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Automatic Feed-processing Control

With Electronic Weighing

TEXAS A&M UNIVERSITY
TEXAS AGRICULTURAL EXPERIMENT STATION
R. E. PATTERSON, DIRECTOR, COLLEGE STATION, TEXAS

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Summary

Development of an automatic feed-processing control system using automatic weight proportioning is the result of research conducted by the Department of Agricultural Engineering.

A prototype unit was designed and constructed incorporating the following control sections or actions: (1) weight control, (2) sequence control and (3) event control. Reliability tests made with the unit show that commercial electronic components can be adapted and assembled into an electronic weighing system which will enable an operator to program and process a predetermined ration without continuous supervision.

A schematic diagram of the control system is shown in this report. The actual operation of the control sequence is explained in detail.

Automatic Feed-processing Control With Electronic Weighing

Ralph J. McGinty and Price Hobgood*

THE NEED FOR MECHANIZING feed-processing operations has been well established. The main object is to free labor from time-consuming tasks. Less obvious, perhaps, is the possibility of operating small capacity equipment around the clock and saving on dollars invested and power costs (1, 2, 3). The continued decrease in the number of agricultural workers and the increase in the size of farms demand a change to more efficient labor-saving methods of production.

Work has been done to automate specific pieces of equipment, such as an automatic load regulator for a feed grinder (4). Also, there have been several tests and reports on volumetric feed meters for small automatic mills (5, 6, 7).

As feed-processing operations become more complex it becomes necessary to develop control systems in which the various components are controlled as a unit. In a well-designed system each component must perform a given job with all parts working together at a specific signal. Most automatic farm-size feed-processing systems now in existence use volumetric proportioning which is limited to free-flowing materials. Many of the larger commercial-type installations use weight proportioning, but it is usually done manually rather than automatically. Since weight proportioning is preferable to volume proportioning, there is a need for an automatic feed-processing system using weight proportioning.

A complete search of the literature, as well as correspondence with leading manufacturers, was accomplished in the spring of 1961. The conclusion was that no known commercial automatic weight controller was suitable for producer use, though the PTL load system came close to the desired specifications. Therefore, work was initiated to develop an automatic feed-processing system using automatic weight proportioning. To keep the system practical, the unit was to be designed and built from commercially available components. The unit also was to have a process control program which was flexible rather than designed for a specific job.

Procedure

A feed-processing operation usually follows a denifite sequence of events. However, occasionally an optional event may be included or excluded. Using weight proportioning with small-capacity equipment requires repeating the sequence of events many times. Any given event can be controlled by multiple factors which determine if that event should be included or excluded for that cycle. The stated conditions determine that the control action must consist of three parts: (1) weight control, (2) sequence control and (3) event control. The three parts or control actions were developed separately and then incorporated in a prototype unit.

Weight Control

The weight control appeared to be the most critical part and was developed first. Since the Baldwin-Lima-Hamilton PTL load system came close to the required specifications for the weight controller, a unit was purchased for study. The unit consisted of a voltage-regulated amplifier and control relay. In operation a constant voltage was supplied to a strain gage bridge circuit. The unbalanced voltage, proportional to the load, was fed to a two-stage voltage amplifier. The output voltage from the first amplifier was fed to a second two-stage amplifier with a plate circuit relay in the final stage. Two potentiometers in the cathode circuit of the first stage determined the opening and closing points for the relay. One of these potentiometers was used to balance the unit at no load and the other to control the weight at which the relay tripped.

In the unit purchased, two problems developed. First, the weight-control potentiometer proved to be the limiting factor in accuracy because of its small range of movement from no load to full load. Second, there was no provision for more than one controlled weight, thus the unit had to be changed manually for each change in weight. Separate amplifiers could have been used for each ingredient, but the cost would be prohibitive.

