ENERGY FOR IMPACT CUTTING OF WHEAT STEMS

Thesis for the Degree of M. S.
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Han-Hsiung Wu

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ABSTRACT

ENERGY FOR IMPACT CUTTING OF WHEAT STEMS

by Han-Hsiung Wu

Hand sickle cutting is a typical impact cutting with the energy supplied by muscles. Theoretically speaking, the energy is a function of several variables such as, crosssection area, density, compressibility, cutting height, cutting angle and other factors. This study is intended to investigate the knowledge which may help in analysis of impact cutting energy.

The method of approach to this study is outlined below:

1. The mathematical relationship of cutting energy and all the parameters involved were derived theoretically.

2. The pendulum-like apparatus was built for this investigation to conform to the theoretical equation.

Based on the limited data, a conclusion was reached that:

1. Cutting energy is linear to the crosssection area of the stem and cutting height.

2. Cutting energy is nonlinear to the velocity of cutting.

Approved: H. F. McColly
Major Professor

Carl W. Hall
Department Chairman

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By

Han-Hsiung Wu

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INTRODUCTION

Harvesting can be analyzed as two actions. One is the cutting action and the other is the action of threshing. The cutting action disconnects the stem from the ground, and separating the grain from the stalks is the threshing action. This investigation will consider only cutting action.

In Asian grain producing countries as a harvesting implement the sickle maintains a very important position. Simply, the action of the sickle's cutting is partly impact cutting, which is using the higher speed for passing through the stem and severing it. This is quite heterogeneous with shearing cut, giving some resistant forces against the shearing action.

Cutting crop stems is different from cutting metals by shearing, for the stems are mostly fibrous materials and severing of the fibers is a very important part of the cutting process. The grain crops, like wheat, rice and barley all belong to the monocotyledons.

The type of secondary tissue formed in monocotyledons is very different from that formed in other groups. The cells that form the tracheids become 15 to 40 times their original length; the other cells elongate little or not at all. The thickening which takes place in the bases of some stems is not due to the activity of a definite cambium layer but is, rather, the result of gradual increase in size of cells and of intercellular spaces, and, rarely of the proliferation of stands of tissue to form new fibers; it represents long-continuing primary growth.

Basis for the Problem

The cutting methods, which have been investigated by several researchers include:

1. Cutting between two elements (commonly called shearing).

2. Slicing or sawing by which the fibers are believed to be separated individually from the stem and caused to fail in tension by tearing action.

3. Cutting on impact by a single, high speed element.

In cutting with a single element, the stems are not supported in the vicinity of the cutting element. Since stem resistance to bending is insufficient to provide the force necessary to oppose the knife pressure required to penetrate the material, the cutting process depends on the inertia of the stem to give the required opposing force. Since knife velocity is one of the important factors, the type of cutting is often defined as impact cutting.

Analysis

There are two things to consider for impact cutting. One is force, and the other is energy. Actually, the force will be involved in the energy. In order to set up the equation of motion, we can obtain with the help of Newton's Second Law of Motion.

$$F = ma$$

$$\text{Work} = F \cdot S.$$

$$d\,\text{Work} = F \,.\, ds$$

$$\text{Work} = \int F.\, ds = \int_{S_1}^{S_2} F \cdot ds$$

$$\therefore \text{Work} = \int_{S_1}^{S_2} mv\, dv/ds \quad ds = \int_{V_1}^{V_2} mvdv = \tfrac{1}{2}\, mv^2 - \tfrac{1}{2}\, mv_1^2$$

Energy requirements for the stem cutting process were evaluated with respect to these variables:

1. Knife velocity before cutting.
2. Cross section area of stem.
3. Density of the stem.
4. Compressibility factor of the stem.
5. Distance of cutting point from the point of soil surface.
6. The angle of cutting
    a. Vertical angle
    b. Horizontal angle
7. Type of the blade.
8. Thickness of the cutting edge.
9. Meteorological factors.

The moisture content of the stem is actually included in the density of the stem, because density is the ratio of weight and volume. The increasing or decreasing of the water will definitely influence the weight. It is true that the water particles increase the volume as the weight increases. It is also true that the increased volume is infinitesimal compared to the increased weight. Therefore, the ratio of the two quantities will become infinitesimal.

By the use of similarity and Dimensional Methods we can simplify the cutting energy required as follows:

V: Knife velocity before cutting. (L/T)

ρ: Density of the stem. (M/L^3)

A: Cross section area of stem. (L^2)

Cp: Compressibility factor of the stem. (M/T^2L)

L: Distance of cutting point from the point of soil surface. (L)

So $E = F(V, \rho, A, Cp, L)$.

