Performance and Electrical Load Characteristics of
AUTOMATIC 5-HORSEPOWER GRINDERS AND MOTORS

By M. W. Forth and E. W. Lehmann

CONTENTS

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By M. W. FORTH and E. W. LEHMANN[2]

GENERAL ACCEPTANCE of automatic electric feed-grinding equipment on the farm is dependent on getting a reliable, trouble-free system that calls only for setting a time clock and pushing a starting switch. Such a system requires integrated design of grinder, power unit, conveyors, and automatic-control devices.

The first requirement is a grinder that will operate smoothly without undue fluctuations when ears of corn are fed into it. It should react on control devices to maintain near-maximum capacity and operate within the effective power range of the motor.

The second essential is a motor that operates at full load and maximum efficiency without high current fluctuations. In general, a 5-horsepower single-phase motor is suitable for use on most rural lines. It must be made safe to operate under the somewhat hazardous conditions often found in buildings where grain is ground.

Other elements of a satisfactory automatic system for grinding ear corn include electrical controls and conveyor equipment for removing corn from cribs and feeding it into the grinder. These devices were developed at the Illinois Agricultural Experiment Station, both laboratory and farm installations were made, and reports published.[3]

The importance of grinder and motor characteristics was recognized early in the studies of automatic grinding. Grinders vary not

[2] M. W. FORTH, formerly First Assistant in Agricultural Engineering, and E. W. LEHMANN, Professor of Agricultural Engineering and Head of Department.

[3] Previous reports pertaining to the project include:

"Automatic ear corn grinding with 5-horsepower electric motor," by L. S. Foote, M. W. Forth, and R. W. Mowery. Agr. Engin. **32**, 601-605. 1951.

"Electrical control system for automatic feed grinding," by R. W. Mowery. Ill. Agr. Exp. Sta. Bul. **555**. 1952.

"Crib drag, drive unit, and hopper for automatic ear corn grinding." Univ. Ill. Dept. Agr. Engin. Plan 513. 1952.

"Hammermill design for automatic ear corn grinding with electric power," by M. W. Forth. Univ. Ill. master's thesis (unpublished). 1952.

only in type but also in the designs within a given type. Motors differ in their "current curves" and other characteristics, so that one type may be more suitable than another for use in an automatic installation. This report deals with tests of 5-horsepower grinders and electric motors when used in an automatic grinding system and the results obtained from them.

Scope of Study

The objectives of the investigation reported here were to determine the performance and load characteristics of mills for grinding ear corn automatically and of motors under the conditions imposed by grinder loads.

Two kinds of tests were made: (1) laboratory studies with ear corn only, where it was possible to control conditions and measure the significant factors; and (2) field tests on farm installations under the varied conditions found.

Altogether twelve different makes of feed mills and ten different motors were tested. Each grinder had its own particular load characteristic, and each motor reacted differently to the automatic grinder load. Thus the findings provide information of value to manufacturers and power suppliers in their joint effort to develop complete units. In turn, the farmer who uses the equipment will benefit.

Preliminary Considerations

The difference in performance of grinders and motors may result in wide variations of electrical load conditions, reaction of controls, dependability, capacity, and acceptability to the operator. With suitably designed equipment, the owner can reasonably expect satisfactory results. But a combination that produced objectionable characteristics might cause difficult wiring problems, unnecessarily troublesome operation, and high operating costs.

Grinders. The types of grinders — hammermills, burr mills, and others — vary as to their load characteristics and their fineness and uniformity of grind. In some mills, for example, the design is such that a steady feed-in of one or two ears of corn at a time produces a fairly uniform full load. Others transmit the impact of each ear back to the motor and produce a constantly fluctuating load.

Controls. The key feature of the automatic control system developed for ear-corn grinding is a jam relay, operating on the same principle as a solenoid. The relay is wired in series with the grinder

motor. When the current to the motor exceeds the control setting, the feed-in devices stop momentarily until the grinder is cleared; thus the "current curve" of the motor as related to horsepower is highly significant in obtaining compatibility of motor to the control system.

The control setting of the jam relay provides for about a 6-ampere differential between the on and off positions. The control must be set somewhat above normal rated current to assure operation at or above the 5-hp. rating for highest efficiency. For example, with a full-load motor rating of 24 amperes, the control should be set to stop the feed-in apparatus at 30 amperes and restart it at 24 amperes.

Motors. The current curves of two motors with a 6-ampere control differential are shown in Fig. 1. Motor A, operating under these conditions, would vary within a range of 5 to 6½ hp., and therefore pro-
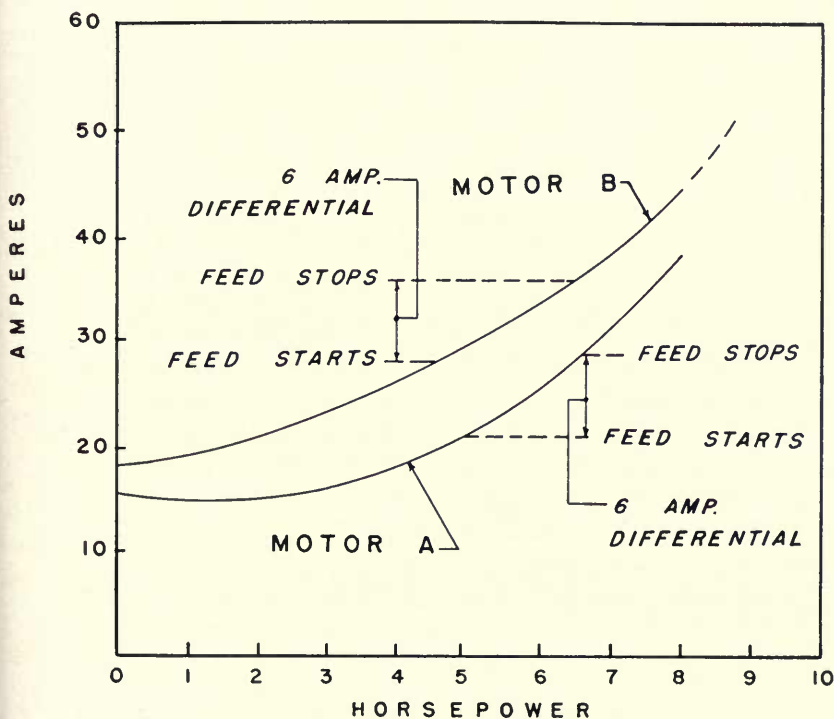
Characteristic current curves of typical 5-hp. single-phase motors. The curve of Motor A is the most desirable for automatic grinders because of the narrow control range, low rated current, and low starting and locked rotor current (above 8 hp.).   (Fig. 1)

vide high efficiency within minimum fluctuation. Motor B, having a
flatter curve at or below normal full-load output, has a wider fluctua-
tion of horsepower within the 6-ampere control range. This causes de-
lay in restarting the conveyor. The curve of Motor B rises sharply as
the overload extends beyond the control range to increase the severity
of high current surges. A higher setting of the control to obtain more
operating time at rated load would impose high overload demands and
severe current fluctuations. These cause voltage drops, light flicker,
and sometimes activate circuit breakers and motor-protection devices.

Method of Study

Tests of electrical load characteristics on the grinders and motors
were made in the laboratory. Test apparatus consisted of three Ester-
line-Angus recorders linked together to provide synchronized readings
of volts, watts, and amperes. Speed was measured with a Jagabi re-
cording hand tachometer. A Ro-Tap machine was used to check fine-
ness modulus[1] and uniformity of grind. Other apparatus included
totalizing watthour meter, scales, stop watch, and drying oven.