To eliminate these two problems the weight-control potentiometer was removed from the circuit and a bank of ten-turn precision potentiometers was used in its place. A separate potentiometer was used for each ingredient. Each potentiometer in turn was switched into the circuit in place of the original weight control. The additional range of movement from no load to full load greatly increased the accuracy with which the desired weight could be set. By using a separate potentiometer for each ingredient, it could be automatically switched

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*Respectively, former instructor and professor and head, Department of Agricultural Engineering.

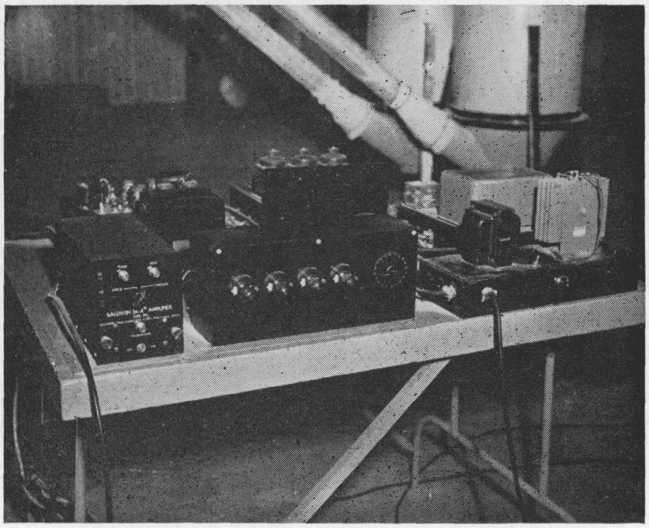


Figure 1. Prototype control unit. ***Front row left to right: Baldwin strain gage amplifier, modified controller with four set-point dials and manual select switch, power supply. Back row left to right: event control relays, time delay relays, automatic electric stepping switch.***

into the circuit when needed; thus, eliminating manual adjustment for each cycle. Relatively high wattage potentiometers were chosen to reduce warmup drift due to switching cold potentiometers into the circuit. Tests showed that the resistance differences among the potentiometers were negligible and any one of the potentiometers could be used to calibrate the system. Only four weight-control potentiometers were used in the prototype unit; however more could be added if needed. The only limitation to the number of potentiometers would be the size of the switch needed to switch them into and out of the circuit.

With these modifications, it was possible to set accurately the weight-control potentiometer to 0.1 percent of the full-scale value or to 1 pound in 1,000. The modified Baldwin-Lima-Hamilton PTL system appeared to meet the necessary specifications for accuracy and reliability, provided a precision linear load cell was used.

Sequence Control

An automatic electric type 45, five-bank, 50-position stepping switch was selected for sequence control. The switch was hermetically sealed, capable of stepping at the rate of 75 steps per second, with a rated life of 10 million operations. One switch bank was used to provide a path for stepping pulses, two banks were needed to switch the set-point potentiometers, one bank was for the operation sequence control and the fifth bank was a spare. With 50 positions, up to 50 sequenced events could be controlled. Switches with more or fewer positions could be purchased if needed. Unused positions can be bypassed at approximately 75 per second. The extra positions add flexibility to the unit.

Event Control

Each event controller must be individually designed as each event is unique. One event might be the weighing of an ingredient, another the augering or conveying of grain and still another the mixing of ingredients. In the simplest case the event controller could consist of a relay controlled by the step-switch. The relay in turn could control a motor. In another case, a time delay might be required in starting or stopping a motor, a time interval required for mixing or a pause of one auger until another auger catches up. Satisfactory circuits for the mentioned cases and for many others have long been in existence. Thus, standard relays, timers, time delays, pressure switches and photocells to control each type of event can be selected according to the specific need.

Prototype Control Unit

A prototype unit was designed and constructed incorporating the three control sections, Figure 1. The stepping switch provided sequencing control. The weight controller was activated by the step-switch whenever an event consisted of weighing an ingredient. The step-switch also selected the proper weight-control potentiometer for each ingredient. Each event control circuit was activated in turn by the step-switch.