Where M is the dimension of mass, L is the dimension of length, and T is the dimension of time. The dimension of energy is $(\frac{ML^2}{T^2})$. So, $(\frac{ML^2}{T^2}) = (\frac{L}{T})^{\alpha} (L^2)^{\beta} (\frac{M}{L^3})^{\gamma} (\frac{M}{T^2L})^{\kappa} (L)^{\phi}$

For M we get

$$1 = \gamma + \kappa \quad \ldots\ldots (1)$$

For L we get

$$2 = \alpha + 2\beta - 3\gamma - \kappa + \phi \quad \ldots\ldots (2)$$

For T we get

$$-2 = -\alpha - 2\kappa \quad \ldots\ldots (3)$$

Solve (1), (2) and (3)

we get $\alpha = 2 - 2\kappa$

$$\beta = \frac{3 - \phi}{2}$$

$$\gamma = 1 - \kappa$$

$$E \sim \left(\frac{V^2}{V^{2\kappa}}\right) \left(\frac{\rho}{\rho^{\kappa}}\right) Cp^{\kappa} \left(\frac{A^3}{A^{\phi}}\right)^{\frac{1}{2}} (L)^{\phi}$$

$$V^2 \rho \quad A^{3/2} \left(\frac{Cp}{V^2 \rho}\right)^{\kappa} \left(\frac{L}{A^{\frac{1}{2}}}\right)^{\phi}$$

$$= V^2 \rho \quad A^{3/2} f_1 \left(\frac{Cp}{V^2\rho}\right) f_2 \left(\frac{L}{A^{\frac{1}{2}}}\right)$$

The energy is the function of $\left(\frac{Cp}{V^2\rho}\right)$ and $(L/A^{\frac{1}{2}})$. The relation is derived on purely analytical ground. Therefore, we should use experiments to confirm it.

Objectives

This study will concentrate on the following major phases of the problem and will be conducted accordingly:

1. To study the mathematical relation of effect of the various cross sections on the cutting energy.

2. To study the mathematical relation of effect of the various height of cutting on the cutting energy.

3. To study the mathematical relation of the various velocities effect on the cutting energy.

4. With the data, to investigate the mathematical model of cutting energy.

REVIEW OF LITERATURE

History of Hand Cutting

In the neolithic age, women were accustomed to gathering the seeds of certain wild grasses and grinding them for food. Then man began to discover cereals as a new and lasting source for food. The anthropologists call that time the beginning of the age of food production. From anthropology, we know that man has invented many agricultural implements for planting, tilling, and harvesting.

The early forms of sickles used for harvesting were discovered through anthropological research. These were wooden sickles armed along its cutting edge with serrated flint blades. Most of them had a shape similar to the modern ones, but the materials used in forming them were different.

Although time has changed, the sickle though perfected is still a useful tool for harvesting. The literature, reveals but brief engineering information about harvesting tools used in Asian countries.

In the Philippines, harvesting time is usually around August to October in most provinces with distinct wet and dry seasons. Some late varieties of crops are still harvested during December. The harvesting tools used in the

Philippines, are mostly hand tools, such as the yatab, the karet and the lingkao.

The yatab (pang-ani) is a 6 inch hand knife fasted across a wooden handle.

The lingkao is a piece of hook-curved wood with a knife on its back. It is usually used in some fields of lowland rice.

The karet (panggapas) is a kind of small sickle with the teeth on its blade.

The mechanical rice harvester is a small type of combine, but it is used only by very few farmers during the dry seasons.

In the southern peninsula of Thailand, it was found that harvesting was done by cutting the rice panicle from the stalk in a single hand operation using a special hand-held blade. The shape of this blade is something like the "yatab" used in the Philippines. In all other regions, harvesting was done by sickles.

In Japan harvesting rice is done during the period from September to November. In northern Japan, generally, it extends from September to October, and in the western part it is usually from October to November. The majority of Japanese farmers still harvest with some blade sickles and saw sickles. There are many types of blade sickles designed for various purposes. The sickle used for rice harvesting has a blade 18 centimeters long and the angle between blade and handle is 90 degrees.

The blades would be roughly divided into two types. 1) The curve type called "ECHEZEN" type. 2) The straight type called "SHINSHU" type. The former is used in western Japan, and the latter is used in the northern provinces. The saw type sickle is used only for rice harvesting. The angle between toothed blade and the handle is almost 150 degrees. The size of the saw sickle is always smaller than that of the blade sickle.

Reaping methods with the sickle varies according to the dryness of paddy field, cultivation method, crop condition, etc. Generally, the standing rice plants are cut at a height of 1-3 centimeters from the soil surface, and made into suitable size bundles.

Besides the hand blade sickles and the notch saw-type hand sickles there are several types of improved cutting implements such as hand dropper, hand rice binder, etc.

Hand dropper. The implement with two sickle knives approximately 40 degrees apart cuts the crop 2 to 3 centimeters above the soil. The operator then pulls the lever, which is near the handle, and seizes the stems tightly in the frame. Next, the implement is pulled backward a little to cut the seized stems completely which then may be dropped and laid in the field. There are two types of "hand dropper" the single handle and the double handle.

Hand rice binder. This is a machine for harvesting and binding the crops in the same operation. It operates as follows: After the operator cuts the crop for 2 meters or more, he stops and raises the left handle to seize the cut crop which is ready to bind into a sheaf with straw rope.

There are some improved small combines which are connected with the walking type tractor. Today, in Japan there are many factories producing the cutting mechanism, harvesting machines and walking-type tractors. However, the hand sickles are still used extensively during the harvesting season.