Tests were controlled throughout, except for minor variations in
moisture content of grain and differences in variety. Ear corn was
completely husked and placed in a crib by hand to avoid the transfer
of shelled corn and husks that would produce nonuniform feeding
conditions. Corn was taken from the crib by an automatic crib un-
loader either directly to the mill or by way of a conveyor. When oats
were included in rations, they were introduced by a revolving disc
meter from an overhead bin. The present study, however, was con-
cerned primarily with grinding ear corn. A typical setup for the tests
is shown in Fig. 2.

The procedures were similar for testing both grinders and motors.
Equipment was assembled and checked for rated operating capacity
and speed. Voltage was adjusted to motor nameplate voltage with an
induction regulator. Test data were recorded after preliminary runs
had been made to observe general performance. The preliminary period

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[1] Fineness modulus is an index or measure of the size of particles in a
ground feed ration, determined by the method adopted by the American Society
of Agricultural Engineers. The procedure involves shaking an oven-dried sample
through graduated screens and then computing the modulus from the percent of
material left on each screen. The coarsest grind that can be measured by this
method would have a modulus of 7, in which all particles would stay on top of a
⅜″-opening screen. A fineness modulus of 1 would indicate that all the material
passed through all but the last screen, which is 100 mesh. If all passed through
the 100-mesh screen, the fineness modulus would be zero.
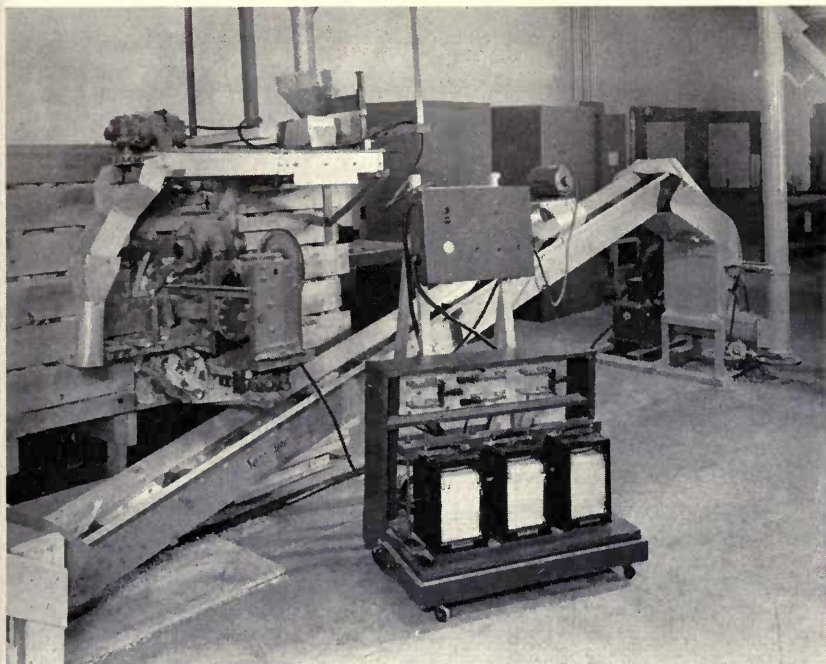
Test equipment for grinder and motor studies. Note the control panel, re-
cording instruments, and crib conveyor. Since this mill was not designed for
automatic electric operation, a long conveyor was necessary to reach the
mill hopper.   (Fig. 2)

gave time for motors, bearings, and other parts to reach normal oper-
ating temperature and establish stable conditions. Tests consisted of a
series of two- and three-minute runs. Runs were repeated several times
to obtain duplication of data and offset possible variations in oper-
ating conditions. Data included weight checks of capacity, electrical
records, and speeds. Each complete test involved grinding 25 to 30
bushels of ear corn.

Grinder Tests and Analysis

With two exceptions, the grinders were tested with the same "base"
motor. The motor was a 5-hp. repulsion-induction start-and-run motor
with a current curve similar to that of Motor A (Fig. 1). Twelve
grinders were tested, representing the following general types and
design features:

Hammermills
  Low inertia, swinging hammers, conventional.............3
        Experimental inverted 3
  Fixed hammers, conventional.............................1
  High inertia hatchet mill, side-fed through knives
        on hammer rotor...................................3
  Burr mill, vertical feed down into burrs................1
  Reel-type cutterhead and screen.........................1

Results of the tests on grinders are summarized by representative data for each type of mill studied (Table 1) and by the ammeter chart analyses of load characteristics (Figs. 3 to 7).
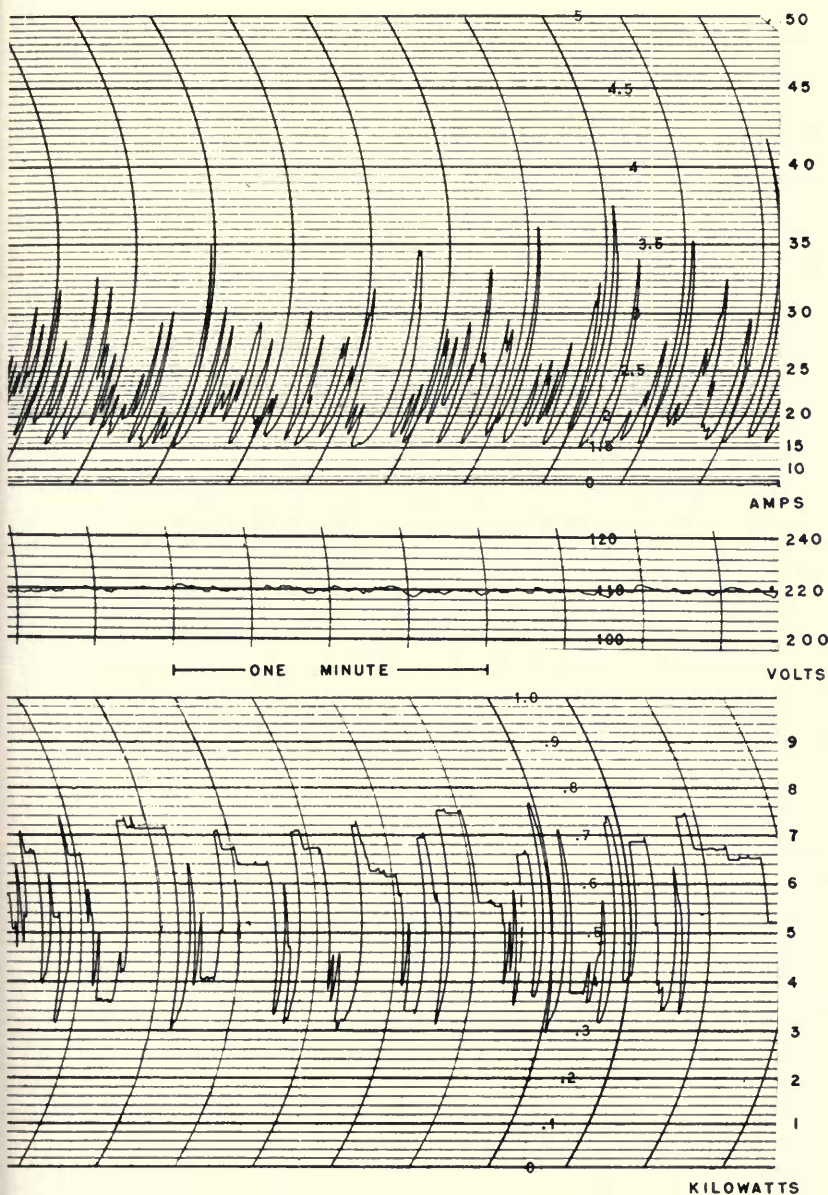
While all of the grinders were satisfactory in that they could be fed and controlled automatically, some were superior in performance and electrical load characteristics. On the basis of the data in Table 1 and visual analysis of the ammeter charts, the following interpretations are made:

Swinging-hammer low-inertia mill (Mill No. 1, Table 1, Fig. 3). This mill was adequate in capacity and operated without severe overload for grinding ear corn. The ground feed blower plugged, however, if mixed rations of ear corn and small grain were ground. Then the mill became clogged with ground feed before the overload was transmitted to the motor controls. Later a redesign of the mill and blower remedied the condition.
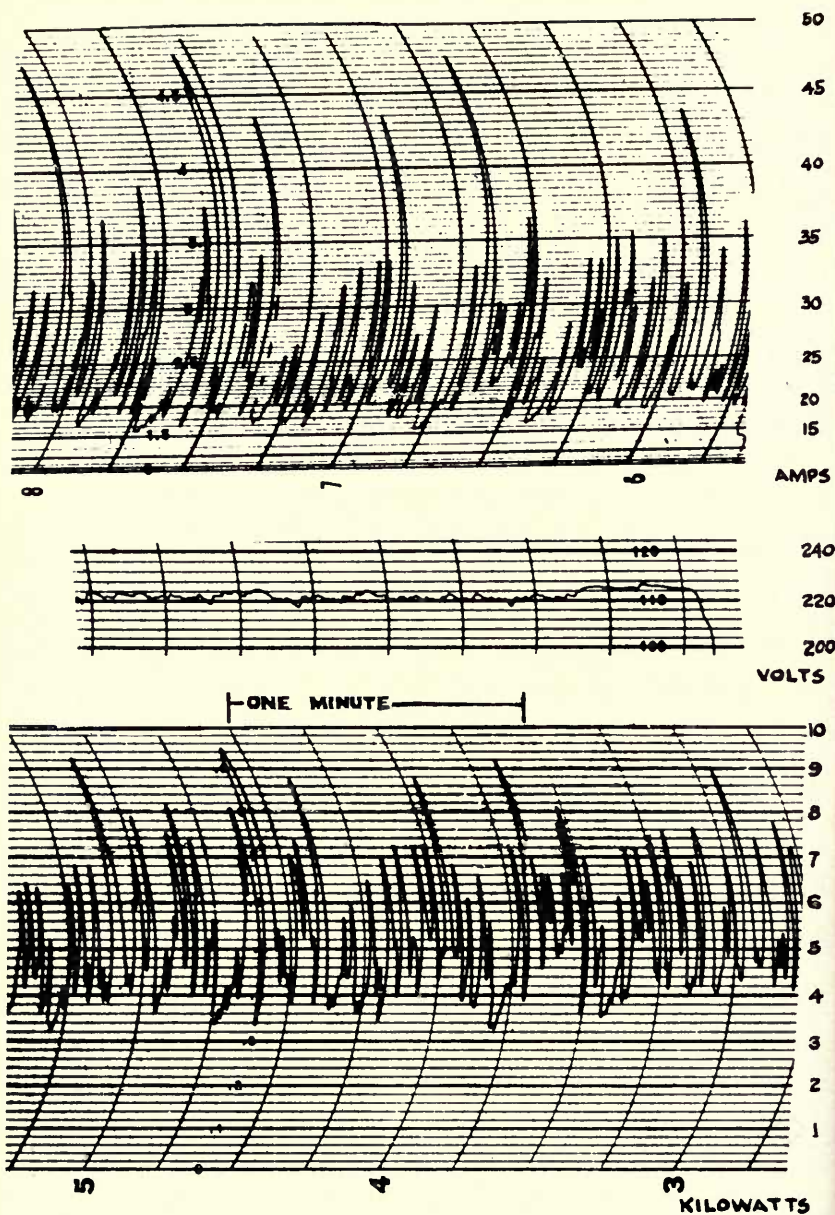
Experimental inverted hammermill, low inertia (Mill No. 2, Table 1, Fig. 4). The experimental mill was similar to the conventional type, No. 1, except that the mill was inverted to place the screen at the top.

Table 1. — Electrical Loads Imposed on a 5-Horsepower
Motor by Automatic Feed Grinders

Grinder type	Rate of grinding (pounds per kilowatt-hour)	Fineness modulus	Proportion of operating time when current was—			
			Under-load (below 25 amperes)	Desir-able load (25 to 30 amperes)	Accept-able overload (30 to 40 amperes)	Severe overload (over 40 amperes)
			perct.	*perct.*	*perct.*	*perct.*
Swinging-hammer low-inertia mill	407	4.10	62	21	16	1
Experimental inverted hammermill, low inertia.......	324	3.58	54	23	19	4
Hatchet mill, high inertia....	170	3.74	41	14	31	14
Burr mill, vertical feed......	426	4.90	80	12	6	2
Cutterhead mill, slow speed..	538	4.33	100	..	..	..

Electrical load conditions created by a small low-inertia swinging-hammer mill of conventional design (Mill No. 1). While the current and power fluctuated frequently, the maximum current did not exceed 42 amperes, and overload periods were of short duration. (The wattmeter curve of Fig. 8 is more typical of this model.)   (Fig. 3)

Electrical load created by the experimental inverted hammermill. The current surges reached 48 amperes, but the length of time in such severe conditions was short.   (Fig. 4)
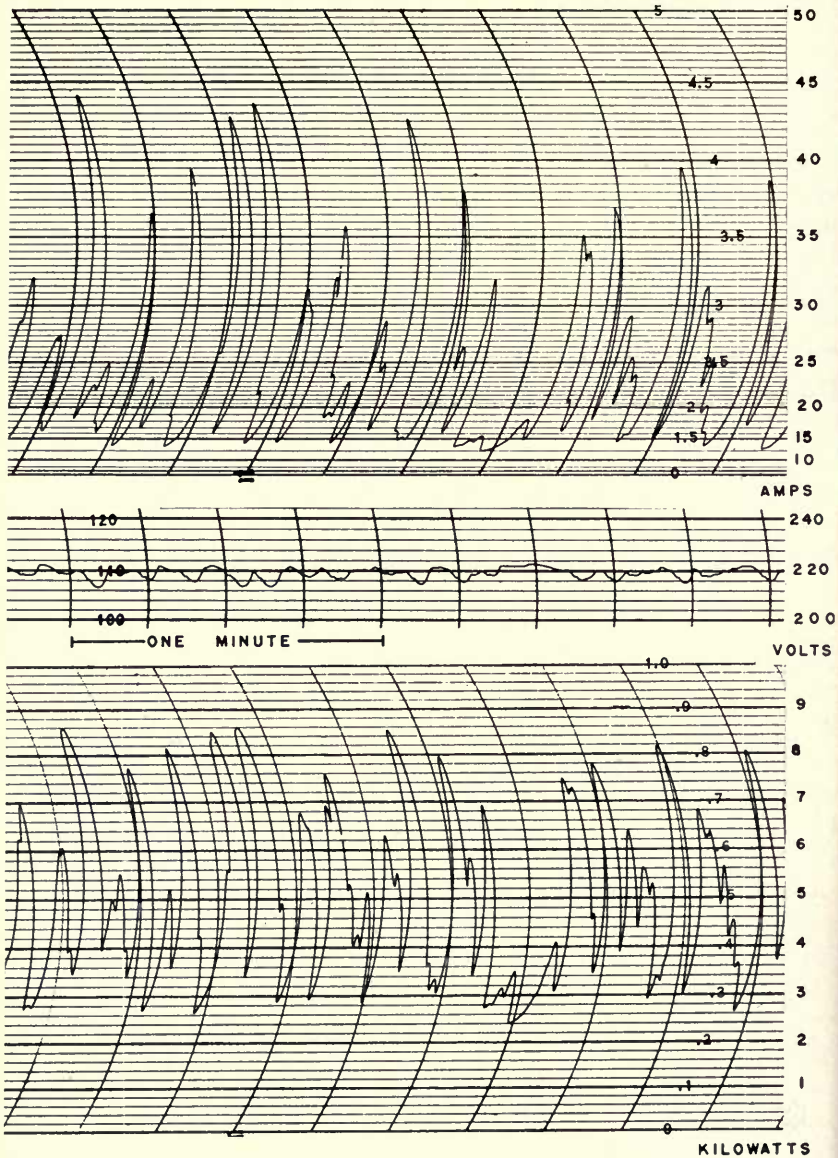
The electrical load characteristics were similar to those of the original, but for a given screen size the capacity was reduced and the feed was ground finer. The principal value was that the mill did not plug or clog and was self cleaning when stopped under full load.