At this stage of development of the automatic process control system, no attempt was made to optimize the actual design or size of the circuits. The three control sections and their common power supply were built on separate chassis and connected by cables. Extra components were included to insure flexibility. All components were deliberately oversized to increase reliability. Small pilot relays were used between the step-switch and power circuits to insure long switch life. A low-voltage isolated power supply was used for safety. Both 24 volts AC and 24 volts DC were provided in order to experiment with various available AC and DC relays. Suitable switches were included so that the system could be operated manually or automatically. Connections to the step-switch were made from terminal strips which provided simplicity in changing the sequence program. Sequence order could be changed, events added or dropped in a matter of minutes simply by changing some connections. This feature greatly increased the flexibility of the system.

Testing the System

Initial laboratory tests on weighing water flowing into a barrel indicated the weight-control unit was satisfactory. To test the entire system it was necessary to weigh batches of grain repeatedly while testing for (1) absolute accuracy, (2) repeatability and (3) reliability. The first two items depend mainly on the weight-control unit while the third depends upon all components in the system. The three items can be tested by virtually any type of processing program since the main requirements are weighing and repetition. Many factors which would be important in an actual process would have no bearing on the performance of the control system itself. For example, the thoroughness of mixing would depend upon the design of the mixer used and not upon the relay which turned the mixer on and off. Since only the control system was being tested, many simplifications could be made for convenience.

Since many repetitions were to be run, it was desirable to use the same grain many times; this ruled out grinding and mixing operations. Unground sorghum grain was used to simplify conveying. Because of limited space only two ingredients, both unground sorghum grain, were used. For this test, it was immaterial what actually took place during the interval between weighing batches, so a hypothetical sequence was simulated, Table 1.

In the simulated system a weigh tank, consisting of a 16-cubic-foot hopper-bottom barrel, was suspended from a steel pipe frame, Figures 2 and 3. A Baldwin-Lima-Hamilton type TXX precision linear load cell with a capacity of 1,000 pounds formed a link in the suspension system. The load cell was electrically connected to the amplifier. Two storage bins, similar in design to the weigh tank, were mounted a few yards from the weigh tank. Each of the storage bins had an auger running from their hopper bottom to a point just above the weigh tank. One of the storage tanks was arbitrarily labeled A and the other B. Grain from A and B was augered into the weigh tank. Power relays mounted on the weigh tank frame controlled motors operating augers from tanks A and B. A short, horizontal auger mounted in the bottom of the weigh tank emptied the weigh tank into a hopper. A second auger simultaneously elevated grain from the hopper into the dummy mixer. The dummy mixer consisted of a fourth bin identical to the storage bins. Lights on top of the dummy mixer were used to signify when "mixing" was taking place.

TABLE 1. PROGRAMMED SEQUENCE OF EVENTS[1]

Event number	Event
1	Weigh X pounds of ingredient A
2	Weigh Y pounds of ingredient B
3	Fill mixer
4, 5, 6 and 7	Mix and while mixing refill weigh tank with X pounds of ingredient A and Y pounds of ingredient B; then wait until mixing is complete
8	Empty mixer
3	Fill mixer
4, 5, 6 and 7	(Same as 4, 5, 6 and 7 above)
.	
.	
.	
n-2	Stop signal
n-1	Finish cycle and mix last batch
n	Empty mixer, *stop*

[1] The reader should keep in mind that the actual sequence followed was entirely arbitrary. In practice any 50 events could be arranged in any necessary order.

