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W. F. Lalor
University College Dublin

Wesley F. Buchele
Iowa State University

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Abstract
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W. F. Lalor and W. F. Buchele
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LITERATURE REVIEW

Kolganov (1)* tested a multistage threshing mechanism and found that the highest quality seed was threshed in the first stage at low cylinder speeds; the remaining seed was removed at normal cylinder speeds in the second stage. This arrangement reduced the mechanical damage to seed due to impact.

Experiments performed by Park (2) on clover showed that the threshing losses with a rasp-bar cylinder may be as high as 40 percent and that only slightly better results were obtainable with angle-bar types.

Wessel (3) reported tests performed on a conical rotor. Threshing efficiencies and amounts of seed damage, comparable to those found in conventional machines, were reported. Lamp (4) has shown that threshing can be accomplished by subjecting the heads to centrifugal force.

This paper reports the testing of a full-size threshing cone invented and patented by Buchele (5). The thresher cone was constructed and tested (6) in the agricultural engineering laboratory of Michigan State University in 1961.

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The authors—W. F. LALOR and W. F. BUCHELE—are, respectively, lecturer, faculty of agriculture, University College (Dublin, Ireland) and associate professor of agricultural engineering, Iowa State University.

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* Numbers in parentheses refer to the appended references.

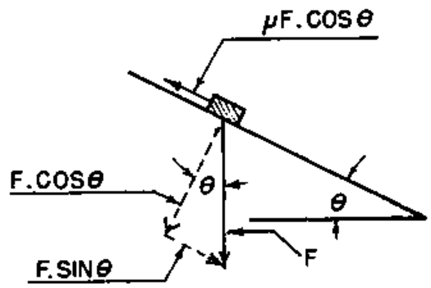

FIG. 1 Calculation of cone angle, θ.

DESCRIPTION AND DESIGN OF THRESHING CONE

The machine consisted of a truncated, stationary outer cone made of perforated sheet metal. A conical rotor was fitted within the stationary cone and the clearance between the rotor and stationary cone was approximately one-half inch. The rotor consisted of eight rubber-covered angle bars similar to those used in Allis-Chalmers combines. The material to be threshed entered the annular space between the rotor and the outer cone at the apical end of the thresher. The component of centrifugal force, acting parallel to the cone surface, caused the material to move toward the base (large end) of the cone. During this process, threshing and separation occurred. The threshed grain passed through the perforations in the outer stationary cone and the straw (retained within the cone) left the cone by way of an opening tangent to the base.

The following factors affect the performance of the threshing cone: (a) the apical angle of the cone, (b) the length of the cone from entrance to exit measured along the surface, (c) the length of the slots in the stationary cone, (d) the direction of the slots in the stationary cone, and (e) the rpm of the cone shaped rotor.

Apical Angle

The magnitude of the apical angle was selected on the basis of the following, simplified analysis. (A rigorous analysis was developed after the cone was constructed) The inner surface of the cone can be considered a plane on which the crop rests. Let the force, F (Fig. 1), act on the material and make an angle θ with the normal to the cone surface. The forces acting parallel to the cone surface are as follows: (a) the friction force, preventing the material from sliding down the plane, and (b) the force, $F \sin \theta$, which tends to cause the material to slide down the plane. The maximum value of the friction force μN, where μ is the coefficient of friction between the material and the plane, and N is the normal force which in this case is $F \cos \theta$. When slippage is impending

$$F \sin \theta = \mu F \cos \theta$$

and

$$\mu = \tan \theta$$

In this simplified analysis θ must be greater than $\tan^{-1}\mu$ for the material to slip on the surface. Let the force, F, be the centrifugal force resulting from the circular motion of the material within the cone. The apical angle of the cone is then defined as 2θ.

The magnitude of θ was determined by placing the straw on a piece of vibrating perforated sheet metal which was tilted from the horizontal until slipping occurred. At this point, the angle between the sheet and the horizontal was measured. This procedure indicated that the magnitude of the apical angle should be approximately 54 deg, or $\theta = 27$ deg.

Cone Length

The length of cone necessary to achieve complete threshing and separation was one of the factors to be determined during the course of this research. The cone, therefore, was made longer than might have appeared adequate in order that the correct length could be determined. Because Buchele's (5) model had a cone length of 24 in., a length of 48 in. was chosen for the field prototype.

