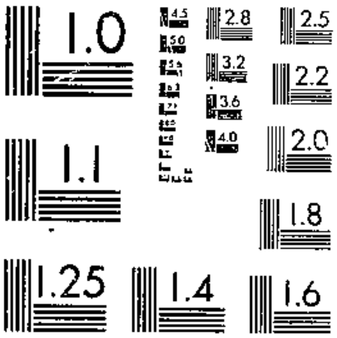
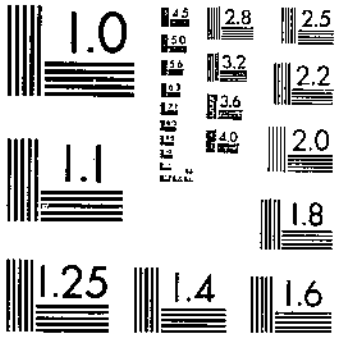
TB 1394 (1968) USDA TECHNICAL BULLETINS UPDATA
PERFORMANCE OF SMALL HAMMER AND ROLLER MILLS FOR GRINDING LIVESTOCK FEED
PUCKETT, H.B.; DAUM, D.R. 1 OF 1

START



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Performance of Small Hammer and Roller Mills For Grinding Livestock Feed

Technical Bulletin No. 1394

UNITED STATES DEPARTMENT OF AGRICULTURE
Agricultural Research Service

CONTENTS

Washington, D.C. Issued June 1968

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price 15 cents

Performance of Small Hammer and Roller Mills For Grinding Livestock Feed[1]

By H. B. Puckett, *investigation leader, Farm Electrification Research Branch, Agricultural Research Service, U.S. Department of Agriculture*, and D. R. Daum, *assistant professor of agricultural engineering, University of Illinois*

Farmers' interest in feed processing equipment has grown as their practice of preparing feed on the farm for their dairy and beef cattle, swine, and poultry has increased. Feed-grinding mills and feed mixers are the principal processing equipment needed in preparing livestock or poultry rations.

More definite information is needed on the performance of feed-grinding mills to enable engineers to design automatic feed preparation systems. This report describes the only tests that have been made on small (2- to 5-horsepower) feed grinders since the small combination feed grinder and mixing device was developed. These tests were conducted because little information was available on hammer mills and roller mills. These test data will assist engineers to correlate the effects of the several parameters on feed mill performance.

TYPES OF GRINDING MILLS

There are three common types of feed-grinding mills, the burr mill, the hammer mill (fig. 1), and the roller mill (fig. 2). The knife mill, a fourth type, is not as popular as the others. The mills are used to abrade or crush grains and forages, to change their physical forms so that animals can use them more efficiently, or to mix them with other ingredients. The type of mill that is selected will depend on the requirements for preparing a given ration and also, in a large measure, on the operator's choice.

All feed mills are easily damaged by foreign objects, such as "tramp iron" (small pieces of iron or steel, such as nails, and short pieces of wire) and rocks. An effort should be made to eliminate this material before it gets into the mill. If it reaches the mill, the damage may be extensive and the repair costly. If it passes through the mill, as tramp iron sometimes does, it may injure the livestock. Short pieces of baling wire and nails will puncture the

[1] Report of cooperative research with the Agricultural Engineering Department of the University of Illinois, Urbana, Ill.

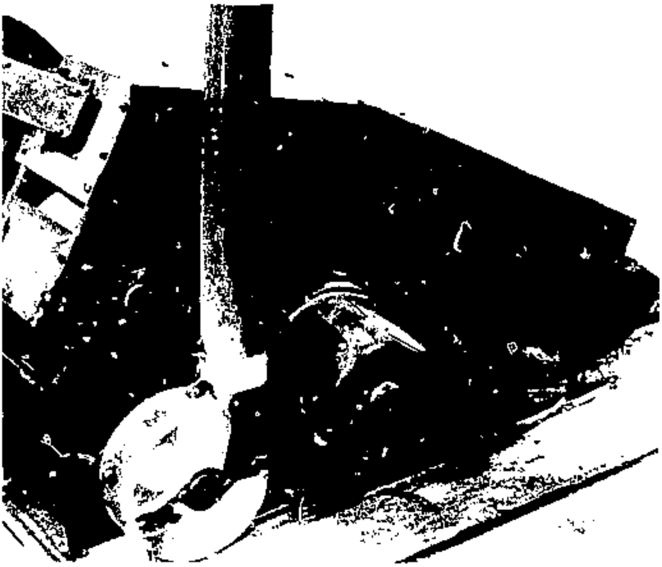


FIGURE 1.—The hammer mill is simple in design and can grind a wide range of materials, from small grain to hay. It can be operated while empty with no damage.

stomachs of cattle. Taking care not to pick up foreign objects and using strong magnets at the mill are the best ways to keep foreign materials out of the grinder and the feed.

The hammer mill and the roller mill are the two types of feed grinders used most often to prepare livestock feed. These mills are rugged and can grind several types of grain with only minor adjustments or changes. Some hammer mills are more useful to the livestock producer than others because they can also grind hay.

Both the hammer mill and the roller mill are relatively easy to control automatically. This feature makes them attractive to the producer who is interested in automation and wants to reduce production costs and routine tasks.

Burr Mills

The burr mill is one of the earliest types of reduction mills. It descends directly from the mortar and pestle and the stone mill. It has a relatively low cost and it can grind grain to almost any desired degree of fineness. In coarse grinding, it will produce a lower percentage of "fines" (small particles, powder, and dust) than the hammer mill. But it will usually grind only one type (or size) of grain at one time, and it cannot grind hay. Also, the burrs wear out rapidly and may be damaged if the mill is operated while empty.

Hammer Mills

The hammer mill is perhaps the most popular type of feed mill. It will grind all dry feed materials and will also do a relatively good job of grinding different grains at the same time. The hammer mill relies on the impact of high-speed hammers to reduce particle size. The size of the screen will determine the average number of times a kernel or particle is struck before it passes through the screen. Screens are usually available with $\frac{1}{16}$- to 1-inch-diameter holes in $\frac{1}{32}$-inch steps. The impact produces a relatively high percentage of fines, which livestock feeders find objectionable. The hammer mill may be operated while empty without damaging the machine. The variation in screen size plus the ability to satisfactorily grind more than one grain at a time makes the hammer mill well suited for use in automatic feed-processing systems.

Roller Mills

The roller mill usually costs more than either the burr or the hammer mill because it must be more rugged. It has a higher

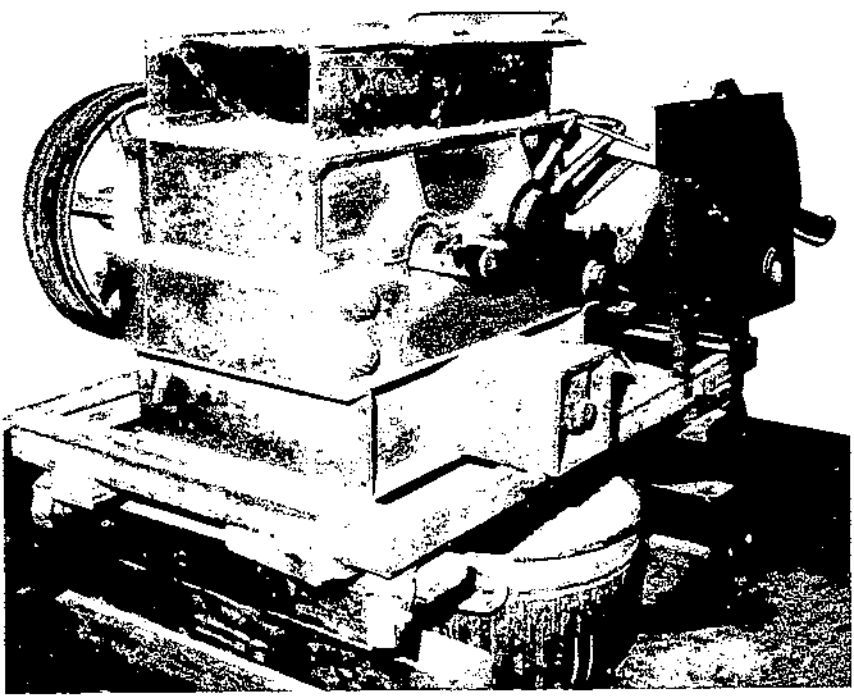


FIGURE 2.—The roller mill, though simple in design, requires strong parts. It can be operated while empty with no damage. It is used to crush small grain and is popular with cattle feeders.

capacity per horsepower input because it reduces the particles less than the other mills do. Usually it breaks only the outer coat, making digestion of the feed easier and more complete. The roller mill is becoming more popular among cattle feeders, primarily because it produces few fines.