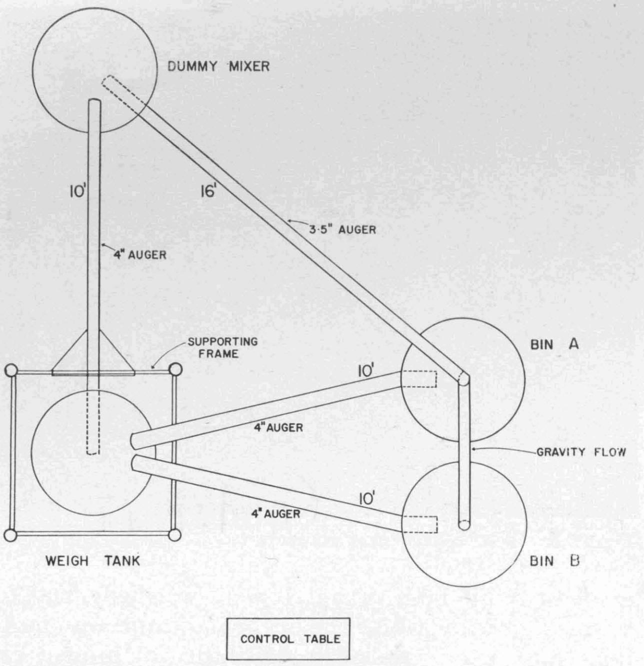


Figure 2. Plan view of test system.

Pressure switches were located near the bottom of both the weigh tank and mixer. These switches activated time-delay relays when the bins were nearly empty. The time-delay relays allowed the bins and augers to empty completely before a new event was started. An interval timer controlled the mixing time. After mixing was completed, the mixer was emptied. An auger mounted in the hopper bottom of the mixer elevated the grain to the top of the two storage bins, filling A then B. A schematic diagram of the control system is shown in Figure 4. The actual operation of the control sequence is explained in detail in the Appendix.

In order to test the accuracy of the weight control, a set of crane-type scales were mounted in the suspension linkage above the load cell. The scales were calibrated over their entire range from 0 to 500 pounds at 20-pound intervals and found to be accurate within ±½ pound. The scales were marked at 1-pound intervals and could be estimated to ½-pound. To avoid implying ultraprecision the scales were read to the nearest pound.

As can be seen from the previously outlined event schedule, Table 1, some weight readings could be taken during a pause (while mixing) and thus read very carefully. However, the weight of in-

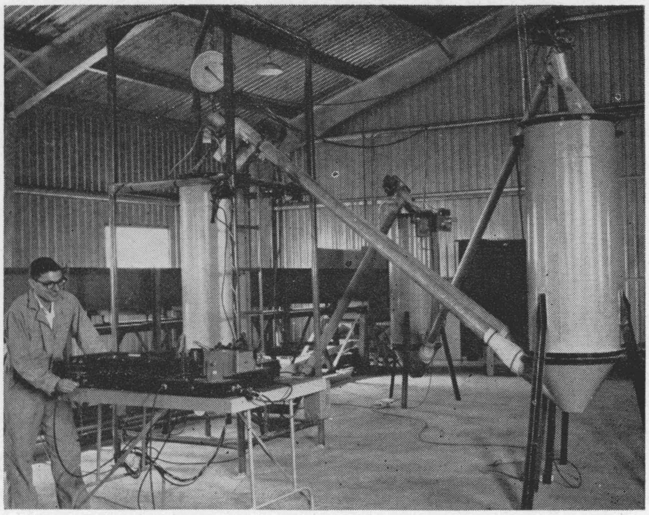


Figure 3. Test system and controls.

gredient A (if both A and B were weighed) had to be read quickly while the scale indicator was moving. Such readings had a possibility of human error and so were labeled "estimated" in the data. Frequent checks were made on the accuracy of A by setting B to zero pounds for a few cycles which then permitted A to be read during a pause.