<u>China</u> located in the northern hemisphere extends through roughly 30° of latitude, or from 20° to 50° north. Due to the great variation and extremes of climate and topography, the agricultural products in this country are varied. Rice, oats, wheat and barley are the main products. Crop production is chiefly rice in southern China.

The harvesting times are different due to location and weather. The implements used for harvesting are mainly sickles. Some places use machines which are imported from foreign countries, and some are manufactured by local factories. The ordinary sickles consist of a 6 inch iron blade with a loop formed at the heel to receive the short, round straight wooden handle. Actually, there are different shapes in different localities. In Checkiang Province, the eastern province of China, they use the serrated sickle, the average width 7/8 inches, the blade at one end narrows to a tang which passes through the rudely shaped wooden handle and is clinched where it emerges. The teeth are cut into the edge with a cold chisel. In the western provinces, some localities use the scythe, the bamboo pole handle about 5 feet long, as the angle which the metal blade forms with the handle. In north China particularly, the swinging sickle is used, which somewhat resembles a cradle, and the iron blade has a wire net or slatted sack behind it to catch the cut grain.

Research Literature

In reviewing modern literature some research on cutting crops was reported.

Stroppel (1953) compared many cutting processes known today and the blades and mechanisms used to accomplish these processes. He defined cutting as "a mechanical separation process on a solid body by the use of a cutting tool whose wedge-formed cuting parts are under pressure and overcome the cohesion of the material due to the higher specific normal and thrust forces along the cutting edge. . . ." On the basis of this broad definition he claimed that sawing and many other separation processes are cutting processes.

He differentiated between knife cut and shear cut from the technological viewpoint. They do not correspond to cutting with a single element and cutting with two opposed elements. He demonstrated that cutting with a single element can be a shear cut; with two elements can be a knife cut. For knife cut the wedge angle should be as small as practical. The sharpness of cutting edge is of great importance and is indicated by the wedge angle including the fineness to which this angle is maintained.

He also differentiated between a pressing cut in which the knife moves only perpendicularly to its cutting edge and a slicing cut in which the knife has a component of velocity in the direction of the edge. He related the effectiveness of the slicing cut to the fine saw action of the microscopic notches along the edge which came from grinding irregularities.

Power (1948) found that the minimum practical included edge angle for cutting sugar beets is 12 degrees. He stated that the effective included angle can be decreased by introducing a component of velocity parallel to the cutting edge.

Fisher, Kolega and Wheeler (1957) determined the energy to cut a single stalk between two sharp blades. A pendulum was used and the height on the upswing was measured after release from a fixed height. Knife velocity was 113 inches per second. Different crops were treated at various stages of maturity, and stem diameter at the point of cut was measured.

Fisher, Schlemn and Eggert (1955) placed on a flywheel type chopper one knife each which had a bevel angle of 14, 24, 30 and 40 degrees. A special breaker apparatus was used to measure the power during the cutting arc of each knife. Thus each blade was subjected to essentially the same conditions, while power requirements were measured individually. The machine was operated 15 hours. All energy requirements were compared to that of the 14 degree knife.

Koniger (1953) considered sliding the stalks along the knife edge an advantage as the cutting edge picks out the splitting point of least resistance. The moment cutting occurs the sliding ceases and cutting depends mostly on the effective wedge angle. He describes the shearing of fibrous organic materials as a process by which the "cut is introduced through penetration of the sharp wedge, whereupon in splitting, the failure always precedes the wedge," thus, he concludes that the wedge angle or sharpness of cutting edge is the prime factor governing the force required to shear the material.

He worked on cutting with two opposed elements considering sliding the stalks along the knife edge an advantage as the cutting edge picks out the splitting point of least resistance. The moment cutting occurs the sliding ceases and cutting depends mostly on the effective wedge angle.

Blazak (1955) investigating forage choppers claimed the average resistance of the material to the knife, or the normal pressure, is not dependent upon the angle between the knife and the material as long as the material is not pushed away from its position.

Feller (1958) studying alfalfa and Sudan grass concluded that the shape of energy curves and the distance the cut parts of the stalks were thrown indicated the amount of energy transmitted to the separated parts and increase as the knife angle was increased. This energy was relatively large for tall alfalfa stalks at the high velocities used.

Chancellor (1957) in studies involving alfalfa, foxtail, and timothy found that the speed of blade, as long as it was 130 feet/sec. or more, had little effect on the deflection sustained while the size of the stem appeared to be the most significant factor. As the knife strikes farther from the point of support the amount of energy required increases to cause a given deflection.

Prince (1960) found linear relationship between cutting energy and numbers of stalks for alfalfa and timothy crops. The cutting energy values increased with numbers of stalks cut.

TEST APPARATUS

General Description

a) A pendulum-like cutting apparatus was designed and built for this study (Fig. 1).

The apparatus consists of an aluminum tube in "T" shape. The top part of "T" shape steel tube is supported by passing through a steel shaft which is mounted on a frame with two ball bearings with pillow block so that the pendulum can swing freely with very little friction.