Hatchet mill, high inertia (Mill No. 3, Table 1, Fig. 5). This grinder had the lowest capacity and the most prolonged overloads among the mills tested. The high-inertia rotor, well designed for nonuniform hand feeding, did not immediately transmit an overload to the automatic controls. Because of this, the conveyors fed in an excess of material, which then had to be ground and full speed attained before the conveyors again started. For this reason the ammeter curve is a series of looping fluctuations with extended periods of severe overload.

Burr mill (Mill No. 4, Table 1, Fig. 6). The burr mill had relatively high capacity per kilowatt-hour and indicated less severe electrical load characteristics. The material was not as finely ground and the burr mill had no greater hourly capacity than the other mills. At the relatively slow speed and with low mechanical inertia, occasional overloads completely exceeded the capacity of the motor and the machine stalled. Thus for automatic operation it is necessary to operate well below the capacity of the mill and motor in order to have a reserve of power to prevent stalling. In the tests the motor was operated at underload for 80 percent of the time to provide the necessary reserve.

Cutterhead mill, slow speed (Mill No. 5, Table 1, Fig. 7). Although the principle of design of this mill has been used in roughage mills for many years, this unit has just recently been made available as an ear-corn grinder. It has a reel-type cutterhead with three knives on the rotor. The knives grind against two fixed bars and a screen. The grinder had the highest capacity and the least fluctuations of electrical load among the mills tested. In the tests the motor was never up to full load because the automatic feed-in conveyors were not adjusted to the mill capacity. This indicates that a still higher rate and greater efficiency might be obtained. Although the mill had exceptionally desirable characteristics for grinding ear corn, it was much less efficient than the hammermills for grinding oats fine enough for hog and poultry rations.

At the time the cutterhead mill was tested, the manufacturer had not established a recommended speed for electric power operation. Thus it was necessary to conduct separate tests to determine the optimum speed. The problems involved screen size, grinding rate, fineness modulus, and motor load (Table 2).

"Looping" fluctuations with long periods of time in each overload cycle are
created by a high-inertia mill. These reduce the operating time of the feed-
in mechanisms, thus reducing capacity.   (Fig. 5)
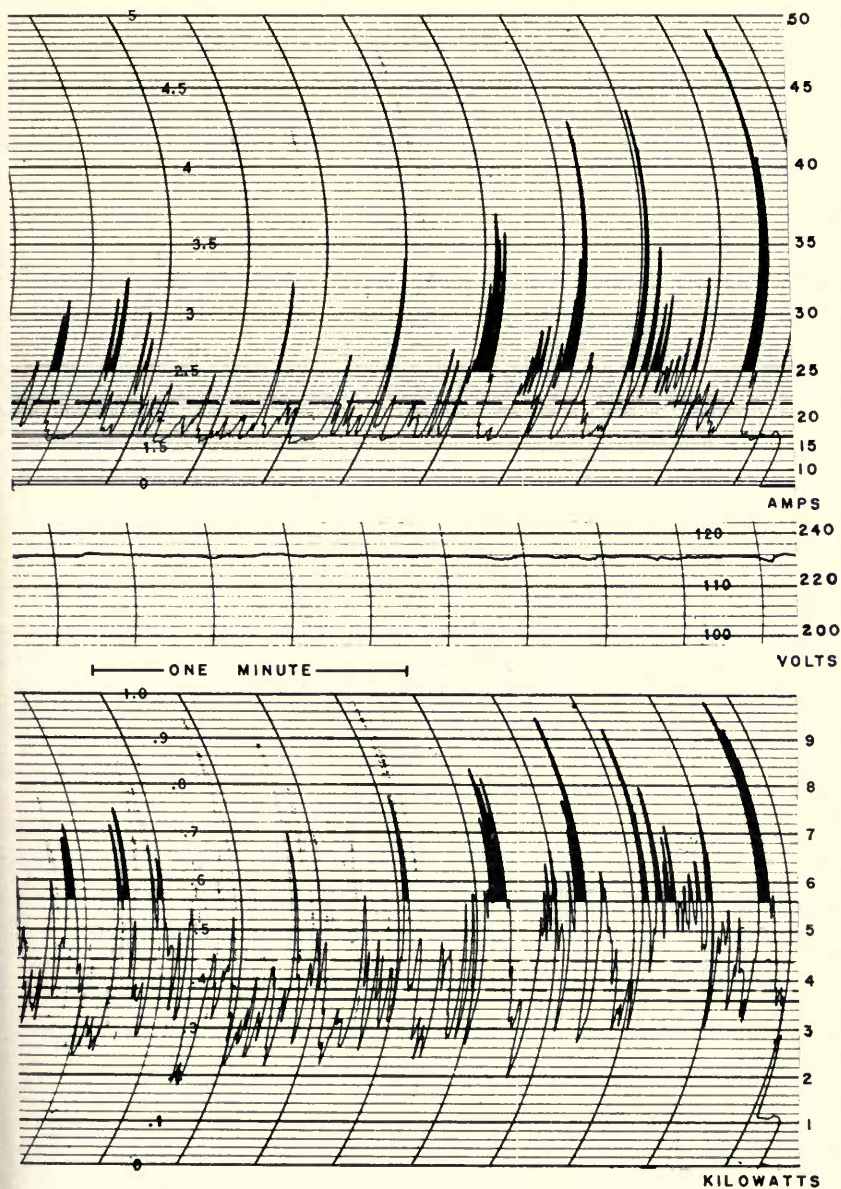
The electrical load characteristics of the burr mill were similar to those of the hammermills. Fluctuations were less frequent and of short duration, but occasionally very severe, approaching 50 amperes.   (Fig. 6)
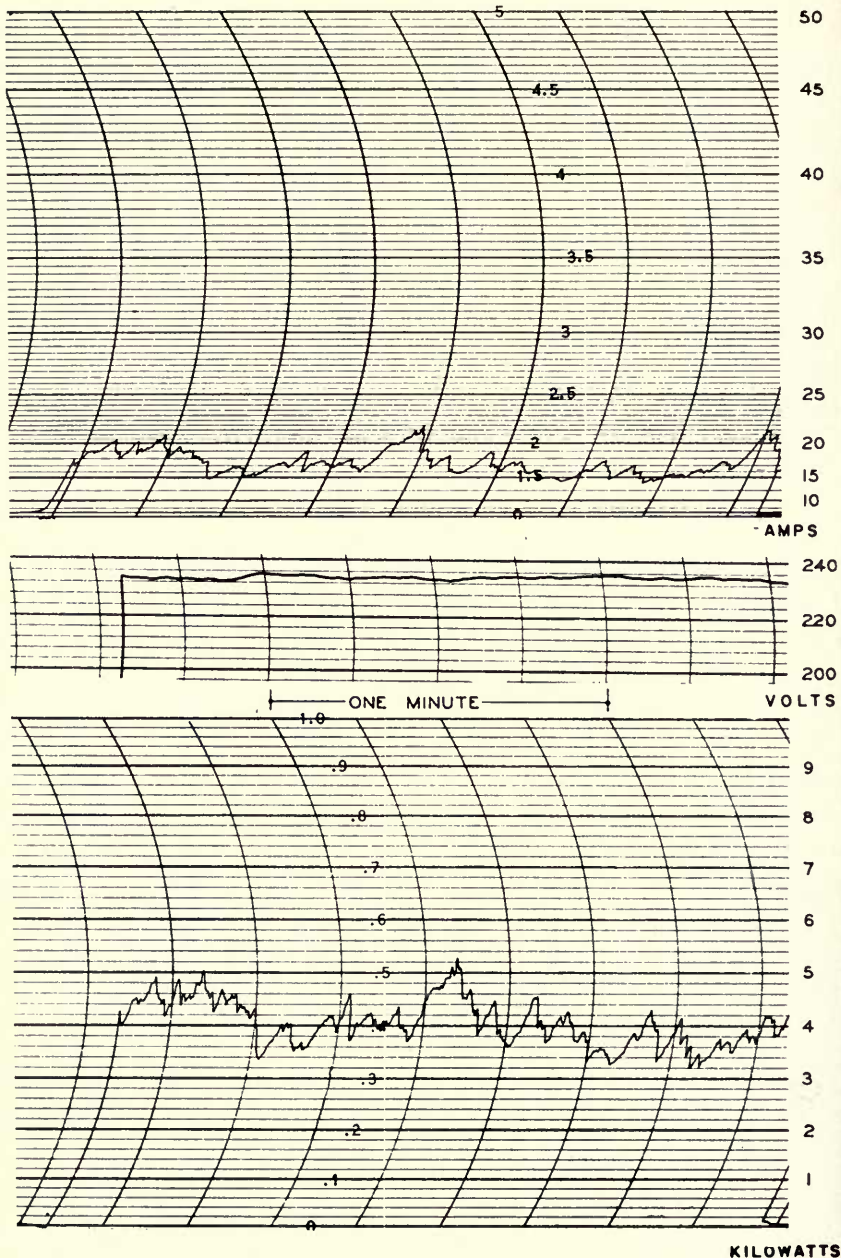
Unusually low and uniform current and power curves were obtained with the cutterhead mill. The automatic electric controls were not activated since no overload fluctuations exceeded 25 amperes, yet the capacity exceeded that of all other mills.   (Fig. 7)

