relay adjusted to open when motor current reached 26 amperes. (Fig. 4)

Mill motor current; A with electronic control, B with magnetic control. Feed meter control relay adjusted to open when motor current reached 30 amperes. (Fig. 5)
Segment of chart of motor current on farm installation. The mill was fed with vibrator feeders and regulated with an electronic controller. (Fig. 6)

This electronic controller was developed as part of a cooperative research program between the Agricultural Engineering Department of the University of Illinois Agricultural Experiment Station and the Agricultural Research Service, U. S. Department of Agriculture.

The controller represents further development of an automatic grinding control system as first reported by R. H. Mowery in Illinois Agricultural Experiment Station Bulletin 555.

Funds of the Illinois Agricultural Experiment Station were provided in part by the Illinois Farm Electrification Council, an association of electric power suppliers serving the farmers of Illinois.

This bulletin reports research conducted by H. B. Puckett, Agricultural Engineer, Agricultural Research Division, Agricultural Research Service, U. S. Department of Agriculture.
Rear view of electronic controller.

(Fig. 7)