Slot Length

The slots in the outer cone must be of such a length that the seed can pass through them without striking the edge of the opening. This meant that the seed had to pass through the slot in the same time that it took to pass over the length of the slot. If the acceleration of the seed, in the radial direction, is $r\omega^2$, where r is the radius of the cone at that point and ω the angular velocity of the seed, the required slot length can be found by equating the time for the seed to pass through the opening to the time for it to traverse the length of the slot [See Lalor (6)]. In this manner the slot length is found to be a function of the radius of the cone as follows:

$$z = \sqrt{2\,ry} \qquad [1]$$

where z is the slot length and y the distance through which the seed must pass in order to clear the outside edge of the screen.

The foregoing expression for the slot length is based on the assumption that the path of the grain is parallel to the axis of the slot. If the path of the grain is not parallel to the long axis of the slot, but makes some angle (ϕ) with it, the effective slot length will then be given by

$$z_e = s/\sin \phi$$

where z_e is the effective slot length and s is the slot width.

Construction of the Cone

The diameter of the base of the cone was 60 in. and that of the entrance to the cone was 16 in. The cone was made of eight sections of sheet metal, the four sections in the front (apical end) having a slot length of 2 in. and the four in the rear having a slot length of 3 in. The cost of having a cone made from perforated sheet metal with the slots varying in accordance with equation [1] was prohibitive.

Feeding was achieved by means of an auger mounted on the rotor shaft. The auger forced the material into the space between the rotor and stationary cone. Due to the high peripheral velocity of the material by the time it had reached the base of the cone, it was possible to remove the straw through a chute at a tangent to the base of the cone. So great was the velocity of the straw that it could even be loaded on a wagon with an appropriate ducting system.

Testing Procedure

Genessee wheat was threshed in all tests. The tests were performed at five rotor speeds as follows: 300, 350, 400, 450, and 500 rpm. As the material passed through the perforations of the outer cone, samples were taken at two locations on the cone surface:

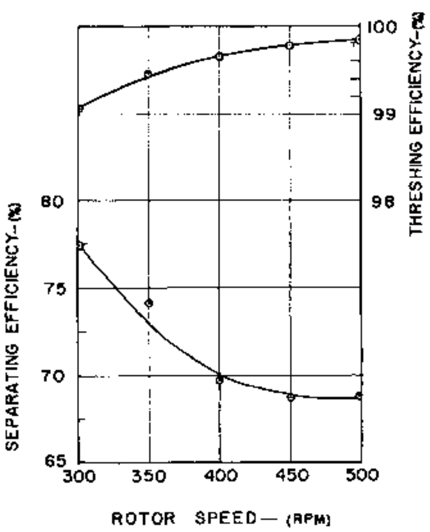

FIG. 2 Relation between threshing efficiency, separating efficiency and rotor speed.

(a) the "box sample" which was collected in the segmented sampler box described below, and

(b) the "circle sample" which indicated the effect of slot orientation on separating efficiency.

The main portion of the separated material was collected in a box placed under the cone.

The segmented sampler box in which the box sample was collected, extended from the entrance of the cone to its base and covered a 30-deg arc of the cone surface. It was divided into six equally long sections and the amount of grain found in each section at the end of a test was an index of the amount of grain emerging through the entire circumference of the cone at a particular distance from the entrance. This was intended to indicate the required length of cone necessary for complete threshing and separation.

The circle sample was collected from a circular area of the cone in which the direction of the slot relative to the plane of the base could be changed. This was achieved by cutting a circular sec-

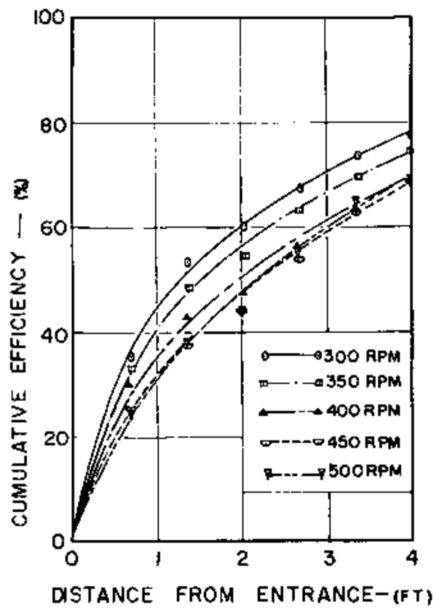

FIG. 3 Cumulative separating efficiency as a function of the distance from the entrance of the threshing cone.

tion from the cone, rebending the section and replacing it with the slots in the desired orientation. The amount of grain collected from this area was compared to that emerging from a similar area where the slots were parallel to the plane of the base. The ratio (R) of the weight of grain recovered from the oriented portion to that recovered from the other portion would be maximum for that orientation which would achieve the maximum amount of separation. The angle between the slot direction and plane of the base is the slot angle, α.