The cutting implement (Fig. 2) is connected to the end of the bottom part of "T" shape tube by a screw bolt. The knife is fixed on a turning semicircular bar which has both ends through a small structure. The structure is connected with bottom part of the tube.

At one end of the semicircle steel bar is placed a brass spot pointer which is wired to the distributor which is on a generator driven by an electric motor. The recording plate is made of aluminum and is movable by means of a worm and gear mechanism (Fig. 3).

Although the apparatus is pendulum-like, the swing arm cannot be considered to be a true pendulum for it does not oscillate and the angle involved in the angle swing is large. The classical law for pendulum motion is restricted

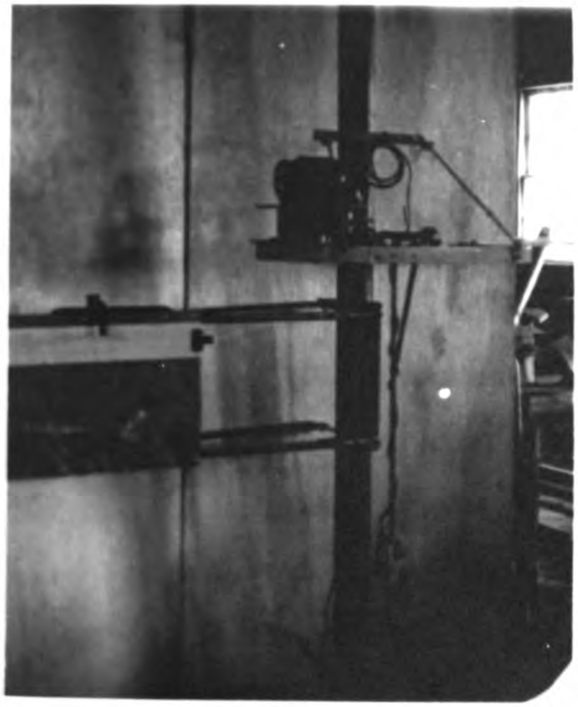

Figure 1. The sideview of the pendulum-like apparatus.

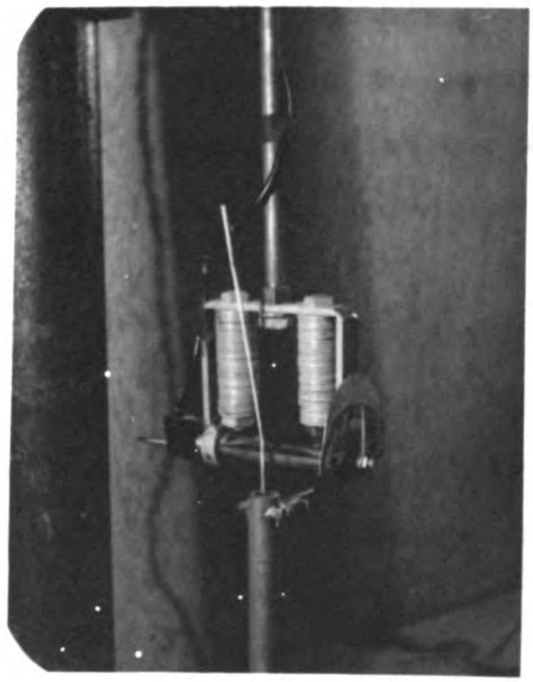

Figure 2. The cutting implement and stem holder.

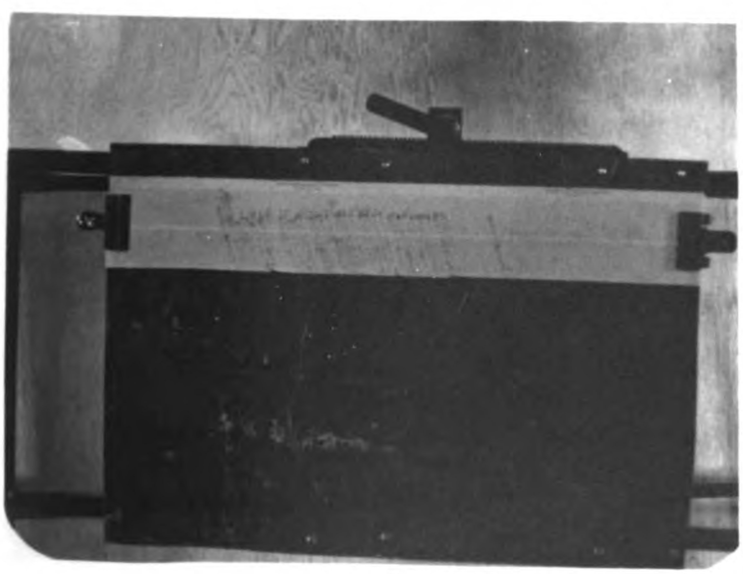

Figure 3. The recording board.

to the small angle of oscillation. Therefore, a distinction is made there and the moving part of apparatus is referred to as swing arm rather than a pendulum.

The apparatus was designed to give maximum possible peripheral knife speed with maximum sensitivity to indicate energy. The thickness of the knife was 0.0059 in.

b) The design of the apparatus for testing the deflection of the straw is based on the idea of a free supported beam. It is in general a single structure with the weight placed in the middle as an applied weight.