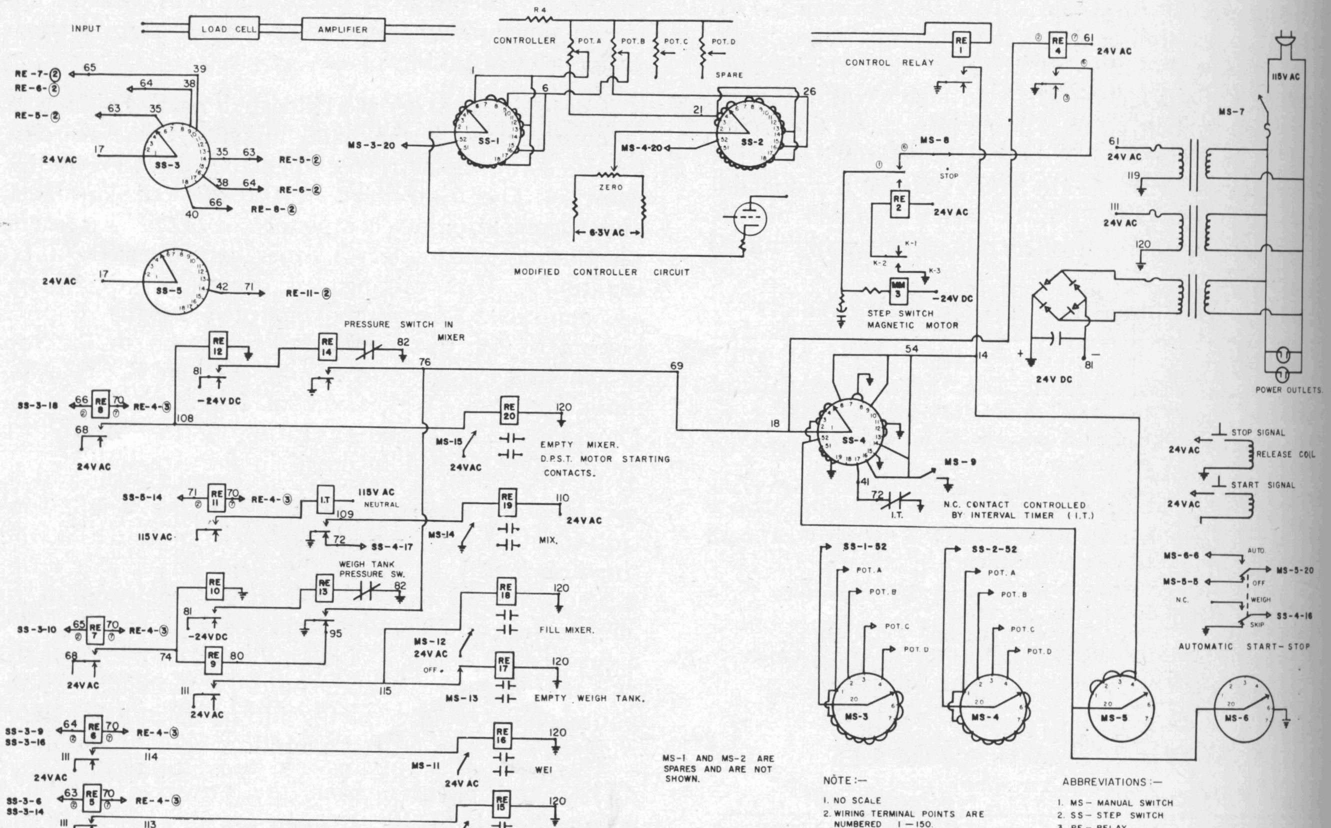
A record of faults and their causes was kept along with the weight record. This was for the purpose of determining the reliability of the various components. More extensive tests of a final unit will be required to prove or disprove long-term reliability.

Results

Reliability tests were started in the fall of 1963, but no attempt was made to check the accuracy of weighing. A few mechanical problems appeared and were eliminated. No trouble was encountered in the control circuit itself.

A precision load cell was obtained the latter part of November, and weight tests were started. The system was first calibrated on December 2, 1963. A minor adjustment in calibration was made on January 8, 1964. Experimental changes were made in the calibration on February 10 and 11. Other than these, the only other adjustments consisted of checking the zero setting at the start of each test.

To be practical, the system would have to remain accurate over a reasonably long interval of time and under widely varying conditions. To test the accuracy under severe conditions, only occasional adjustments were made on calibration, and the unit was operated with only a 2-minute warmup in temperatures ranging from 25° F. to 74° F. (higher



MS-1 AND MS-2 ARE SPARES AND ARE NOT SHOWN.