The threshing efficiency was determined by threshing the straw with a

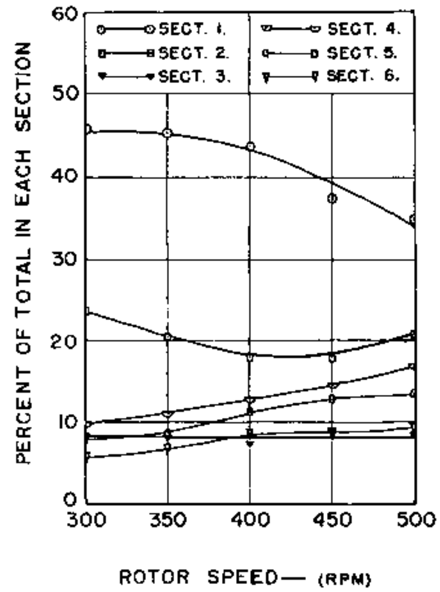

FIG. 4 Weight of grain in each sampler-box section as a percentage of the total weight of grain in the sampler box.

spike-tooth thresher after it had been threshed with the threshing cone. The separating efficiency was determined by shaking the loose grain from the straw before threshing it with the spike-tooth thresher.

Results and Discussion

Threshing Efficiency

The relationship between rotor speed and average threshing efficiency is shown in Fig. 2. The threshing efficiency was above 99 percent for all rotor speeds; however, at 300 and 350 rpm the feeding mechanism clogged occasionally and the operation was not considered satisfactory. Above 350 rpm the operation of the feeding mechanism was completely satisfactory.

Separating Efficiency

The separating efficiency is defined as the weight of grain passing through the cone perforations expressed as a percentage of the total weight of grain entering the thresher. Fig. 2 shows that the over-all separating efficiency decreased from 77 to 68 percent as the rotor speed was increased from 300 to 500 rpm. Since the threshing efficiency was over 99 percent at all rotor speeds tested, threshing does not require high rotational speeds. Instead, the feeding mechanism must be improved to give reliable performance at rotor speeds below 350 rpm. The separating efficiency of the threshing cone at all speeds compared favorable with the amount of separation occurring in a conventional threshing cylinder (4).

The cumulative separating efficiency is shown in Fig. 3 as a function of the distance from the entrance to the cone. The curves again indicate that the separating efficiency decreased as the rotor speed increased.

If the 300 rpm exponental curve in Fig. 3 were extrapolated to secure approximately 98 percent separation, the cone length would have to be approximately 7 ft.

Analysis of Data From Sampler Box

The weight of grain found in each section of the box was expressed as a percentage of the weight of grain in the entire box. This indicated how the separation process was distributed along the length of the cone at the various rotor speeds and the results are shown in Fig. 4.

The location of the separation shifted from the small to the large end of the cone as the rotor speed increased, with the result that sections 1 and 2 of the sampler box received less grain at high speeds than at low speeds, while sections 4, 5 and 6 received more grain. That fraction of the grain entering section 3 remained relatively constant and section 3 acted as a "pivot" point about which the shift in separation, with change in speed, took place. The fraction of the total grain received by section 3 was smaller than might have been expected, due to the fact that the joint between the small slot and large slot screen was located in this section. (A steel band was placed around the screen and the screen sections were screwed to the band.)

The increase in the proportion of grain entering sections 4, 5 and 6, however, did not compensate for the decrease in the proportion entering sections 1 and 2, with the result that there was a loss in total separation as the rotor speed increased.

Inspection of Fig. 3 shows that in the first 8 inches of the cone length, approximately 35 percent separation was accomplished at 300 rpm. In the next 8 inches an additional 18.2 percent separation took place. In 16 inches, or one-third of the total cone length, therefore, 53.7 percent separation occurred; this corresponds to 69.4 percent of the total separation which took place in the cone. At 450 rpm, 37.9 percent separation took place over the same surface area; this corresponds to 55 percent of the total separation. Thus it can be concluded that high rotor speeds made inefficient use of the surface area of the cone for separating the threshed grain from the straw. Observation of the thresher in action showed that, at low rotor speeds, the material moved slowly in the direction of the base of the cone and was subjected to more rubbing between the beaters and the screen, in the area immediately inside the entrance, than at high rotor speeds. This is a possible explanation for the higher amount of separation per unit length in the small end of the cone than in the large end. Two other factors may also have contributed as follows: the rotational speed of the material was low in this area, and grain threshed by the auger would have separated in this area since it was loose on entering the cone and would have passed through the screen under the effect of gravity before it was given any rotational motion. Figs. 3 and 4 indicate that the reason for the good separation at the small end of the cone was probably due to the slow rotational velocity of the material.