Theoretical Analysis of Test Apparatus

a) Pendulum-like swing mechanism.

"The change in potential energy is the work done by the force when the particle moves from x to some standard reference point x_o."

$$U(x) - U(x_o) = \int_{x}^{x_o} F(x)\, dx$$

$$\frac{1}{2} mv^2 + U(x) = K + U = E \text{ (total energy)}$$

In this case, it can be analyzed in the following way: $-U = K + U_1 - L$ where $-U$ is the pendulum swing from top point to the lowest point before the knife cuts the stem. K represents the energy for the knife to pass through the stem area. U_1 represents the potential energy due to the pendulum moving from the lowest point after cutting to the highest point which the pendulum stops and completes the whole period of swing. L is the energy loss due to the air friction of swing and the mechanical friction of the mechanism.

From this equation given above, we can measure the energy for cutting straw by the difference between potential energy from the swing without cutting and the swing with cutting action. In order to find out the difference, we use the high voltage spark on a magnetic recording carbon chart to indicate the different height of each swing, because the potential energy is the function of mass, gravity force and height. $U = f(m,g,h)$ In our case, the mass of the pendulum and gravity force are constant so that the only variable in this potential function is height.

$$U = f(m,g,h)$$

$$= f(h)$$

$$v = \sqrt{2gh}$$

$$\therefore v^2 = 2gh \longrightarrow h = v^2/2g$$

$$\therefore h = f(v^2) \qquad \therefore g \text{ is constant}$$

But the velocity of the pendulum (velocity of knife v) is more difficult to determine than finding the height of the pendulum swing. That is the only reason it is desirable to use a high voltage spark to find the difference of potential energies.

b) For finding some physicomechanical properties of the straw.

Density is the ratio of weight and volume. The weight was determined by the electronical balance, and the approximate average diameters of the stem were measured by the wire gage (English standard wire gage no. 188). Because the shape and thickness of the straw's walls are not the same, even in one stem, the thickness gage, by the pressing method, was used to get the several thicknesses of one stem. Then the average was calculated.

$$\text{volume} = \frac{\ell \pi D^2}{4} - \frac{\ell \pi d^2}{4} = \frac{\ell \pi (D+d)\ (D-d)}{4}$$

$$= \ell \pi (D + d)\ (2t)/4$$

$$= \pi \ell\ (D+d)t/2 = \pi\ \ell t\ (R+r)$$

$$= \pi \ell t\ [\ R + (R-t)\ ]$$

$$= \pi \ell t\ (2R - t)$$

So density

$$\frac{\text{weight}}{\text{Vol}} = \frac{\text{weight}}{\pi \ell t\ (2R - t)}$$

for which

D = outside diameter

d = inside diameter

ℓ = stem length

t = average thickness

$R = D/2$

$r = d/2$

Compressibility factor (Cp). Theoretically the straw is an elastic material which makes it most difficult to find the Cp, it being almost impossible. It is assumed that the straw has perfect elasticity properties. So, it is possible to use the deflection to find the factor of compressibility. By the formula of free supported beam,

$$\delta \max = Pl^3/48 \text{ Cp I}$$

So: $\text{Cp I} = Pl^3/48 \ \delta \max$

for which P = the loading in the middle point of the free supported beam

l = the distance between two supports

δ max = maximum deflection of beam.

We used three different kinds of loading which vary from 50 grams to 150 grams. These all depend on the size of the straw. For the value of CpI, three different values of CpI were calculated over different loading and different deflections, then averaged to get the reasonable value for CpI. But for all these processes it should be assumed the theory of the deflection of straw should still follow the general deflection theory of perfect elastic materials.

PROCEDURE

Obtaining the Data

The stems were cut in the field by sickles and brought to the laboratory for testing. There are several things to be done before testing:

1. Examine each stem to be sure that each stem's outside structure is perfect.

2. Cutting the straw into predetermined lengths by the electrical disk saw.

3. Separating stems into different groups from various diameters by fitting them into the holes of the standard wire gage.

4. Putting the stem into the stem holder which will tightly clamp the straw by two springs and soft rubber faces.

The arm was raised by hand and rested on the catch of the release device (Figure 4). Fixed the recording paper on the recording board by two paper clamps, on the predetermined position (height). Turned on the switch, the motor began to run and the arm was then released automatically by the vibration of the release device. Before the fourth step took place, the free swing with no action occurred, and let the arm upswing to the maximum position.