The roller mill is perhaps used more than any other type of mill for grinding high-moisture shelled corn, although the hammer mill can also be used, sometimes without a screen, for this purpose.

A roller mill usually has two rollers of equal diameter (6 inches or larger). One roller is fixed and the other can be moved to adjust the clearance between the two. Although the rollers may be smooth, they usually have grooves parallel to the axis. The two rollers may be operated at the same speed or at different speeds. Turning one roller faster than the other increases abrasion and helps to keep the rollers clean when high-moisture grain is being processed. The roller mill can satisfactorily grind only one size of grain at a time, but special roller mills are available that, in effect, serve as two or three mills (two or three pairs of rollers). Each pair of rollers can be adjusted independently to grind a different grain.

The roller mill cannot be started under load. Two or three kernels of grain between the rollers are sufficient to prevent starting. It can be operated while empty with no damage. When equipped with the proper controls, the roller mill can be operated automatically with an electric motor.

Knife Mills

The knife mill is not used as widely as the other three. As in the hammer mill, screen size determines fineness of grind. Instead of high-speed hammers to crush the grain, the knife mill has rotating knives that pass over the screen and cut the grain. If the knives are sharp, this mill can process more grain per horsepower-hour than a hammer mill. But the knives dull rapidly, and it requires more maintenance than the other mills. The knife mill can be used to grind more than one ingredient at a time and can be operated while empty with no damage.

PERFORMANCE TESTS

Widely differing performance ratings have been ascribed to different models of similar feed-grinding equipment. The design of the equipment has changed significantly during the 35 years since E. A. Silver, of Ohio State University, published the results of his study of feed grinder performance.[2] The most significant change has been the use of the low-horsepower (usually 5 hp. or less) hammer mill with full-circle screen and the roller mill. The growing use of these two mills in automatic systems for producing livestock feed

---

[2] SILVER, E. A. FEED GRINDER INVESTIGATIONS. Ohio Agr. Expt. Sta. Bul. 490, 49 pp., illus. 1931.

prompted the series of tests reported here to determine their effectiveness in grinding common grains (shelled corn, oats, and wheat).

Test Equipment

The power input required by the test mills was determined by measuring the kilowatt demand of the motor. Horsepower output of the motor for a given kilowatt demand was determined by calibrating the motor on an electric dynamometer (fig. 3). The kilowatt demand was determined by measuring the energy consumption for a 12-second period. This figure then represented the average kilowatt demand for 12 seconds and was more reliable than readings from a rapidly fluctuating indicator on a wattmeter.

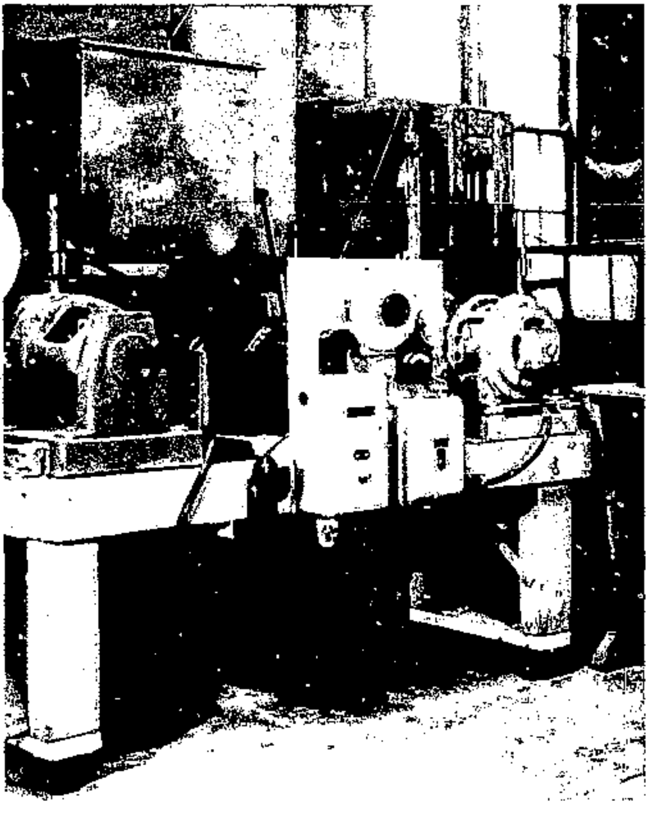


FIGURE 3.—Motors used on the test mills were calibrated on an electric dynamometer to establish the relation between kilowatt input and horsepower output.

A special electric measuring test stand was constructed to measure the energy consumption for these tests (fig. 4). The test stand provided the following features:

a. Master push-button power switch equipped for remote operation.

b. Line voltage correction for either line of a 120/240-volt single-phase service.

c. Electric stop timer equipped for remote operation.

d. Electric interval timer equipped for remote operation.

e. Four power circuits for measuring energy consumption. Any one of the four circuits could be connected to the indicating and recording instruments singly or in groups of two or more. Each circuit was independently controlled.

The interval timer was used to operate the voltage coil of a standard integrating watt-hour meter to measure energy consumption for a specified period of time. The line voltage correction capability was very useful. The test operator could quickly and easily adjust the operating voltage of the motor to that used on the dynamometer test to determine the horsepower more accurately.

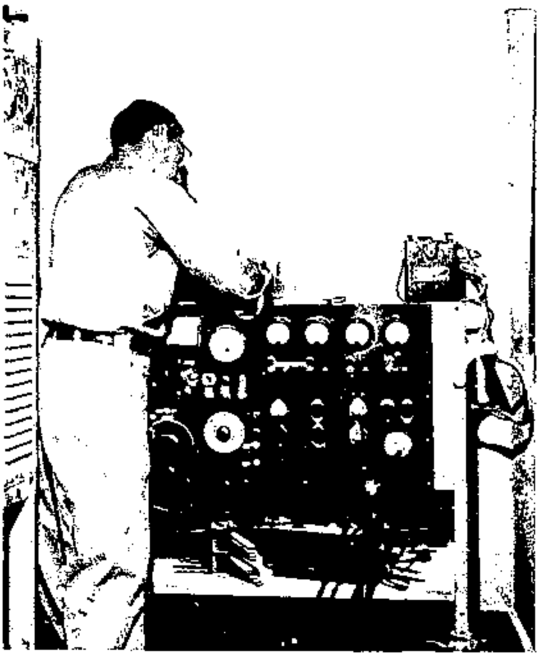


FIGURE 4.—To measure the electricity used by the test mills, measuring instruments were inserted into any one circuit or a combination of four circuits in this power test stand.

Hammer Mill Tests

These tests were conducted with a commercial hammer mill with a full-circle screen 14 inches in diameter and 6 inches wide (fig. 5). Screens of this size are commonly used in the low-horsepower hammer mills powered by electricity. The test mill was capable of fully automatic operation. It was equipped with an interval timer, no-feed and motor-overload safety controls, and a feed meter capable of blending as many as four separate ingredients. It was equipped at the factory with a 3-horsepower, 3,450-r.p.m., single-phase motor.

The feed meter was used in conducting the tests, but all other controls were omitted. The 3-horsepower motor was replaced by a 7½-horsepower motor capable of delivering up to 13 horsepower

FIGURE 5.—The test hammer mill was typical of the automatic electrically powered hammer mills available. It was connected with a supply hopper and placed on a stand to facilitate removal of the ground material.

for a short time (figs. 6 and 7). Use of the larger motor made it possible to determine what would occur in these small mills if rate of grinding was greatly increased, whether the screen could be saturated, and whether grinding efficiency would be affected. The hammer mill test installation is shown in figure 8.

The grinding rate is important to the user and to the engineer who designs a feed preparation system. The grinding or processing rate is a basic consideration in selecting the components for a continuous-flow system. The factors affecting the grinding rate of a hammer mill are size of motor, size of screen openings, percentage of open space of the screen, area of screen, type and number of hammers, hammer tip clearance, hammer tip speed, material to be ground, and moisture content.[3]

[3] For the purposes of this investigation, the size of motor, percentage of open space of the screen, area of screen, type of hammers, hammer tip clearance, and hammer tip speed were assumed to be constant.