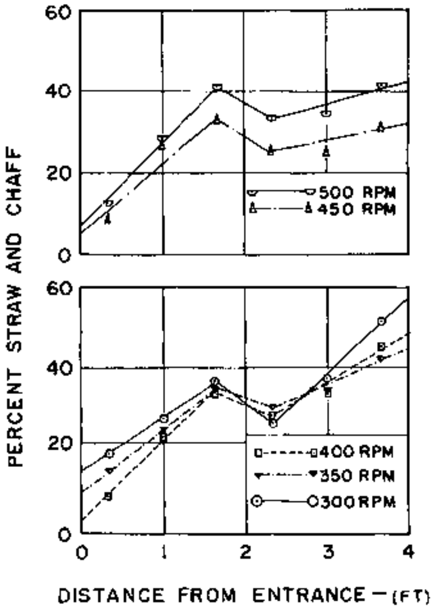

FIG. 5 Relation between percentage of straw and chaff in the separated material and the distance from the cone entrance.

Circle sample data were taken to study the effect of slot angle on separating efficiency.

Chaff and Straw in Sampler Box

The amount of chaff and straw (debris) mixed with the threshed grain is important when a cleaning mechanism is considered. Lamp (4) found that the ratio of debris to grain, on the cleaning shoe of a conventional combine, was in the neighborhood of 0.35. Fig. 5 shows the relationship between the amount of debris and the distance from the cone entrance for various speeds. With the exception of the fourth foot of cone length, the results compare favorably with those found by Lamp for a conventional thresher. The percent of debris in the first two sections was, in fact, considerably lower for the threshing cone than for the conventional thresher. The question of debris is considered further under the following discussion of the circle sample data.

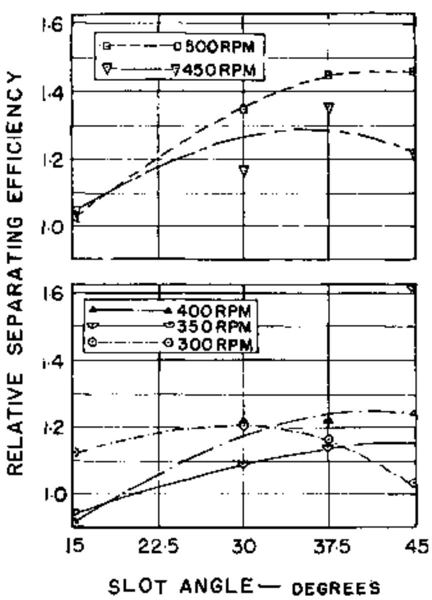

FIG. 6 Ratio of weight of grain in circle sample to that in the control sample (relative separating effciency) as a function of the slot angle, α.

Analysis of Circle Sample Data

Because the cone was made from standard perforated sheets, only a small percentage of the slots were oriented such that the long axis of the slot was parallel to the helical path of the grain. In order to determine the effect of slot angle on separating efficiency, a circular section was cut from the outside, stationary cone. This circular section was rebent and replaced at various slot angles.

The relative separating efficiency is defined as the ratio of the weight of grain in the circle sample (where the slot angle was not zero) to the weight of grain in the control sample (where the slot angle was zero).

Fig. 6 shows the relationship between the magnitude of the slot angle α, and the relative separating efficiency, R. The maximum values of R occurred at high rotor speed and large values of α. The rate of increase of R with respect to α was greater at high than at low speeds. Fig. 6 shows that the orientation of the slots is an important factor in governing separation efficiency.

When the slots made an angle of 45 deg with the plane of the base of the cone (Fig. 6), 46 percent more grain was found in the circle sample than in the control sample. Since the separation efficiency at 500 rpm was 69 percent (Fig. 2), the data from the circle sample may be used to estimate the efficiency to be expected if the slots in the cone made an angle of 45 deg with the plane of the base of the cone. Thus, increasing the separation efficiency of 69 percent by 46.0 percent results in a total efficiency by extrapolations to approximately 98 percent for the entire cone. In other words, complete separation could be accomplished with proper orientation of the slots.

Straw and Chaff in the Circle Sample

Fig. 7 shows the amount of straw and chaff in the circle sample relative to the amount in the control sample. At 500 rpm up to two and a half times as much debris was mixed with the grain for a slot angle of approximately 35 deg as was mixed with the grain from the control area where the slot angle was zero. At low rotor speeds the relative amount of debris in the circle sample was less than the amount present at 500 rpm, but in all cases there was more debris in the circle sample than in the control sample.