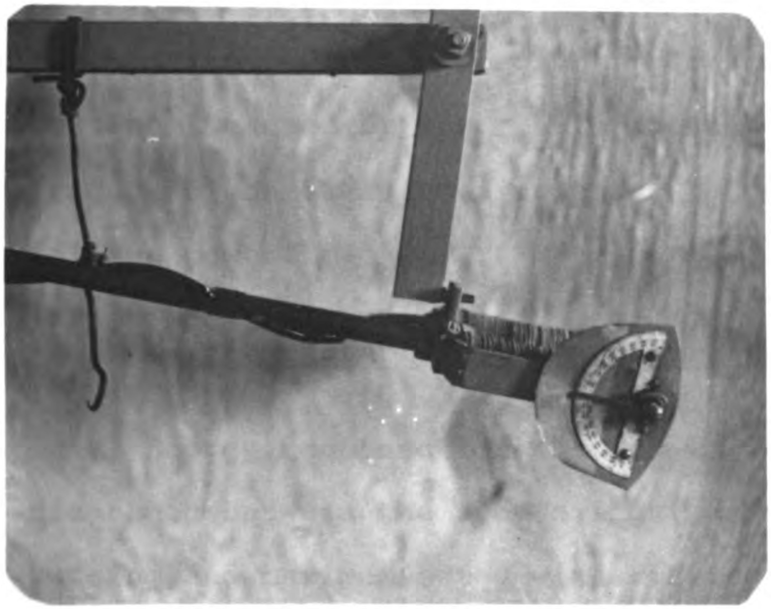

Figure 4. The knife holder and release device.

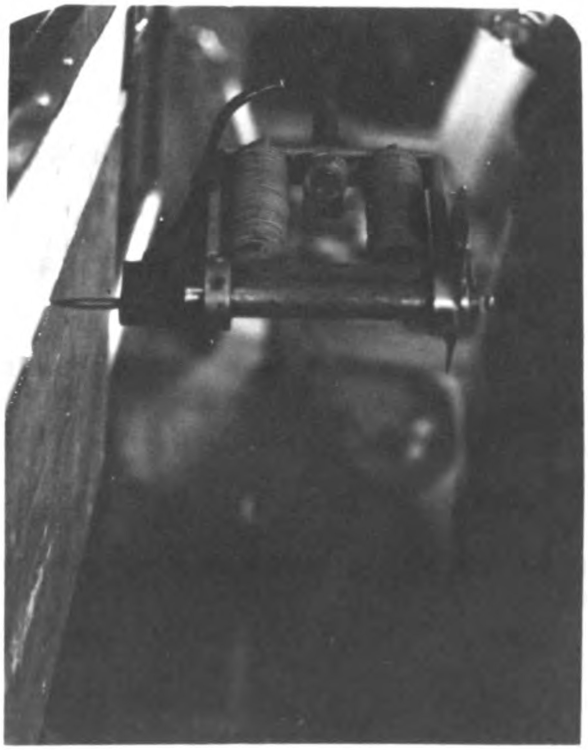

Figure 5. Sparking between electrode and metal plate on recording board.

The real acting action had taken place when the knife reached its lowest position. The maximum upswing (with cutting) reached by the arm is indicated by the spot (Figure 5) on the recording paper by the pointer and high voltage power.

Interpretation of the Apparatus Readings

Energy required for cutting was determined from the clearance between the free swing (maximum swing with no cutting and maximum swing with cutting action). This clearance can be obtained by examining the two different spark spots (free swing and cutting swing) on the recording sheet.

Knife velocity at the beginning and end of cutting is dependent on the length of the swing arm. By the formula

Potential Energy = Kinetic Energy

$$Mgh = \frac{1}{2} I \dot{\theta}^2$$

Such that

$$I = I_{tube} + I_{cutting\ implement}$$

$$= \frac{1}{3} m\ell^2 + ML^2$$

$m = 0.0258$ lb (mass of the tube)

$\ell = 3.46$ ft (length of the tube)

$M = 0.432$ lb (mass of the cutting implement)

$L = 3.85$ ft (length of arm from pivot point to knife)

$I_{tube} = 0.125$ lb-ft^2 (negligible)

$I_{cutting\ implement} = 6.453$ lb-ft^2

$$Mgh = \frac{1}{2}(ML^2)\,\dot{\theta}^2 \qquad v^2 = (L\dot{\theta})^2$$

$$v = \sqrt{2gh}$$

The calculated velocities are for the lowest position of the knife. However, since the place where cutting starts or ends is very close to this position, therefore the difference is negligible.

Variables

1. Crops. The experiments were confined to the cutting of spring wheat stems.

2. Stems diameter. The stalks were selected to fit the holes of standard wire gauge and varied from 0.095 in. to 0.220 in.

3. Height of stems. In order to control this factor the stems were cut to a predetermined height.

4. Cutting height (the distance between cutting point on the stem and the topmost point of the holder). Six different heights were tried in this study, such as 0.5 in., 0.8 in., 1.00 in., 1.20 in., 1.40 in., and 1.60 in.

5. Knife angle. This factor was found to have very little effect on the cutting energy in the range of 120° to 60°. Therefore, the angle was kept near a 90° angle through all the work (Figure 6).

Table 1. Impact Cutting Energy Affected by Changing the Knife Angle

Knife Angle (degrees)	60	70	80	90	100	110	120
Average E/MG. (inches)	0.53	0.57	0.56	0.55	0.57	0.54	0.56

6. Knife velocity when cutting starts. This followed the formula preceding, $v = \sqrt{2gh}$. When h is very close to the value of length of the swing arm, then $\cos\theta \approx 0$ as θ approaches 90 degrees. In this study, four different lengths of swing arm were used: 4.5 ft., 4.0 ft., 3.68 ft. and 3.5 ft. The speeds corresponding to the lengths were 17.05 ft./sec., 16.75 ft./sec., 15.8 ft./sec., and 15.15 ft./sec.