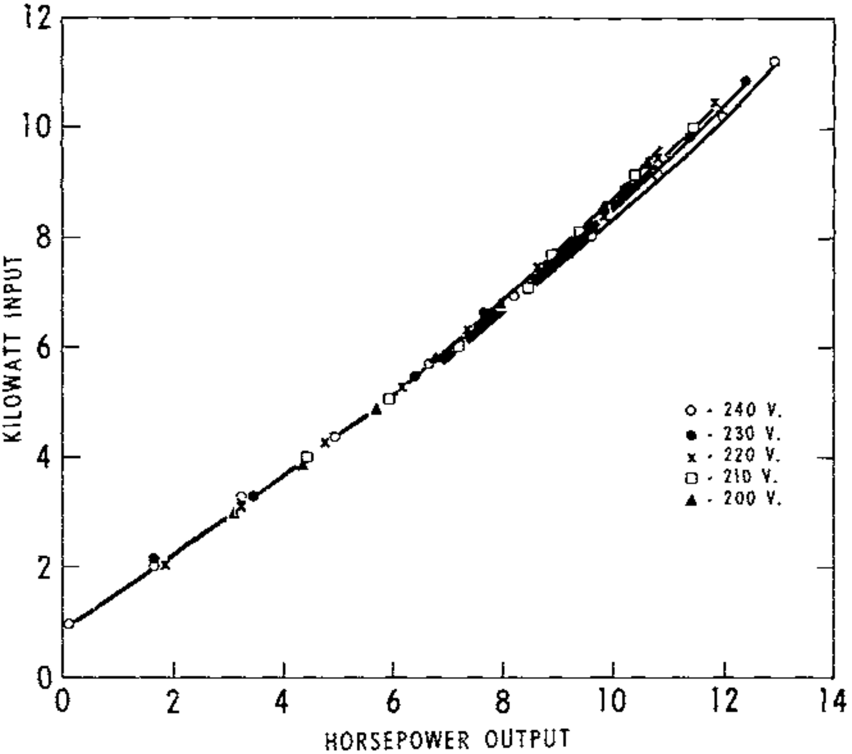


FIGURE 6.—Test of 7½-horsepower hammer mill motor (serial No. 171061). Input vs. output.

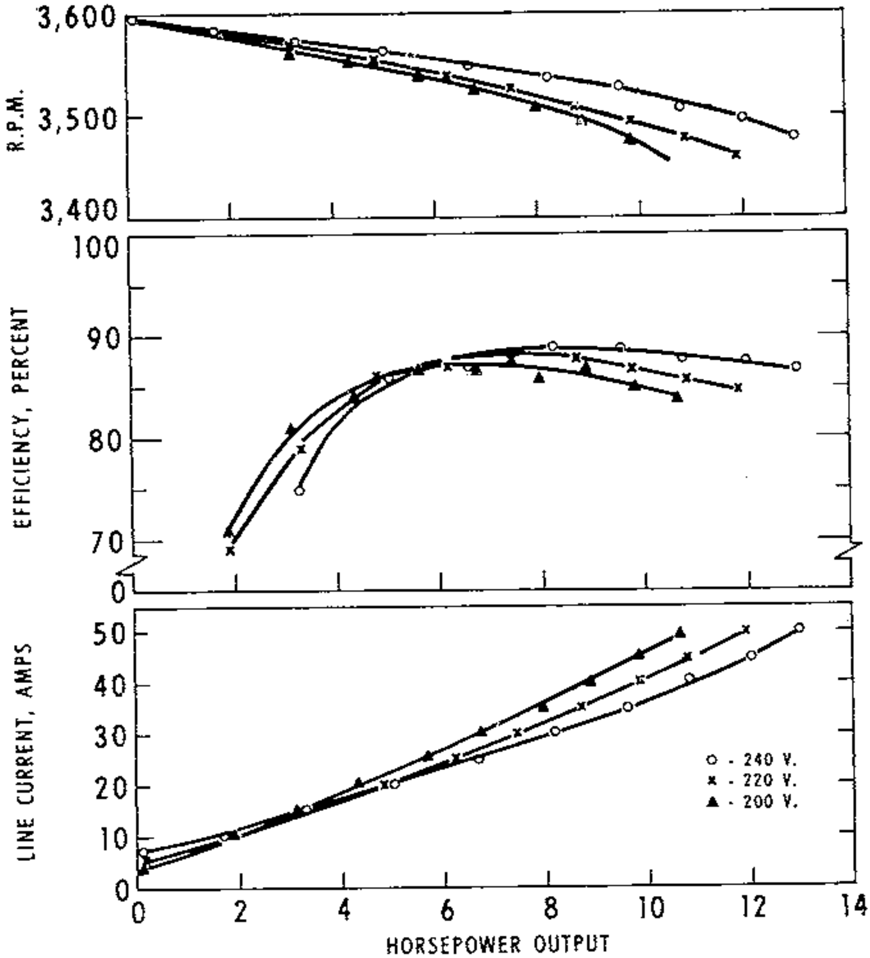


FIGURE 7.—Performance curves for 7½-horsepower hammer mill test motor (serial No. 171061).

The study was limited to the effects of the following:

a. Screen hole size (table 1 and fig. 9).

b. Number of hammers (fig. 10).

c. Material to be ground and its moisture content. Grinding rates were determined by measuring the time required to process a specific weight of material. Grain samples were taken for modulus tests for uniformity and fineness and moisture content tests.

Table 2 shows the maximum grinding rates for shelled corn with 15 percent and 25 percent moisture and oats with 7 percent moisture

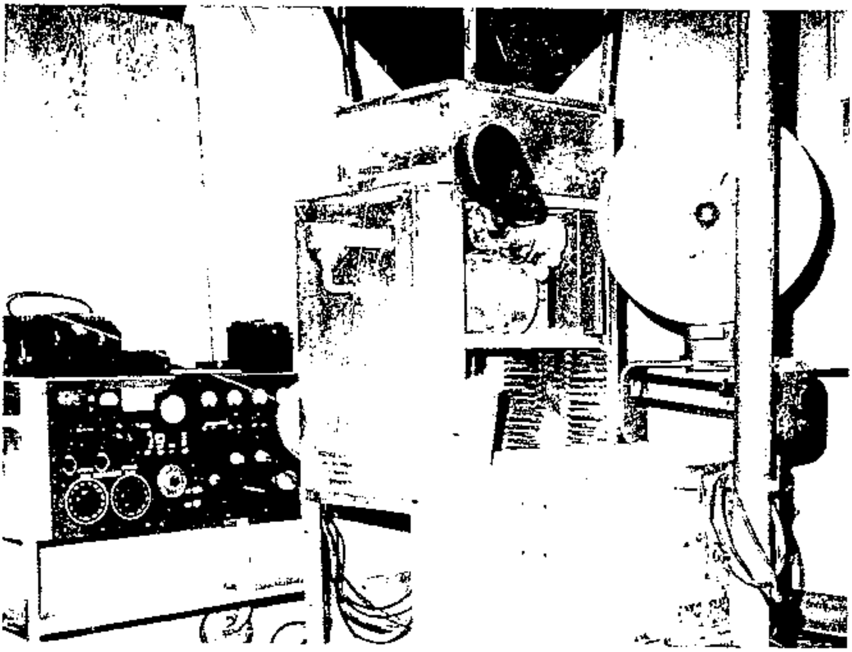


FIGURE 8.—The hammer mill test equipment consisted of the power-measuring equipment, the test mill, and a hopper mounted on a scale.

ground by mills with 2-, 3-, and 5-horsepower motors. Screen openings varied from 1/8 to 1/2 inch, and some tests were conducted with no screen. The maximum grinding rate increased with motor size and screen opening. For any given screen and motor, the rate was less for wet corn than for dry corn and was even less for oats. Sometimes the upper limit was imposed not by the available power, but by other restrictions, such as throat capacity or feed meter capacity.

To study the effect of moisture content, corn with 8, 15, 20, and 25 percent moisture was ground with screen openings varying from 1/8 to 1/2 inch and with no screen (fig. 11). Thirty hammers were used for this test. The energy required to grind the corn increased as the moisture increased from 8 to 20 percent and decreased slightly as moisture increased from 20 to 25 percent. As the screen opening increased, the energy required for grinding decreased. The modulus of fineness[4] increased with an increase in size of screen

[4] Modulus of fineness is an index depicting the average particle size of the material. It was determined by a standard procedure recommended by the American Society of Agricultural Engineers. The higher the index, the larger the average diameter of the particles.

opening. Grinding rate has some effect on energy requirements; the grinding efficiency (hp.-hr./ton) increases slightly at the higher rate.

TABLE 1.—*Size and spacing of holes and percentage of open space in hammer mill screens used in tests*

Size of holes	Spacing	Open space [1]
	Inches	*Percent*
⅛ inch	0.300 by 0.309	14
¼ inch	.375 by .438	30
⅜ inch	.488 by .563	51
½ inch	.508 by .664	58

[1] 100 percent open=no screen.