Table 2. — Test for Optimum Speed for Cutterhead Mill
for Ear-Corn Grinding

Speed	Screen size	Fineness modulus	Grinding rate (pounds per kilowatt-hour)	Proportion of operating time at—		
				Underload (below 25 amperes)	Desirable load (25 to 30 amperes)	Normal overload (above 30 amperes)
r.p.m.	*inches*			*perct.*	*perct.*	*perct.*
385	⁷⁄₁₆	5.55	(ᵃ)	100	0	0
485	⁷⁄₁₆	5.37	(ᵃ)	100	0	0
695	⁷⁄₁₆	4.89	520	100	0	0
815	⁷⁄₁₆	4.83	432	96.8	3.2	0
1200	⁷⁄₁₆	4.68	408	60.7	28.0	11.3ᵇ
1200	1	5.49	(ᵃ)	100	0	0
400	³⁄₈	4.65	622	100	0	0
500	³⁄₈	4.33	538	100	0	0

[a] Too coarse for suitable ration—capacity data not taken.
[b] One percent of this time was above 40 amperes.

The slower speeds with 7/16″ screen and a high speed with 1″ screen gave a product that was too coarse for suitable rations as indicated in Table 2. As the speed increased, the fineness modulus was reduced but the capacity per kilowatt-hour was less, and the amount and severity of load fluctuations increased. The most generally satisfactory results were obtained with a ³⁄₈″ screen and speed of 500 r.p.m. At this slow speed the grind was more uniform with less dust, and the mill could be restarted when stopped with grain in the grinding chamber.

Motor Tests

With two exceptions, the tests on 5-hp. electric motors were made on the swinging-hammer mill with low-inertia rotor (Table 1). The mill had better-than-average performance and desirable electrical load characteristics.

Tests were made on 10 motors as follows:

Repulsion-induction start-and-run, 1,800 r.p.m...........................1
Repulsion-start induction-run, 1,800 r.p.m..............................4
Repulsion-start induction-run, 3,600 r.p.m..............................3
Capacitor-start induction-run, 1,800 r.p.m..............................1
Capacitor-start capacitor-run, 1,800 r.p.m..............................1