7. Relative Humidity. In order to control this factor, the stems were always kept in the temperature-humidity chamber (50 degrees F) except during testing.

RESULTS AND DISCUSSION

Effects of the Cross Section Area

The effects of the cross section area on the cutting energy are shown in Figures 6 and 7.

A general relationship shows as the cutting energy approaches the minimum value for the cross section area, approximating 0.065 inches; and the energy value tends to correspond to the increase of the cross section area. As it shows on the logarithmic chart, it does give some relationship as a nonlinear function with a power of around 2.1. According to the dimensional analysis, we know that if the f_2 is a linear function then theoretically the energy should be related to the cross section area in a nonlinear 3/2 power function. After repeating tests several times, it was found on the chart those relations are very close to each other, which is the average value on Figure 6 and Figure 7.

Compared to the result of Mr. Chancellor, who claimed that large size stems have more and heavier fibers to cut causing not only a great length of time during the application of the cutting force but also a greater force and the force applied to the later cut fibers when the velocity is not increased results in increased energy transferred to the stem. And Professor Prince's results show the relation between

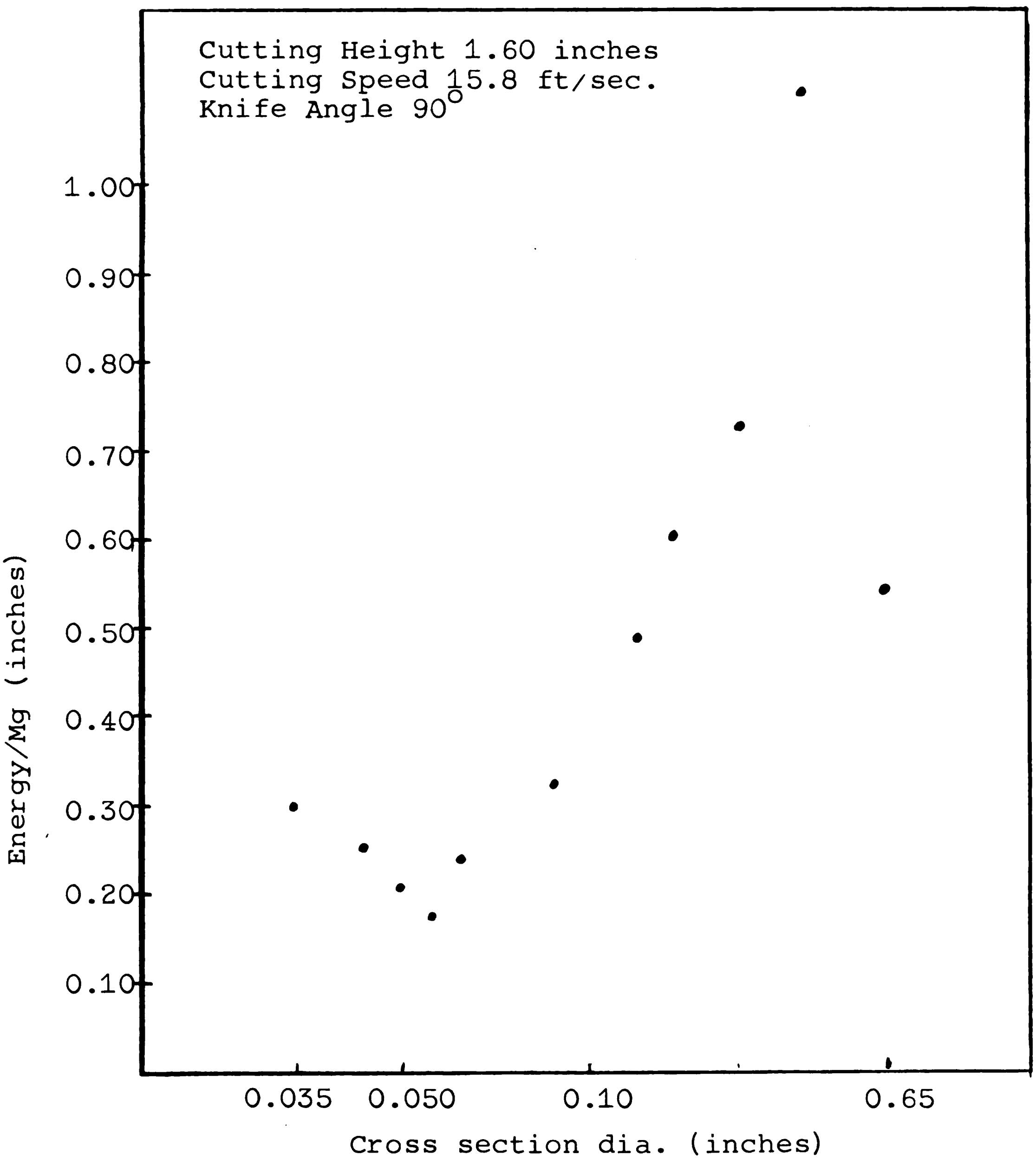

Figure 6. Energy/Mg <u>vs</u>. cross section area.