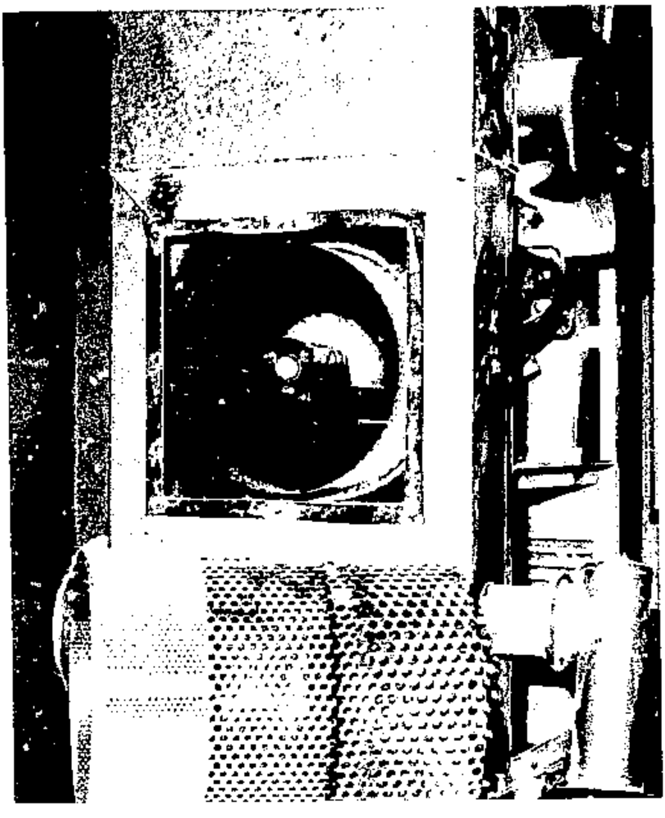


FIGURE 9.—Four sizes of screen openings were used in the hammer mill tests: ½-, ⅜-, ¼-, and ⅛-inch holes.

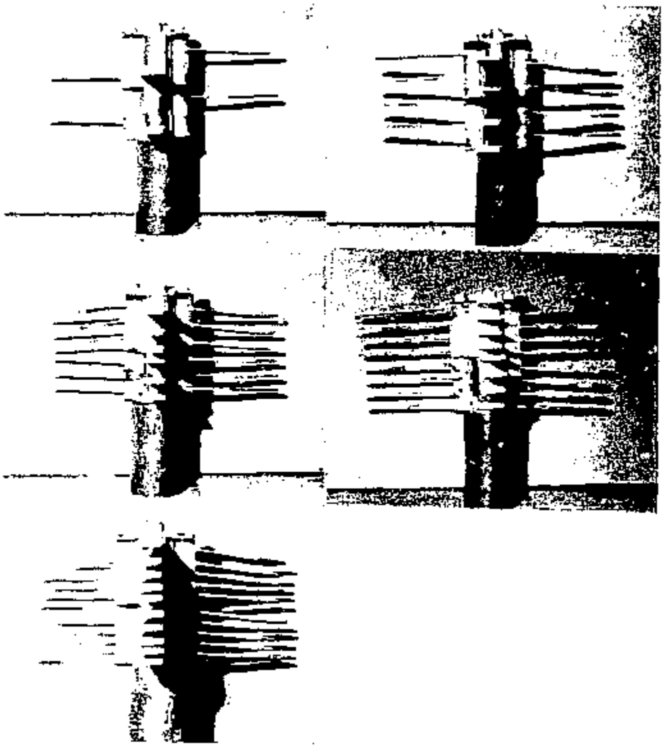


FIGURE 10.—Five hammer groupings were used in the test: 6, 12, 18, 24, and 30. The hammers were arranged in three rows. Hammers were spaced so that no two hammers passed over the same section of the screen.

The effect of number of hammers and screen size was determined by grinding shelled corn containing 15 percent moisture while varying the number of hammers from 6 to 30 and the screen size openings from ⅛ to 1½ inch. A no-screen test was also run (fig. 12, top).

The number of hammers appeared to have little effect on grinding efficiency except with the small screen openings. With the ⅛-inch screen, minimum energy was required with 12 and 18 hammers; with the ¼-inch screen, minimum energy was required with 12 hammers. The energy required to grind shelled corn containing 15 percent moisture decreased and the modulus of fineness (average size of particles) increased as the screen opening increased. The modulus of fineness varied from an average of 2.63 with the ⅛-inch screen to 5.22 with no screen (fig. 12, bottom). At the same time, the energy decreased from an average of 7.87 horsepower-hours per ton with the ⅛-inch screen to an average of 0.88 horsepower-hours per ton with no screen.

TABLE 2.—*Maximum grinding rates for shelled corn and oats for a hammer mill*[1] *equipped with a 2-, 3-, or 5-hp. motor*

Material ground and size of screen	2-hp. motor	3-hp. motor	5-hp. motor
	Lb./hr.	*Lb./hr.*	*Lb./hr.*
Shelled corn, 15 percent moisture:			
1/8 inch	600	900	1,550
1/4 inch	1,200	1,850	3,150
3/8 inch	1,950	3,000	5,150
1/2 inch	2,300	3,650	[2] 5,200
No screen	4,500	[2] 5,200	[2] 5,200
Shelled corn, 25 percent moisture:			
1/8 inch	350	550	----
1/4 inch	850	1,300	----
3/8 inch	1,350	2,100	----
1/2 inch	1,750	2,700	----
No screen	[2] 3,600	[2] 3,600	----
Oats, 7 percent moisture:			
1/8 inch	200	300	450
1/4 inch	600	1,050	1,900
3/8 inch	1,550	2,400	[2] 3,200
1/2 inch	2,250	[2] 3,200	[2] 3,200

[1] With screen 14 inches in diameter and 6 inches wide and 30 hammers equally spaced in 3 rows.

[2] Motor is not limiting factor.

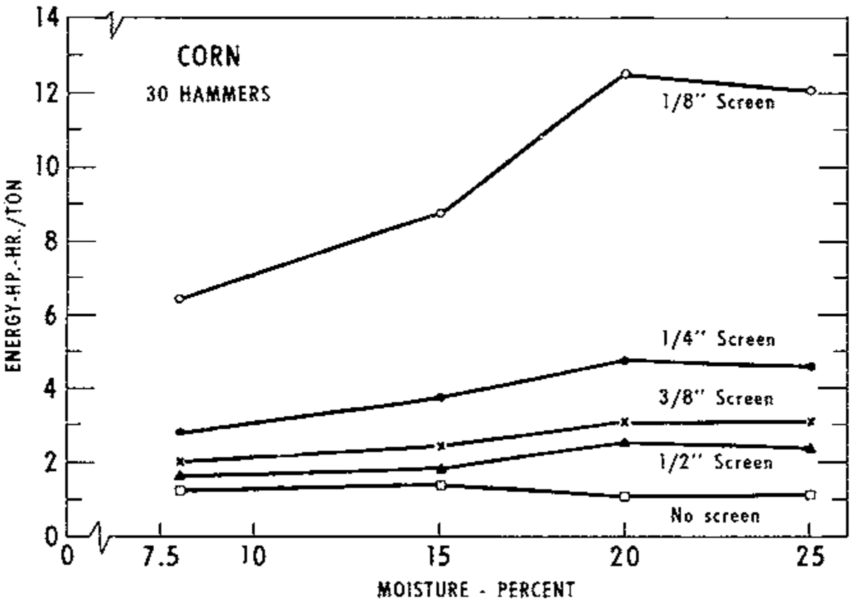


FIGURE 11.—Corn with moisture content of 8, 15, 20, and 25 percent was ground on a mill with 30 hammers, with screens ranging from 1/8 inch to 1/2 inch and with no screen. Up to 20-percent moisture content, the energy required for grinding increased with the increase in moisture content; as screen opening increased, the energy required per ton decreased.