The most important motor-operating characteristics are the maximum current drawn and the length of time spent in severe overload conditions. High currents, even though momentary, create voltage drop and resultant light flicker throughout the lines. Prolonged and
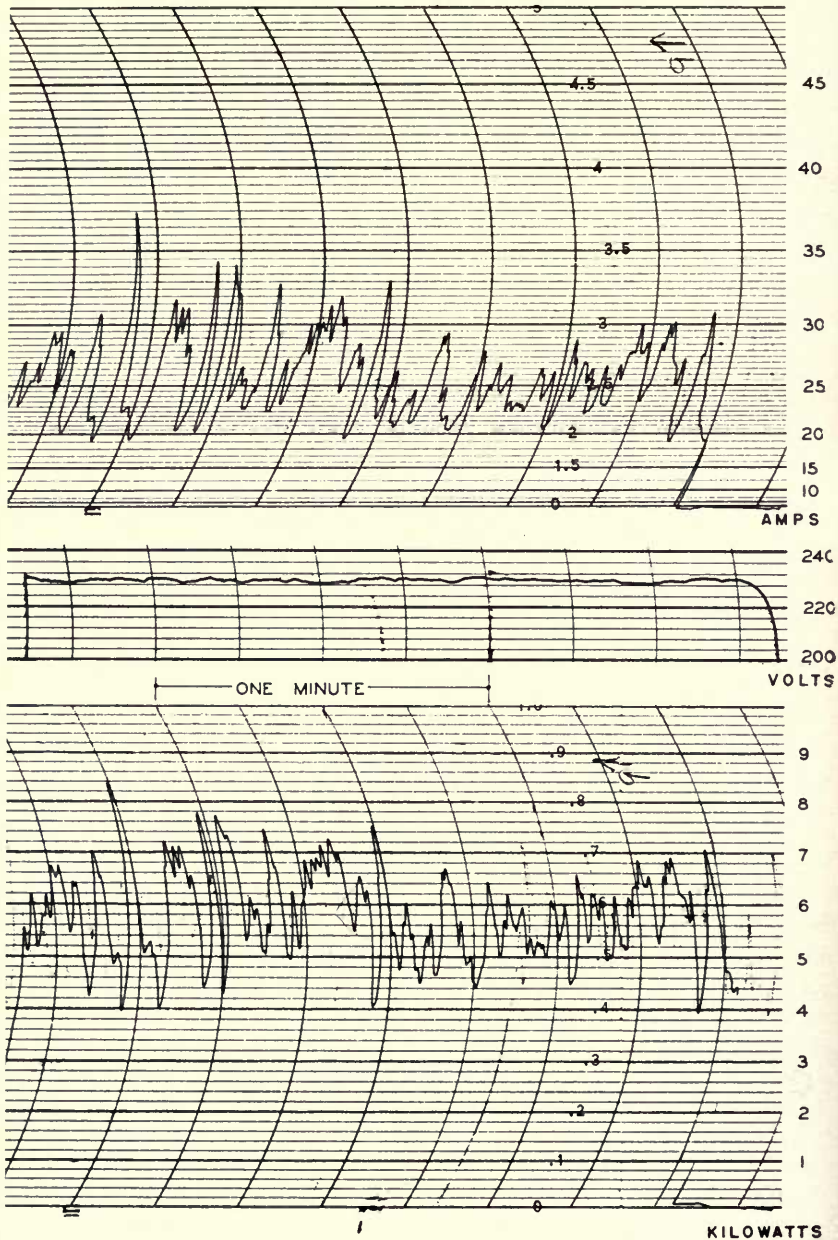
Load conditions of a repulsion-induction, start-and-run motor with relatively low rated current (Motor A, Fig. 1) while powering a small low-inertia mill designed specifically for automatic grinding (basically same as Mill No. 1, Table 1). This was the "base" motor used in all the grinder tests and the grinder was the "base" grinder for the motor tests. Current fluctuations did not exceed 38 amperes and were of short duration. Rate of feeding was 1,965 pounds per hour.   (Fig. 8)
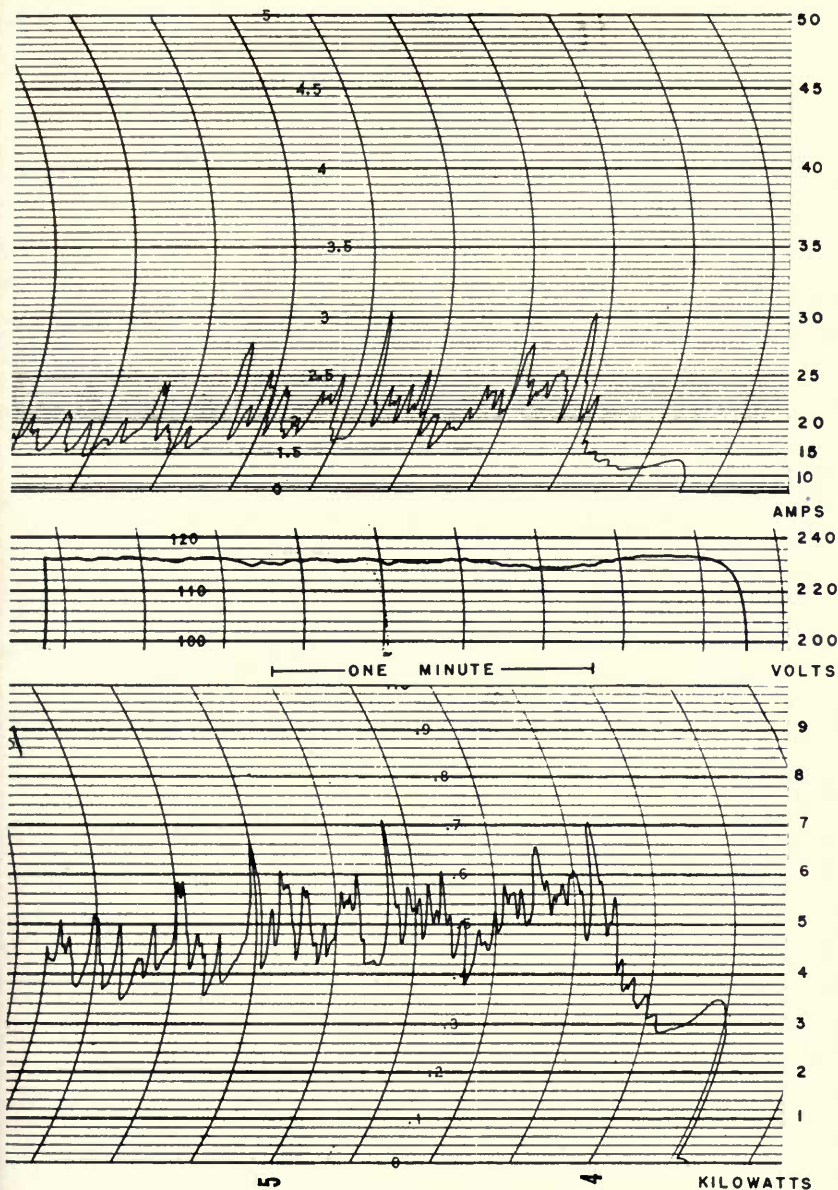
Electrical load conditions created by capacitor-start capacitor-run motor
with relatively low rated current. The tests showed little difference in per-
formance and electrical load characteristics between this motor and the
repulsion-induction start-and-run motor (Fig. 8). Rate of feeding was 1,365
pounds per hour, resulting in a lower curve throughout. The rate per kilo-
watt-hour was similar to that of the repulsion-induction start-and-run motor.
(Fig. 9)

severe overloads cause high power demand, heating in fuse boxes, and overloads on normally satisfactory transformers and wiring.

Excessive power demand can materially affect the economy of electric service where the power rate is based on a demand charge. Thus a motor with a low power factor and high current characteristics may add materially to the demand rate charged the customer. When such conditions exist, it may be profitable to pay 10 or 15 percent more for a motor with high power factor and low demand characteristics.

Due to differences among motors in normal rated current at rated load, the ammeter chart analysis used in the grinder tests could not be applied. Visual comparison of the charts was used to reveal the differences in motor characteristics. The significant items observed and evaluated were:

Maximum current drawn during grinding conditions.

Frequency of extreme fluctuations of current, power, and voltage.

Time on overload. Most protective devices will tolerate 120-150 percent of normal load for short periods.

Slope of recovery curve from a severe current fluctuation. A motor with a quick recovery (nearly vertical curve) allows the feed-in mechanisms to restart quicker and operate for a higher percentage of the time during grinding.

The ammeter charts, Figs. 8 to 11, illustrate the motor performance under the conditions of the tests. The same mill was used throughout the series.

Comparison of Extreme Variations

In order to obtain uniformity, the tests were made largely with one "base" motor on the several grinders tested and with one hammermill as a base for the study of motors. It is evident, however, that a good system for automatic grinding depends not only on good design of both the grinder and the motor. It is also necessary to obtain the best possible combination of the two. Thus in order to minimize the farm wiring and power supply problems and assure satisfaction to the customer it is important that the manufacturers make certain that their motors and grinders are designed to make them suitable for automatic ear-corn grinding.