NOTE:—

1. NO SCALE
2. WIRING TERMINAL POINTS ARE NUMBERED 1—150.
3. RELAY TERMINALS ARE ENCIRCLED.

ABBREVIATIONS:—

1. MS— MANUAL SWITCH
2. SS— STEP SWITCH
3. RE— RELAY

Figure 4. Schematic diagram of the control system.

TABLE 2. SUMMARY OF TEST RESULTS

Number of samples	Set-point weight, pounds	Mean scale reading, pounds	Maximum deviation from set-point, pounds	Maximum deviation from mean, pounds
164	50	50	±2	±2
236	100	98	−3	+2
230	150	147	−4	+2
223	200	198	−3	+2
178	300	299	−3	±2

temperatures did not occur during the period of the study).

Because of the infrequent adjustment of calibration, the actual weight often varied from the set-point weight by 3 to 4 pounds. However, this could have been easily corrected by either adjusting the calibration or off-setting the set-point by a corresponding amount. Calibration adjustment required approximately 15 minutes to perform.

Grain was weighed at the rate of 300 pounds per minute and fell approximately 5 feet into the weigh tank. Over a period of a few hours, the repeatability of the weights was usually ±½ pound. Over an entire day, including the period of warmup, the drift might reach 3 pounds. Allowing 15 to 20 minutes for warmup, instead of the 2 minutes initially used, cut the daily drift by 50 percent. A summary of test results are shown in Table 2.

The use of daily calibration checks and a 15-minute warmup decreased the deviations by approximately 50 percent. As expected, the percentage error decreased with increasing weight. For very small weights it would be necessary to use a smaller load cell.

The results of the reliability tests given in this report indicate that the prototype unit is practical and show that commercial electronic components can be adapted and assembled into an electronic weighing system which will enable an operator to program and process a predetermined ration without continuous supervision.

References

1. Hienton, Truman E. et al. *Electricity in Agricultural Engineering.* John Wiley & Sons, Inc. New York, 1958.

2. Andrew, F. W. et al. *Controls For Farmstead Automation,* Laboratory Manual for Electric Controls Workshop. Department of Agricultural Engineering, University of Illinois, 1961.

3. Paine, Myron D., Harold Winterfield and Dennis L. Moe. *Low Voltage Flexible Sequence Automatic Controls.* South Dakota Agricultural Experiment Station Bulletin 500.

4. Puckett, H. B. *Electronic Controller for an Automatic Feed Grinder.* Illinois Agricultural Experiment Station Bulletin 615, August 1957.

5. Butt, J. L. *Results of Performance Tests of a Small Farm Mixer Grinder.* Alabama Agricultural Experiment Station Progress Report Series No. 57, August 1955.

6. Hobgood, Price and W. E. McCune. *Feed Proportioning, Grinding and Mixing on the Farm.* A Summary of Progress Report to the Texas Farm Electrification Committee. Department of Agricultural Engineering, Texas A&M University, June 26, 1959.

7. Puckett, H. B. and Robert M. Peart. *Volumetric Feed Meters, Their Performance for Automatic Feeding Systems.* Illinois Agricultural Experiment Station Bulletin 618, September 1957.

Appendix

Control Sequence

In the actual operation the control sequence was as follows:

The manual switch designated MS in Figure 4 was turned to Position 5 and the power was turned on.

The equipment was allowed to warmup for several minutes and the zero adjustment on the controller was checked and adjusted if necessary.

The manual switch was advanced to Position 6 which grounded Position 52 on Bank 4 of the step-switch (that is, SS-4-52). This in turn grounded Relay 4. With Relay 4 grounded, its contacts closed and grounded the step-switch magnetic motor. The pulsing action of Relay 2 and the interrupter springs K-2 and K-3 supplied pulses of current to the step-switch motor MM-3 and caused it to advance all five banks of the step-switch (SS-1, SS-2, SS-3, SS-4 and SS-5) simultaneously to Position 6. This started the automatic operation.