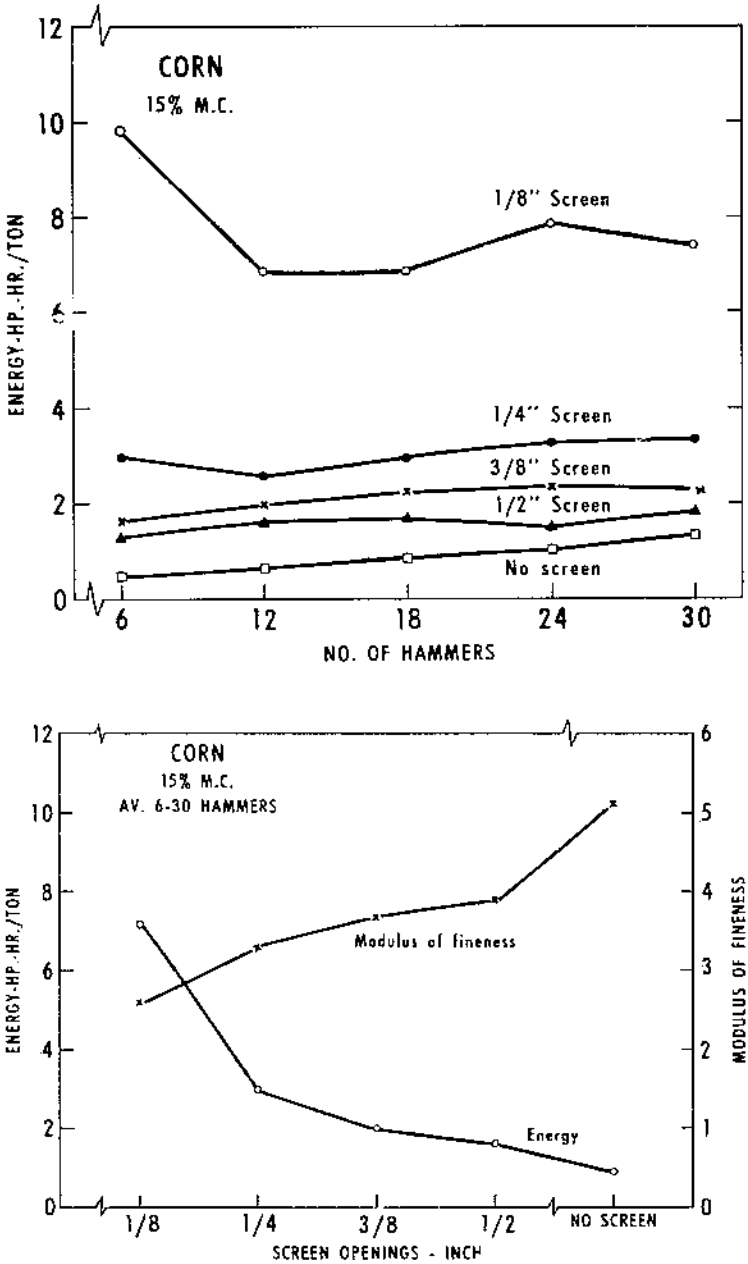


FIGURE 12.—Effect of number of hammers and screen size was determined by grinding shelled corn with 15-percent moisture content using from 6 to 30 hammers. Modulus of fineness varied from 2.63 with the ⅛-inch screen to 5.22 with no screen, and the energy required dropped from 7.87 to 0.88 hp.-hr./ton.

The effect of grinding oats containing 7.3 percent moisture was determined by using from 6 to 30 hammers and screens with openings varying from ⅛ to ½ inch (fig. 13, top). The number of hammers established no definite trend in energy requirement (hp.-hr./ton); however, the minimum energy required for the ⅛-inch screen was with 12 hammers and for the ¼-inch screen with 18 hammers. The small screen openings required the greatest amount of energy per ton and produced the finest (smallest average particle size) product (fig. 13, bottom).

The modulus of fineness varied from 2.01 with the ⅛-inch screen to 4.00 with the ½-inch screen. Average energy requirements varied from 21.22 horsepower-hours per ton with the ⅛-inch screen to 1.37 horsepower-hours per ton with the ½-inch screen. The grinding rate had a slight effect on energy requirements, but no definite trend was apparent. Grinding rate and number of hammers had little effect on modulus of fineness.

Roller Mill Tests

Tests were conducted with a commercial roller mill typical of the small roller mills available to livestock producers (fig. 14). The mill was powered by a 3-horsepower, single-phase electric motor and was capable of fully automatic operation. It was equipped with an automatic timer, limit and safety devices, and a blender that could blend four separate ingredients into the mill. All integral controls and safeties were bypassed to conduct these tests.

The mill used two rollers rotating at the same speed, approximately 525 r.p.m. The rolls were 6 inches long and 8 inches in diameter. Both rolls had V-shaped grooves. Two sets of rolls were used: one with 6 grooves per inch, 1/16 inch deep, and one with 12 grooves per inch, 1/32 inch deep.

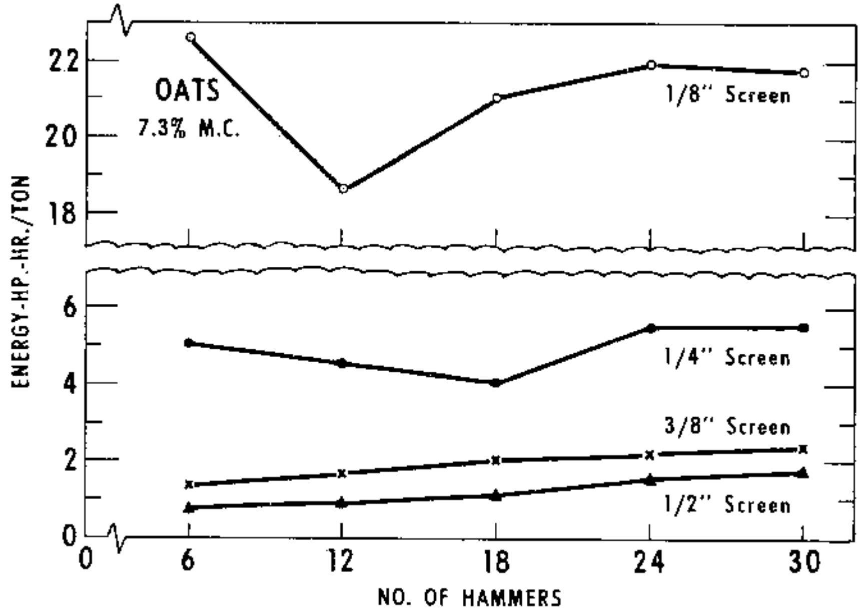
The following are the variables in this test:

a. Material
b. Moisture content
c. Grinding rate
d. Roller clearance
e. Roller surface

The maximum roller clearance for any given test was selected as the maximum clearance that would produce visible cracking or crushing of the grain. Zero clearance was obtained by moving the rollers as close together as possible, with the teeth of one roller meshed in the grooves of the other.

Figures 15 and 16 show the performance characteristics of the roller mill test motor.

Figure 17 shows the power required to roll various materials at several rates with each set of rollers. These curves represent data from tests conducted with roller clearance set at half the maximum clearance that would produce satisfactory grinding results. The maximum grinding rates were established by the maximum capacity of the feed meters on the mill. Power required increased with an increase in rate. With corn at about 10 percent moisture, the two



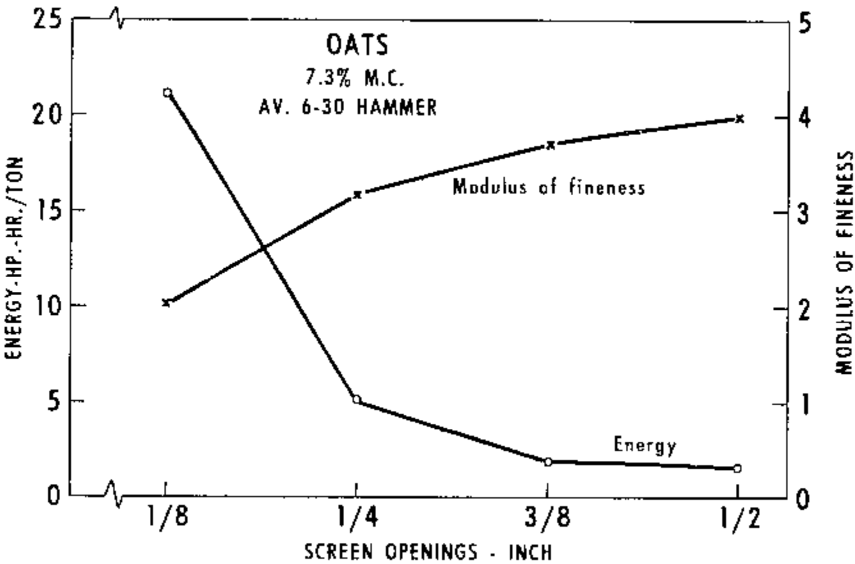


FIGURE 13.—The least energy was required with ⅛-inch screen openings when 12 hammers were used for grinding oats with 7.3-percent moisture content. With ½-inch screen openings, only 6 hammers were needed. Modulus of fineness ranged from 2.01 to 4.00 and the horsepower-hours per ton from 21.22 to 1.37.