The necessity for integrated design is strikingly illustrated in Fig. 12. A grinder with undesirable characteristics (left) was operated by a motor also unsuitable for automatic grinding. The result was that grinding capacity was reduced to 915 pounds per hour; voltage dropped
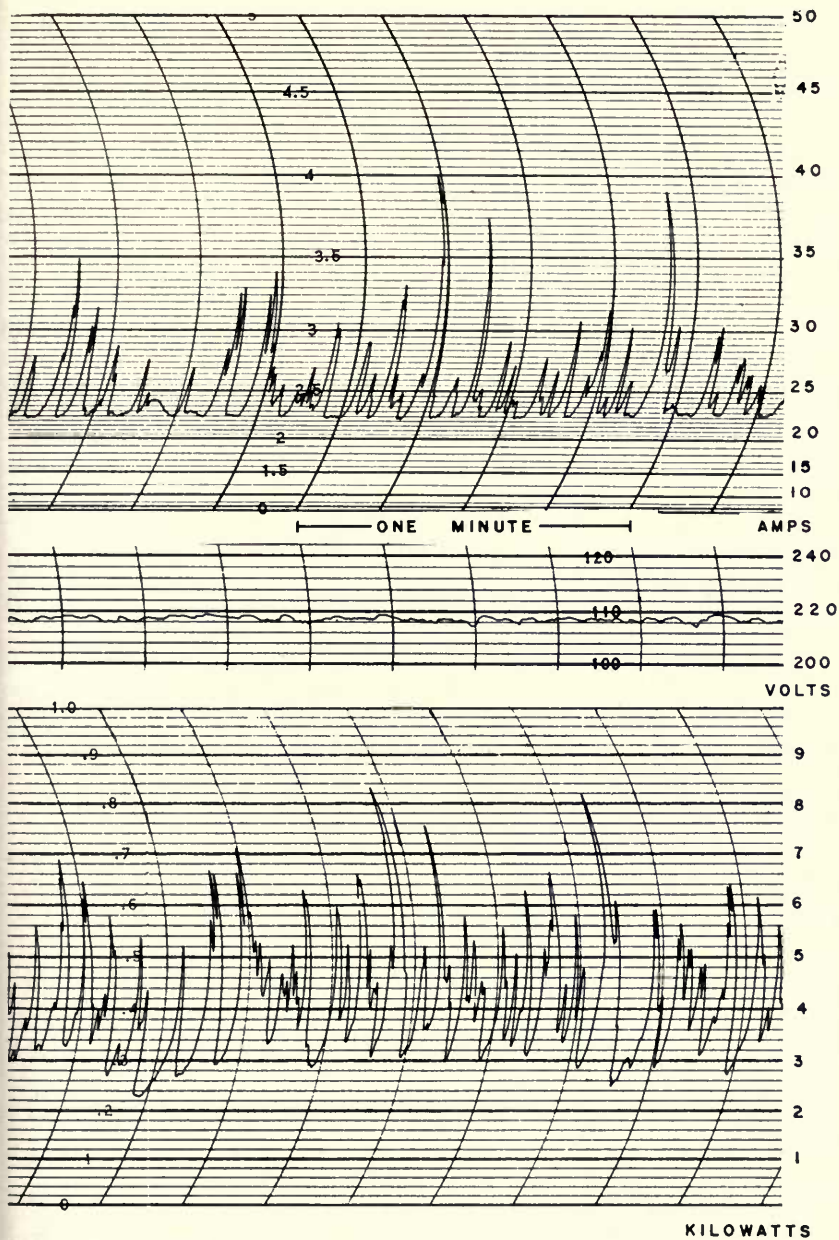
These curves were obtained with a repulsion-start induction-run motor. They are somewhat similar to those in Figs. 8 and 9, but show a clearly defined minimum current. High no-load current tended to delay the action of the control in restarting the feeding devices. Rate of feeding was 1,524 pounds per hour.   (Fig. 10)
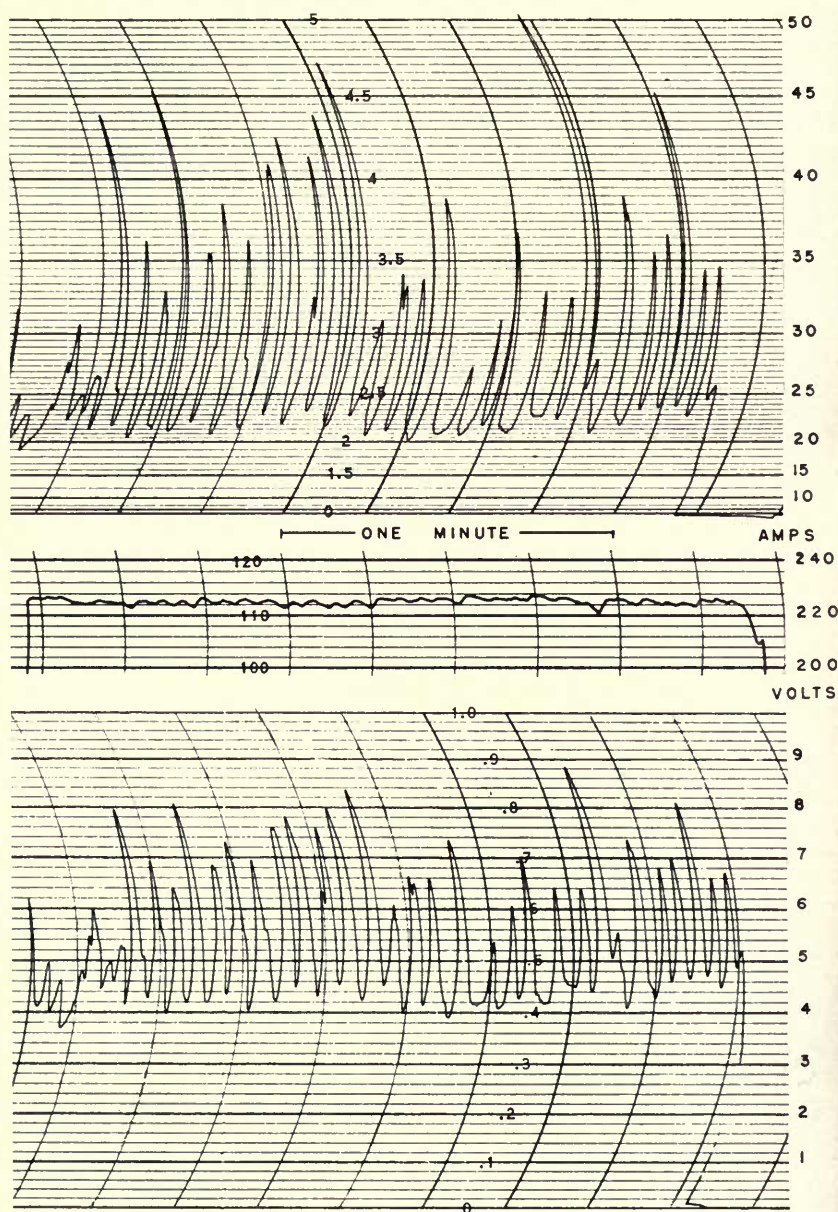
Characteristics of a motor with a current curve similar to Motor B in Fig. 1.
Frequent and severe current fluctuations created a wavy voltage line and
reduced grinding capacity. This was a totally enclosed, fan-cooled, 3,600
r.p.m. motor. While it has the advantages of a 1:1 ratio for small hammer-
mill drive, and the safety feature of total enclosure, its less satisfactory
electrical load characteristics make the use of this motor questionable. Rate
of feeding was 1,170 pounds per hour. (Manufacturer's experimental model.)
(Fig. 11)
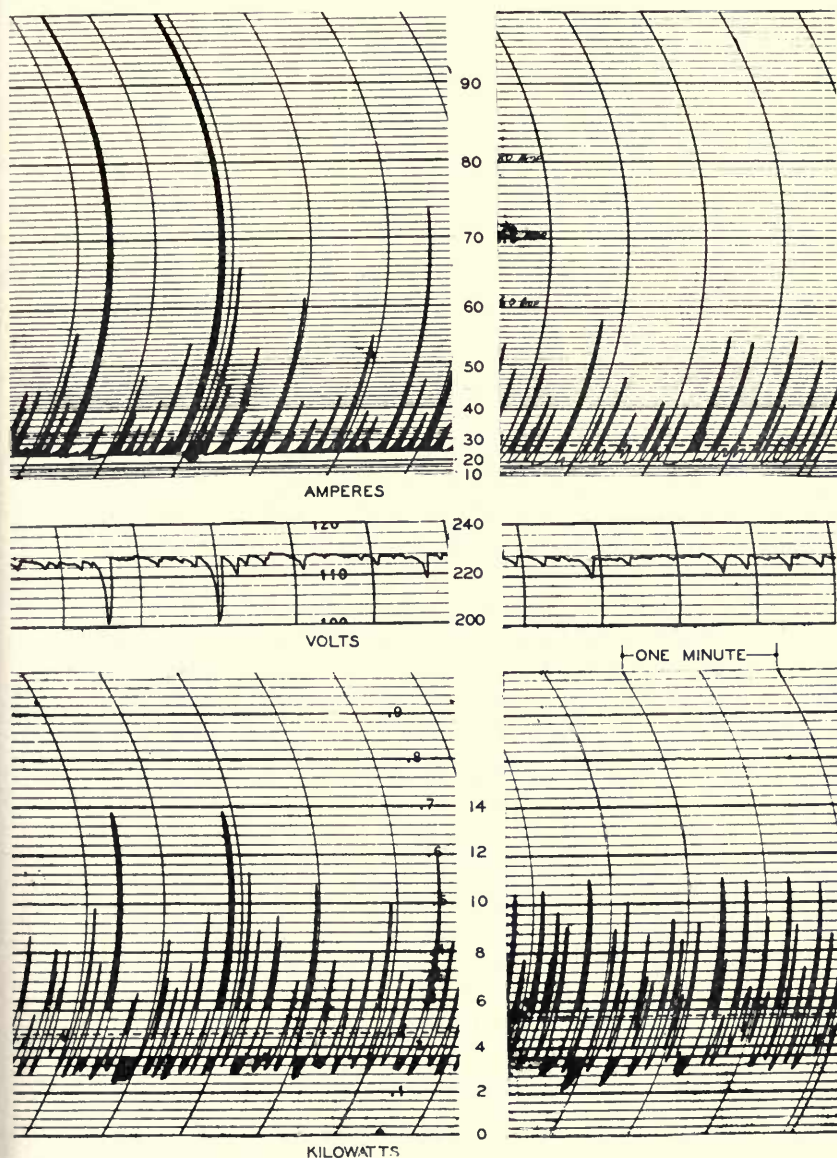
Effect of combinations of extreme conditions. The motor and mill charted at the left had the least satisfactory characteristics when tested separately. When combined, they create a condition that would not be acceptable on most farm power lines. This same mill used with a motor with desirable characteristics reduced current fluctuations from 100 amperes maximum to 60 amperes (right). Rates of feeding were 915 pounds per hour for the combination at the left and 1,125 pounds per hour at the right. (Manufacturer's experimental model.)   (Fig. 12)