Summary

An axial-flow threshing apparatus (cone shaped) was constructed of perforated sheet metal and a rubber-coated angle bar rotor. The threshing efficiency was above 99 percent at all rotor speeds. The separating efficiency decreased from 77 to 69 percent at the rotor speed increased from 300 to 500 rpm.

The material followed a helical path in the cone. An analysis of separating efficiency and slot angle based on the circle-sample data indicated that approximately 98 percent separation was possible when the angle between the slot and base of cone was 45 deg.

The sampler box data showed that over 50 percent of the grain was separated in the first 16 in. of cone length.

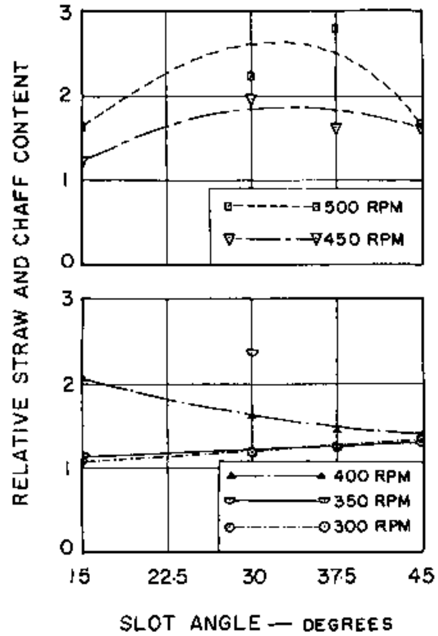

FIG. 7 Ratio of straw and chaff in circle sample to that in the control sample (relative straw and chaff content) as a function of the slot angle, α.

The chaff and straw coming through the cone was similar to that handled by the cleaning shoe of a combine.

Conclusions

1 The threshing efficiency of wheat was above 99 percent at all rotor speeds.

2 Based on the circle-sample data, if slot angle were judiciously selected the separating efficiency could be sufficiently increased to eliminate the need for straw walkers or other separating mechanisms.

3 The amount of chaff and straw mixed with the grain was similar to that found in the material on the cleaning shoe of a conventional combine.

4 The design of the feeding mechanism must be improved to permit operation at lower speed.

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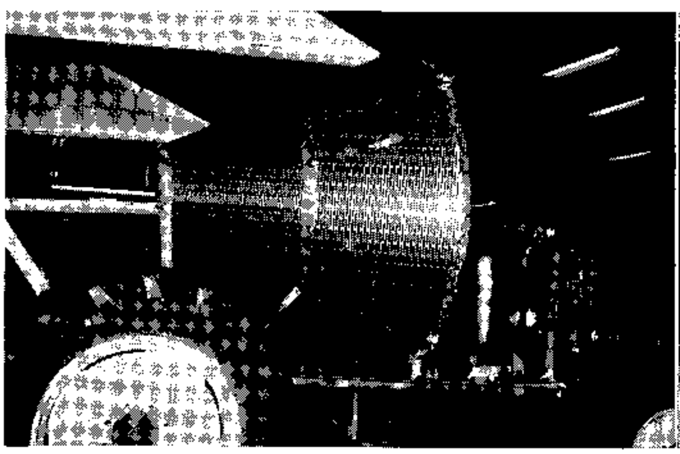

FIG. 8 Side view of perforated cone which mounted on a self-propelled combine chassis.

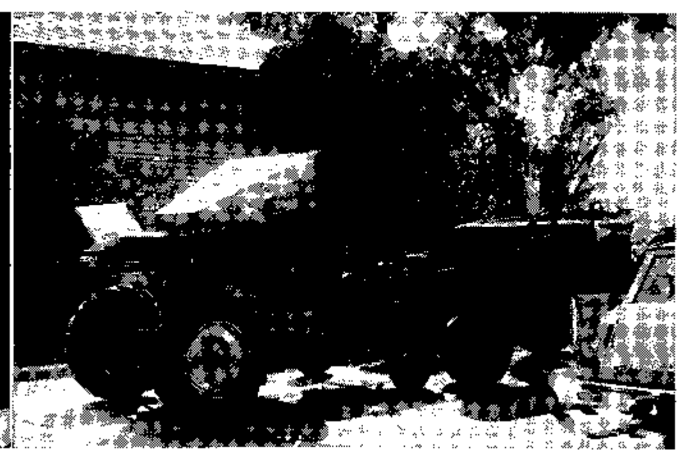

FIG. 9 Side view of test setup. In the tests reported a tractor was used to rotate the cone. (The circle sample duct is shown emerging from the side of the cone.)