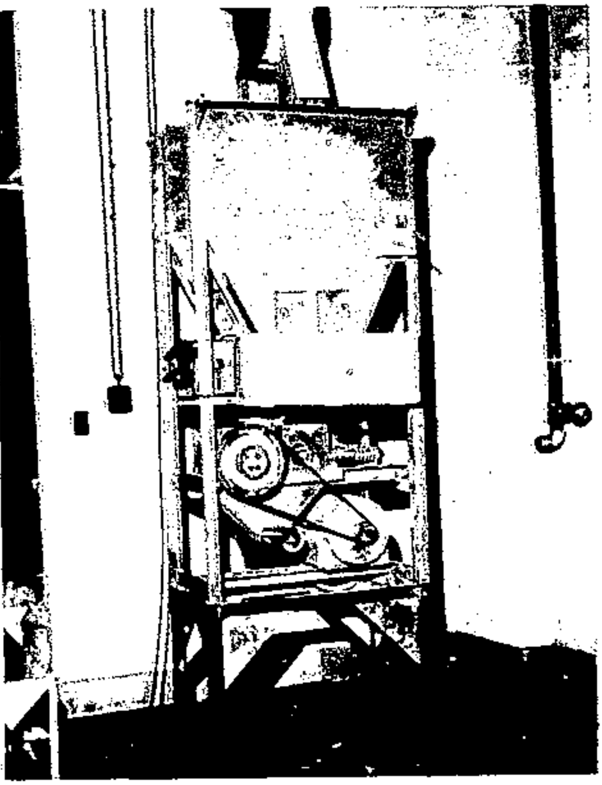


FIGURE 14.—A commercial low-horsepower roller mill was used for tests. Its rollers were 6 inches wide and 8 inches in diameter.

roller surfaces required almost the same power. With the two sets, the 0.075-inch clearance produced nearly the same average particle size. With oats, the set with 12 grooves per inch required slightly more power and slightly greater roller clearance to produce a finished product with equal moduli of fineness than the set with 6 grooves. Grinding shelled corn at 24.8 percent moisture with rollers having 12 grooves per inch required considerably more power than grinding corn at 30 percent moisture with rollers having 6 grooves per inch.

The comparison of energy required to grind shelled corn with 25 and 30 percent moisture is valid even though the rollers had 12 and 6 grooves per inch, respectively, because there was no difference in the results when 6- and 12-groove rollers were used to grind shelled corn with 10 percent moisture. It is therefore reasonable to

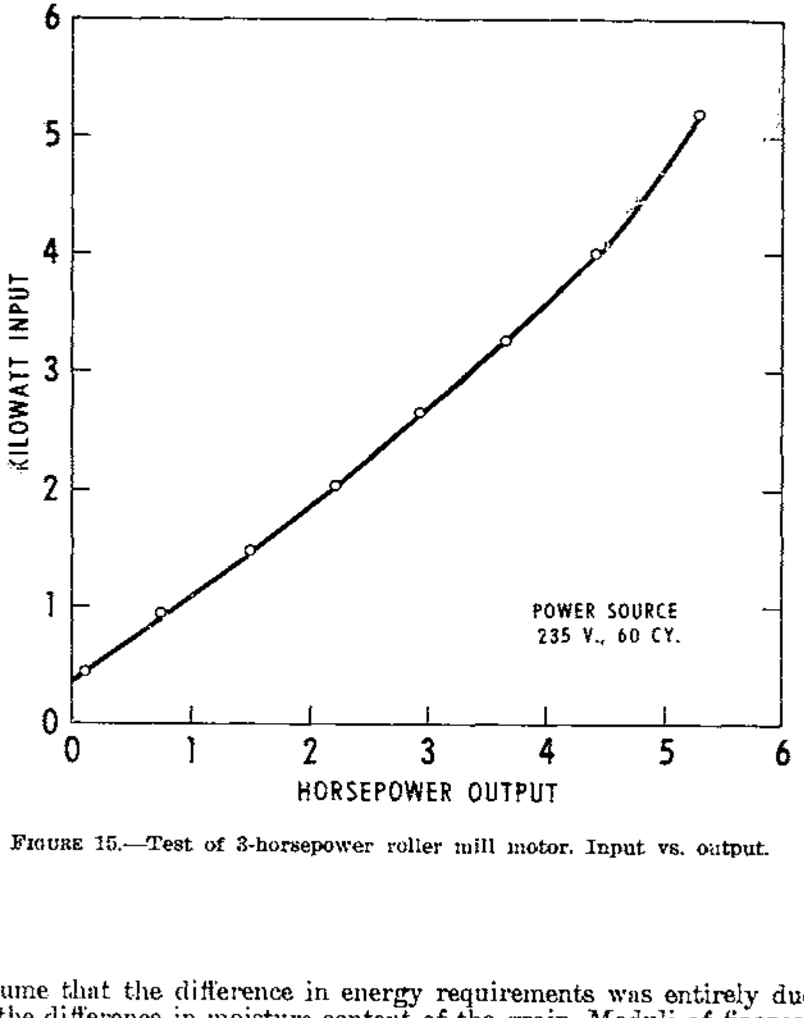


FIGURE 15.—Test of 3-horsepower roller mill motor. Input vs. output.

assume that the difference in energy requirements was entirely due to the difference in moisture content of the grain. Moduli of fineness were practically equal. The power difference was probably due to the greater shear strength of corn at 25 percent moisture than at 30 percent.

Because of the small original particle size, tests with wheat were conducted only with the 12-groove set of rollers.

To study the effects of roller clearance, corn at 10 percent moisture was ground at various rates and the roller clearance was varied from 0.025 inch upward (fig. 18). As the grinding rate increased, the grinding efficiency also increased, as indicated by the lower horsepower-hours per ton at the higher rates. The energy required to grind the corn decreased as the roller clearances increased. An unexpected result, however, was the very slight increase in modulus of fineness with the increase in clearance.

Further analysis of the data shows that the change in the modulus of fineness was due primarily to the change in the per-

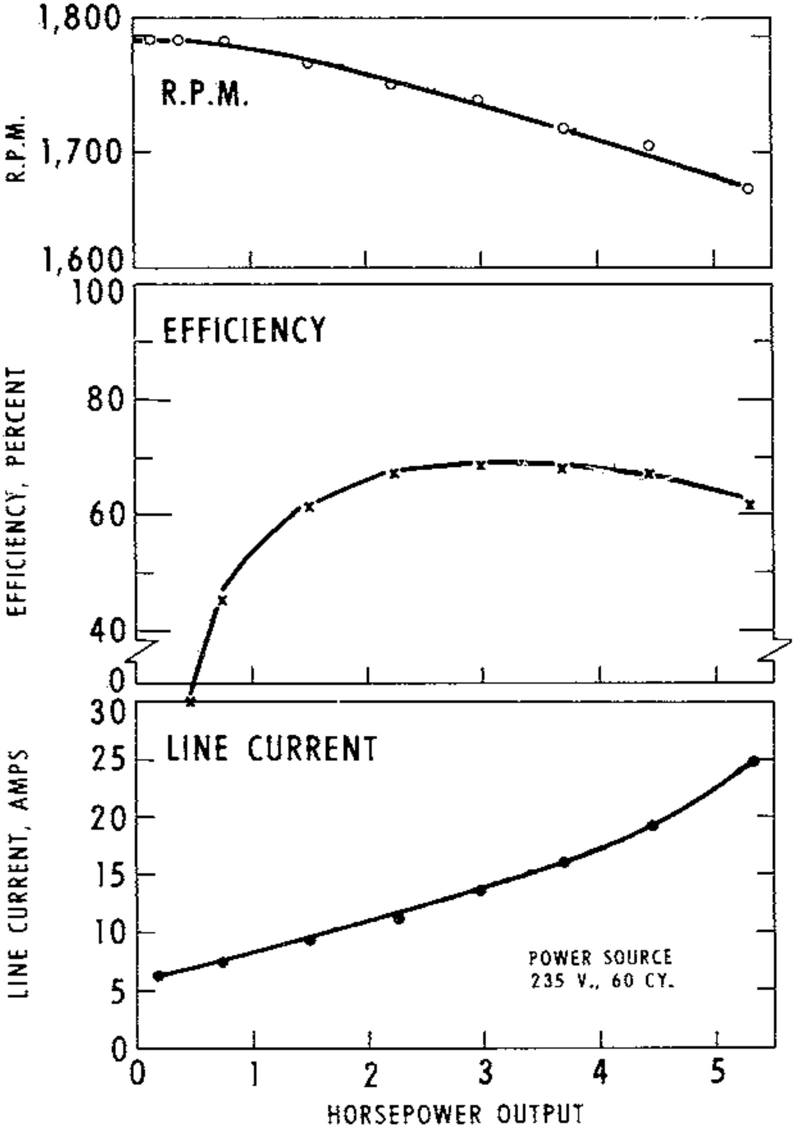


FIGURE 16.—Test of 3-horsepower roller mill motor. Performance curves.