from 228 to 201 volts; and current surges approached 100 amperes. Such a combination could not be used satisfactorily.

The electrical load when the same grinder was operated by a motor with "good" characteristics is shown in the right half of Fig. 12. The capacity of the mill was increased to 1,125 pounds per hour with maximum current surges to 60 amperes.

The well-adapted motor when used with another mill gave grinding capacity of 2,000 pounds per hour with current fluctuations that did not exceed 40 amperes. The best mill and motor combination for ear-corn grinding, from the standpoint of electrical load characteristics, handled 2,500 pounds of ear corn; the current surges did not exceed 25 amperes.

Farm Installation Tests

Five tests of grinders and motors were made on farms where automatic systems had been installed as a phase of the research program. These tests are useful to indicate results under practical farm conditions, but they do not have the same significance as the laboratory studies because it was not possible to obtain uniform test conditions. Moreover, variations in feeding and management practices among farms make it difficult to anticipate capacities, costs, and operating conditions.

In four of the five tests the same make and model of both grinder (Mill No. 1, Table 1) and motor (Motor A, Fig. 1) was used. The test procedure was similar to that used in the laboratory, however, and complete data were taken. The ammeter charts were divided into three parts to show normal range from 75 to 125 percent full load and underloads and overloads outside this range.

In general, the tests showed relatively good performance. On farm No. 4, using a high-inertia mill, the motor was subjected to prolonged overload when grinding oats. On farm No. 5 the motor operated below capacity for a considerable time. Fine grinding naturally reduced the capacity. Oats in the ration invariably cut down the grinding rate and increased the energy consumption.

The conditions found on these farms emphasize the importance of protective devices, explicit instructions, and rugged equipment. The more nearly automatic the machinery, the greater the tendency to neglect regular maintenance. On most farms little attention was given to routine lubrication, mechanical adjustment, belt tension, and replacement of worn parts.

The most serious condition observed was the accumulation of

Table 3. — Conditions and Results of Eight Grinding Tests on Five Farms With Automatic 5-Horsepower Grinders

	Beef rations			Rations for hogs			Dairy rations	
Feed ground	Ear corn	Ear corn	Ear corn	Oats	Oats	Ration 1[a]	Ration 2[a]	Ration 3[a]
Screen size	8⁄4″	3⁄4″	3⁄4″	1⁄8″	1⁄8″	1⁄8″	3⁄8″	1⁄2″
Fineness modulus	4.17	3.82	2.80	2.23	2.28	2.38	3.11	3.81
Farm No.	5	3	4	4	3	5	2[c]	1[c]
Rate of grinding								
Pounds per hour	1,360	1,554	1,590	215	225	696	860	1,894
Pounds per kilowatt-hour	402	345	306	36.8	49.0	151	185	425
Time to reach full speed (sec.)	2.4	2.4	4.2	4.2	2.4	2.4	2.3	2.4
Voltage								
Before start	237	234	238	238	234	237	240	235
Starting	208	209	204	204	209	208	219	204
No load run	228	230	236	236	230	228	238	228
Current (amperes)								
Start	69.5	64.0	79.0[b]	79.0[b]	64.0	69.5	90.0[c]	70.5[c]
Operating maximum	25.0	37.0	33.1	32.1	25.5	23.5	38.5	37.0
Operating minimum	16.0	15.6	18.5	21.0	17.5	18.0	17.0	16.0
Operating average	19.0	21.5	24.7	27.7	21.4	20.6	....	22.7
Percent of time below 75% rated load	34.7	4.0	0	0	0	0	....	10
Percent of time above 125% rated load	0	9.0	38.9	66.9	30.0	0	....	20
Kilowatts								
Start	8.8	8.6	10.4	10.4	8.6	8.8	....	....
Operating maximum	5.59	8.0	7.1	6.82	5.6	5.2	8.4	6.8
Operating minimum	2.20	2.9	3.59	4.16	3.35	3.4	3.2	3.2
Operating average	3.38	4.5	5.20	5.85	4.6	4.6	4.65	4.46
Percent of time below 75% full power	65.3	8.32	.1	0	.1	.1	18.7	13.0
Percent of time above 125% full power	0	7.9	28.8	5.3	0	0	17.4	13.2

[a] Ration 1: oats 30%, shelled corn 55%, supplement 15%; Ration 2: oats 30%, ear corn 70%; Ration 3: oats 50%, ear corn 50%.
[b] Farm 4 had a high-inertia hammermill and a different 5-horsepower motor; others had low-inertia mills of another make and identical motors. All motors were 5-horsepower repulsion-induction type. A significant difference is noted in starting current.
[c] Had 3-horsepower auxiliary blower. The starting current indicated is the total of the starting current of the 5-horsepower motor plus the operating current of the 3-horsepower auxiliary blower motor. The controls prevent simultaneous starting.

grain, ground feed, dust, husks, and trash around the motor and grinder. Air vents in some of the motors were completely blocked off. Such conditions cause overheating, fire hazards, and eventual damage.

Conclusions and Recommendations

Mills of several types can be adapted to automatic operation. The hammermills, burr mill, and reel-type cutterhead mill were tested in an automatic system.

Low-inertia, swinging-hammer mills had the most desirable load characteristics of the hammermills tested.

The cutterhead mill exhibited electrical load characteristics sufficiently uniform to justify further research as to its field performance, durability, and possible design changes.

Important design features for grinders include (1) ready accessibility and simple maintenance features for belt shields, belt-tension adjustment, and repairing, (2) lifetime lubricated bearings wherever possible, and (3) provision for clean operation and minimum leakage and spilling.

Grinder requirements of greatest significance are (1) designs to absorb all the power of a 5-hp. motor without plugging under the screen or in the ground-feed-removal conveyors, (2) ability to handle a nonuniform rate of feeding without transmitting the impact of each ear of corn back to the motor, and (3) immediate reaction to severe overloads in order to actuate control devices.

Motor characteristics found most desirable were a low rated load current (high power factor) and relatively low current under severe overload. In areas where power suppliers have established demand rate service charges, such motors might be worth 10 to 15 percent more if they effect savings in demand rate.

Repulsion-induction motors have been generally recommended as the most suitable for farm loads such as feed grinding. Based on the laboratory tests only, it appears that recent developments in capacitor motors may make them as good as or even better than some repulsion-induction motors for automatic grinding.

Motor design should include features for minimum service and maintenance and protection against rodents, loose grain, dust, and husks. It does not appear feasible or practical, however, to demand totally enclosed fan-cooled explosion-proof motors unless such motors exhibit satisfactory characteristics and can be obtained at a reasonable cost.