In Position 6 the weight-control potentiometer for ingredient A, designated Pot. A in Figure 4, was connected into the controller circuit through SS-1-6 and SS-2-6. SS-3-6 connected power to Relay 5 which activated Relay 15 and caused ingredient A to be conveyed into the weigh tank. When the set-point weight for ingredient A was reached, the controller activated Relay 1 grounding Relay 4 through S-4-6. This supplied power to the step-switch motor causing it to advance to Position 9. (The step-switch was advanced from Position 6 to Position 9 to give all relays time for their contacts to disengage.)

In Position 9 the weight-control potentiometer for ingredient B designated as Pot. B in Figure 4 was switched into the controller circuit by SS-1-9 and SS-2-9. SS-3-9 connected power to Relay 6 which activated Relay 16. This started the conveyor which augered ingredient B into the weigh tank. When the set-point weight for ingredient B was reached, Relay 1 was activated and through SS-4-9 in turn activated Relay 4. The closing of Relay 4's contacts along with the pulsing action of the interrupter springs K-2 and K-3 and Relay 2 provided power to the step-switch motor causing all five banks to step to Position 10.

In Position 10, SS-3 connected power to Relay 7 which activated Relays 9, 10, 17 and 18. Relay 13 was not yet activated because the grain in the weigh tank held the weigh tank pressure switch (in series with Relay 13) contacts open. Relay 9 turned on Relay 17 which emptied the weigh tank and Relay 18 which conveyed the grain to the mixer. Relay 10 was used to switch the relatively large DC current for Relay 13 which was a DC variable time-delay relay. When the weigh tank was nearly empty the contacts of the weigh tank pressure switch closed and Relay 13 started its timing interval. After a short time which allowed the conveyors to completely empty themselves of grain, the contacts of Relay 13 closed. This shut off Relays 9, 17 and 18 and grounded Relay 4, activating the step-switch motor to advance to Position 14.

At Position 14, SS-1 and SS-2 reconnected potentiometer A into the controller circuit. SS-3 supplied power for Relay 5 which started the process of weighing ingredient A into the weigh tank. SS-5 supplied power to Relay 11 which in turn connected the interval timer (I.T.) to 115 volts AC. The interval timer contacts supplied power for Relay 19 which started the mixing process. When the desired weight for ingredient A was reached, the step-switch was stepped to Position 16. An internal holding contact in the interval timer kept the interval timer running although Relay 11 was disconnected by SS-5. In Position 16, weight-control potentiometer B was connected into the controller circuit by SS-1 and SS-2. SS-3 supplied power to Relay 6 and started the process of weighing ingredient B. When the desired weight for ingredient B was reached, the step-switch advanced to Position 17 where it remained until the interval timer contacts in series with SS-4-17 closed, grounding Relay 4 and advancing the step-switch to Position 18.

In Position 18, SS-3 supplied power to Relay 8 which activated Relays 12 and 20. Relay 14 was kept off by the pressure switch in the mixer. Relay 20 controlled the conveyor motor which emptied the mixer. When the mixer was nearly empty, the pressure switch contacts closed and Relay 14 started its delaying operation. At the end of the delay period when the augers had emptied, Relay 14 grounded SS-4-1 which grounded Relay 4 and caused the step-switch to advance. Contacts SS-4-19 through SS-4-51 were grounded which caused the step-switch to advance to Position 52. When operating on automatic control, Position SS-4-52 was grounded through manual switch MS-6-6; this caused the cycle to repeat. The grain weighed in the previous cycle would be empited into the mixer, the mixer started and a new batch of grain weighed. At the end of the operation, the stop signal would switch MS-5-20 from MS-6-6 to MS-5-5 which would stop and step-switch when it reached Position 52. The stop signal would also cause SS-4-16 to be grounded thus preventing any further weighing of grain. The last batch would be mixed and emptied.

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