centage of fines (particles that will pass through a No. 28 sieve) in the feed mixture. The fines dropped from 5.23 percent with 0.025-inch clearance to 1.45 percent with 0.125-inch clearance. In other words, roller clearance had little effect on average particle size, affecting mainly the fine materials, which make up only a small portion of the total product. These data are for tests with rollers

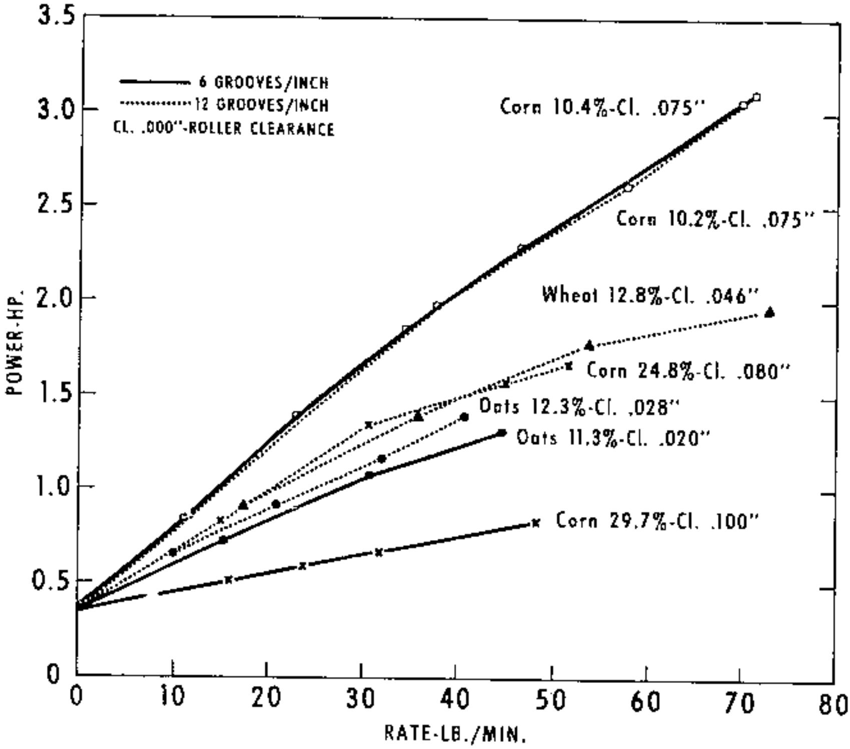


FIGURE 17.—Power required to roll wheat (12.8 percent moisture), corn (10.2, 10.4, 24.8, and 29.7 percent), and oats (11.3 and 12.3 percent) at several rates with rollers with 6 and 12 grooves per inch and roller clearance set at half the maximum clearance that would provide satisfactory grinding results.

having 12 grooves per inch. Rollers with 6 grooves per inch produced slightly coarser particles, but generally required about the same energy.

Figure 19 shows the performance of the mill grinding wet shelled corn at 29.7 percent moisture. These data are for the rollers with 6 grooves per inch. The energy per ton decreased with an increase in grinding rate. Also, the energy per ton decreased with an increase in roller clearance, but the modulus of fineness increased only slightly, as with the dry corn. The percentage of fine material also followed the same trend as in dry corn. Figure 20 shows the same trend for shelled corn with 24.8 percent moisture with slightly higher energy requirement per ton for rolling.

Figure 21 shows the performance of the mill using rollers with 12 grooves per inch in grinding wheat with 12.8 percent moisture. Grinding efficiency increased as grinding rate increased, as shown

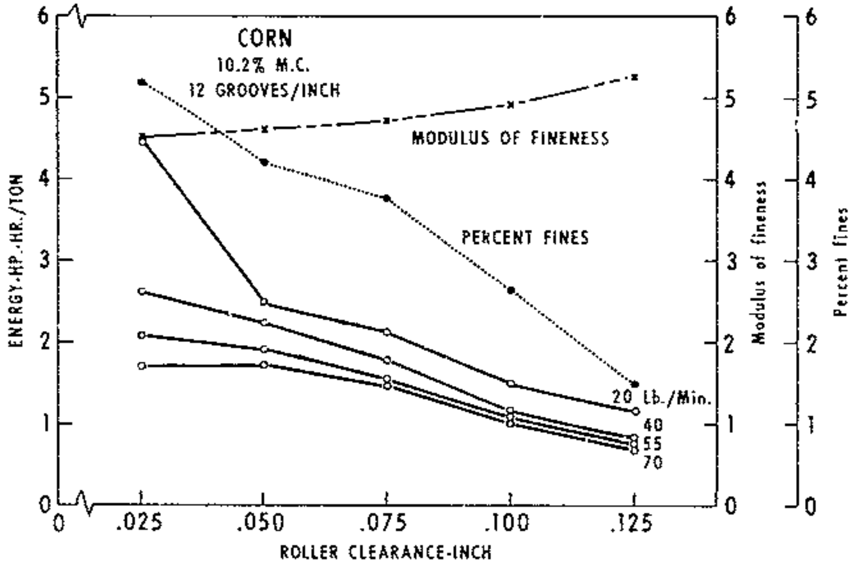


FIGURE 18.—Effects of roller clearance were studied by grinding corn (10.2 percent moisture) at various rates and varying the roller clearance. Energy required decreased, and modulus of fineness increased slightly, as roller clearance increased.

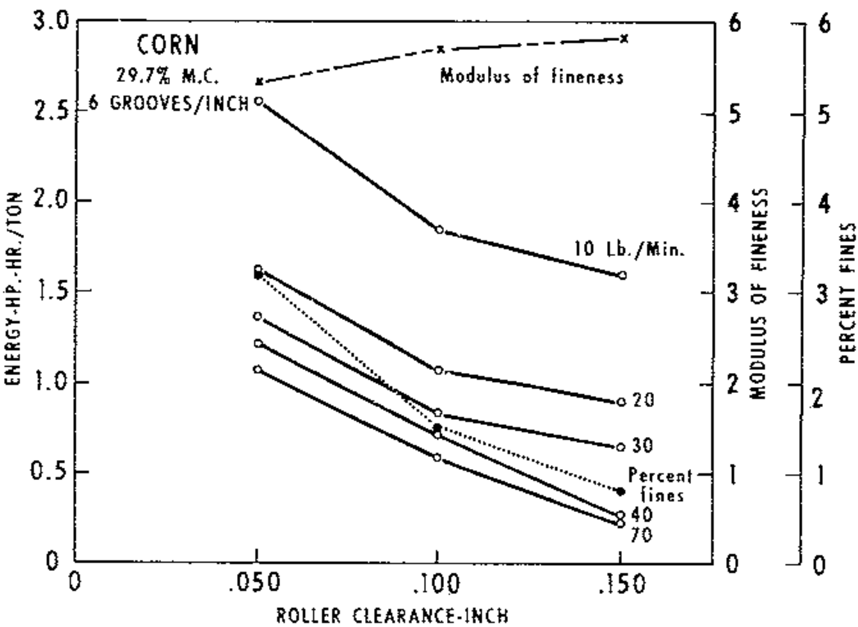


FIGURE 19.—Performance of mill using rollers with 6 grooves per inch grinding wet shelled corn. Energy per ton decreased with increases in grinding rate and roller clearance.

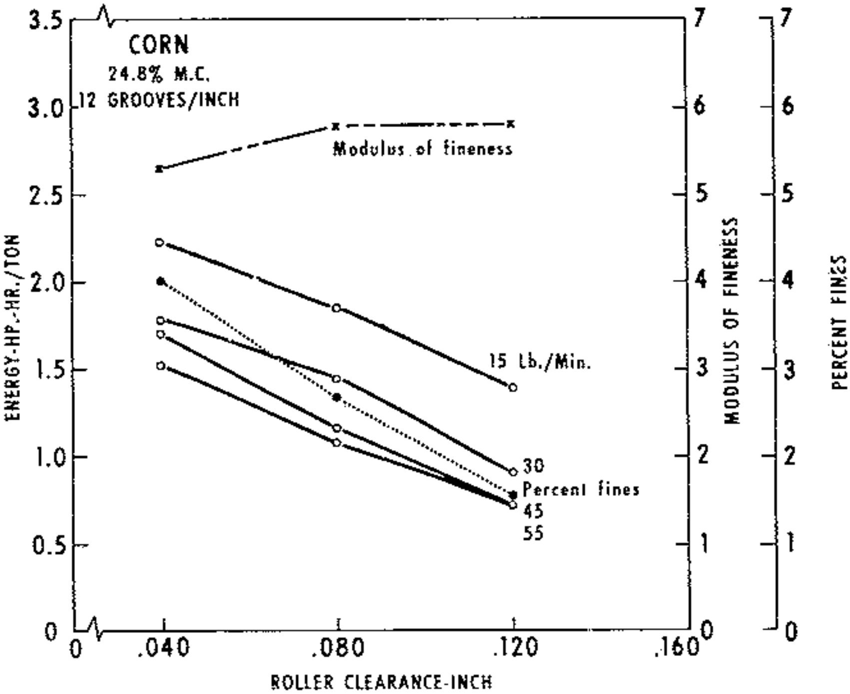


FIGURE 20.—Performance of mill using rollers with 12 grooves per inch grinding corn with 24.8-percent moisture content. Trend was the same as for shelled corn with higher moisture content (fig. 19).

by the lower energy requirements. As with corn, the energy required to grind the material decreased with an increase in roller clearance. At the same time, the modulus of fineness increased only slightly, although the percentage of fines decreased considerably. The change had little effect on the modulus of fineness because the fines represented less than 2½ percent of the total product.

Oats with 11.3 and 12.3 percent moisture were rolled with both sets of rollers at various clearance rates. Figure 22 shows the results of the test with the rollers with 6 grooves per inch. Horsepower-hours per ton decreased as both the grinding rate and the roller clearance increased. With both sets of rollers, the modulus of fineness remained nearly constant as clearance was varied. This result can be explained by the low percentage of fines in oats even at the smaller roller clearances; in all tests there was less than 1 percent of fines. To produce a product with about the same modulus of fineness, the rollers with 12 grooves per inch required greater power at a greater roller clearance (fig. 23).

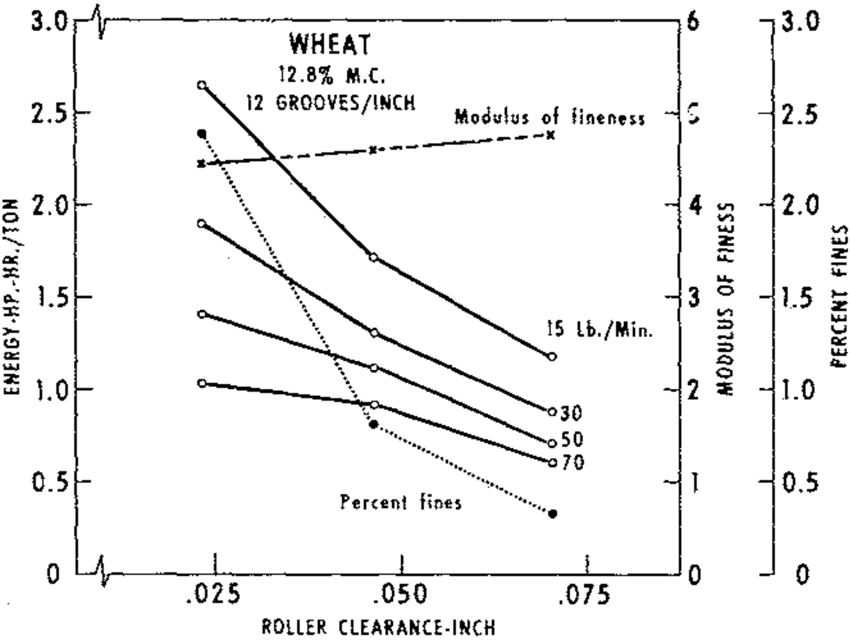


FIGURE 21.—Performance of mill using rollers with 12 grooves per inch grinding wheat. Grinding efficiency increased as grinding rate and roller clearance increased.

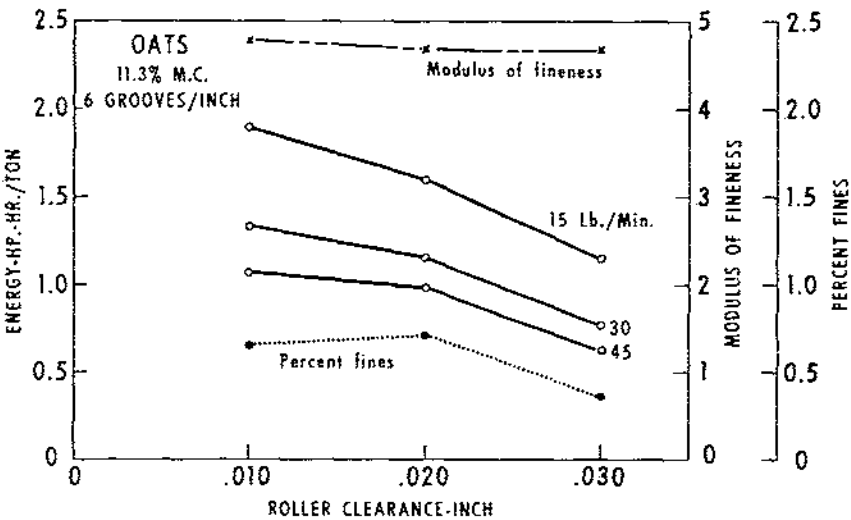


FIGURE 22.—Performance of mill using rollers with 6 grooves per inch grinding oats (11.3 percent moisture). Energy decreased with increases in grinding rate and roller clearance.

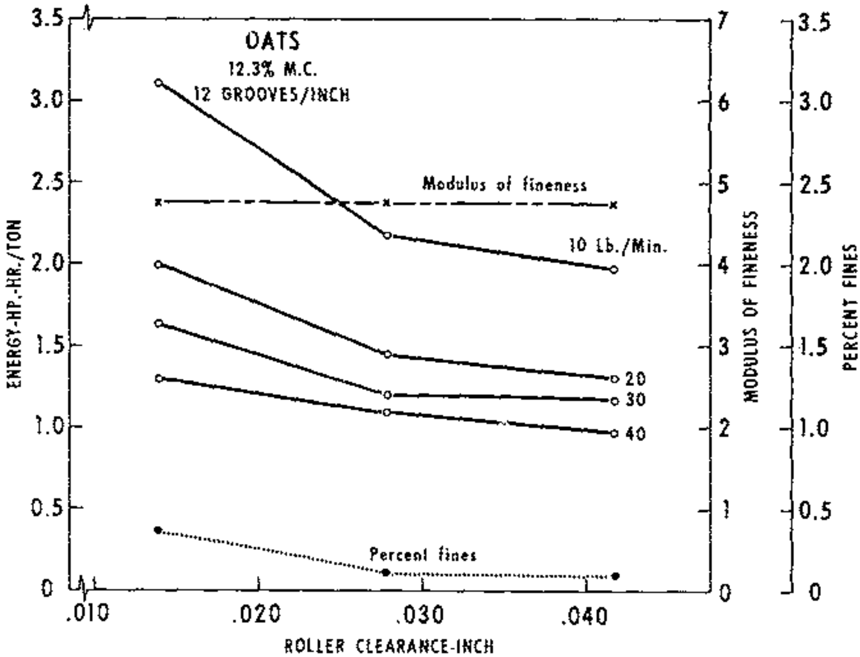


FIGURE 23.—Performance of mill using rollers with 12 grooves per inch grinding oats (12.3 percent moisture). These rollers required more energy and greater roller clearance than rollers with 6 grooves to produce a comparable product.

SUMMARY

The data generally indicated that, for a given situation, the total power input to a hammer mill increases as the grinding rate increases. With an increase in size of screen opening, modulus of fineness (average size of particles) increased in these tests, whereas energy requirements per ton decreased. Grinding rates had little effect on modulus of fineness and affected energy requirements per ton slightly, the higher rates being more efficient. Number of hammers had little effect on modulus of fineness and energy requirements except with the 1/8- and 1/4-inch screens; with these screens 12 and 18 hammers were more efficient than 6, 24, or 30 hammers. Moisture content of corn affects the energy requirements; the energy per ton increases as moisture increases from 8 to 20 percent and decreases slightly as moisture increases from 20 to 25 percent.

Although we can conclude that the power requirement of a roller mill grinding wet or dry corn, oats, or wheat generally increases as the grinding rate increases, the energy requirement per ton decreased in all these tests as the grinding rate increased. The energy requirement per ton also decreased with increased roller clearances. The modulus of fineness remained nearly constant as roller clearance was varied. However, the percentage of fines, which represented only a small part of the total, generally decreased with an increase in roller clearance. Grinding rate had practically no effect on size of particles or on percentage of fine materials.

☆U.S. Government Printing Office: 1968 O—291-039

END