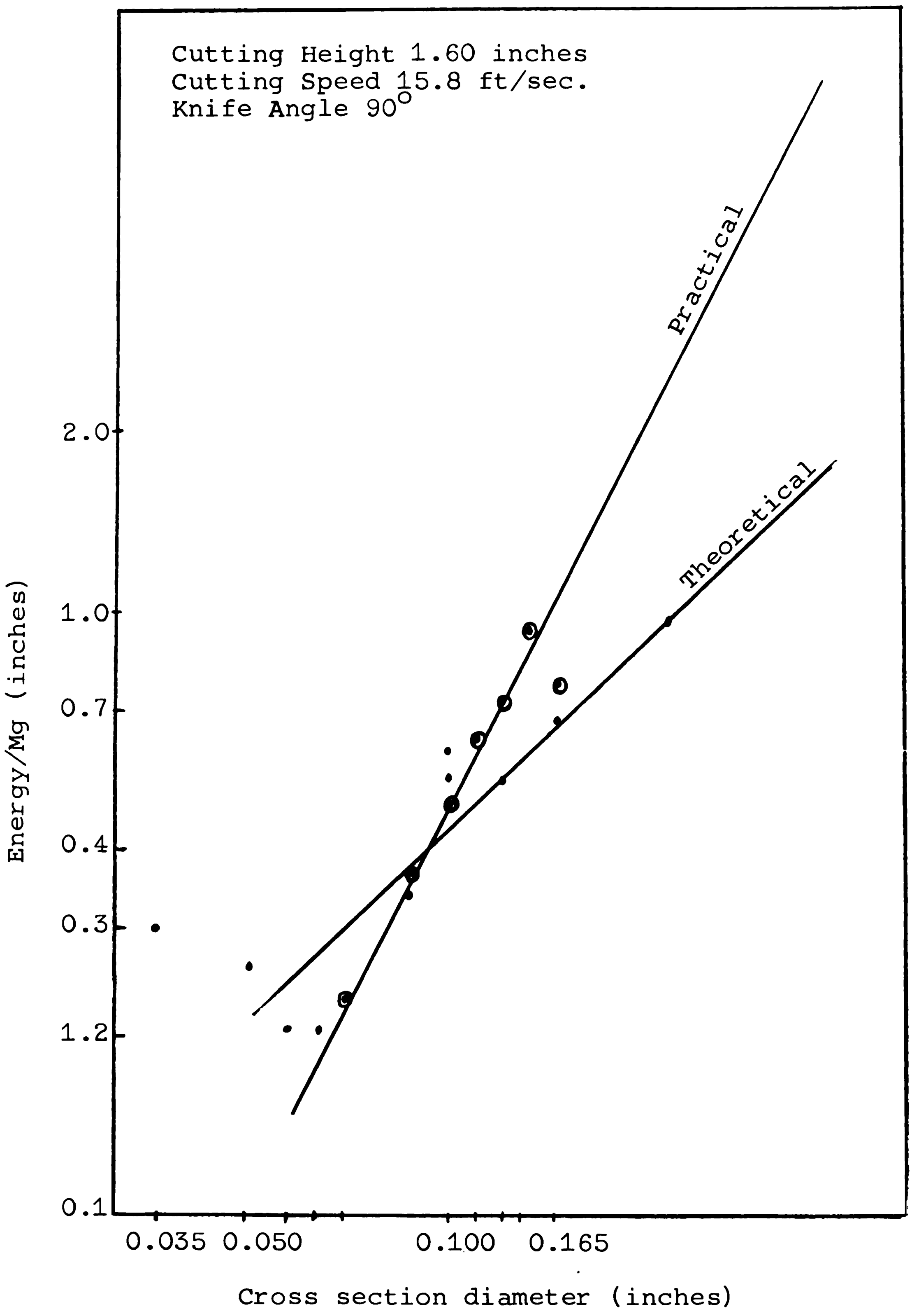

Figure 7. Energy/Mg vs. cross section area in logarithmic chart.

energy and diameter of stem is approximately linear. Although Mr. Chancellor and Professor Prince used alfalfa in their studies, which has different stem organization than wheat, theoretically speaking, the energy lost in cutting will have the same linear relation with the stem cross section area.

Homogeneity

In order to find out the mathematical model of the cutting energy, some physicomechanical properties of samples are needed in order to test the homogeneity of samples. There were only two properties of interest, 1) density of the straw, and 2) compressibility factor. For the density, it was found there was great variation from section to section. Therefore, the average was plotted on the chart vs. the compressibility factor (Figure 8).. It shows the density of samples falling in the range of 3.5 to 5.5 g/in^3, and the relation between the compressibility factors and density can be explained as linear function in certain ranges. Even the groups cluster as several different groups. The lowest value of compressibility factors is around 2500×10^5 dyne/cm^2 the highest will up to 11000×10^5 dyne/cm^2.

Effect on the Cutting Height

The effects of cutting height on the cutting energy are shown in Figure 9.

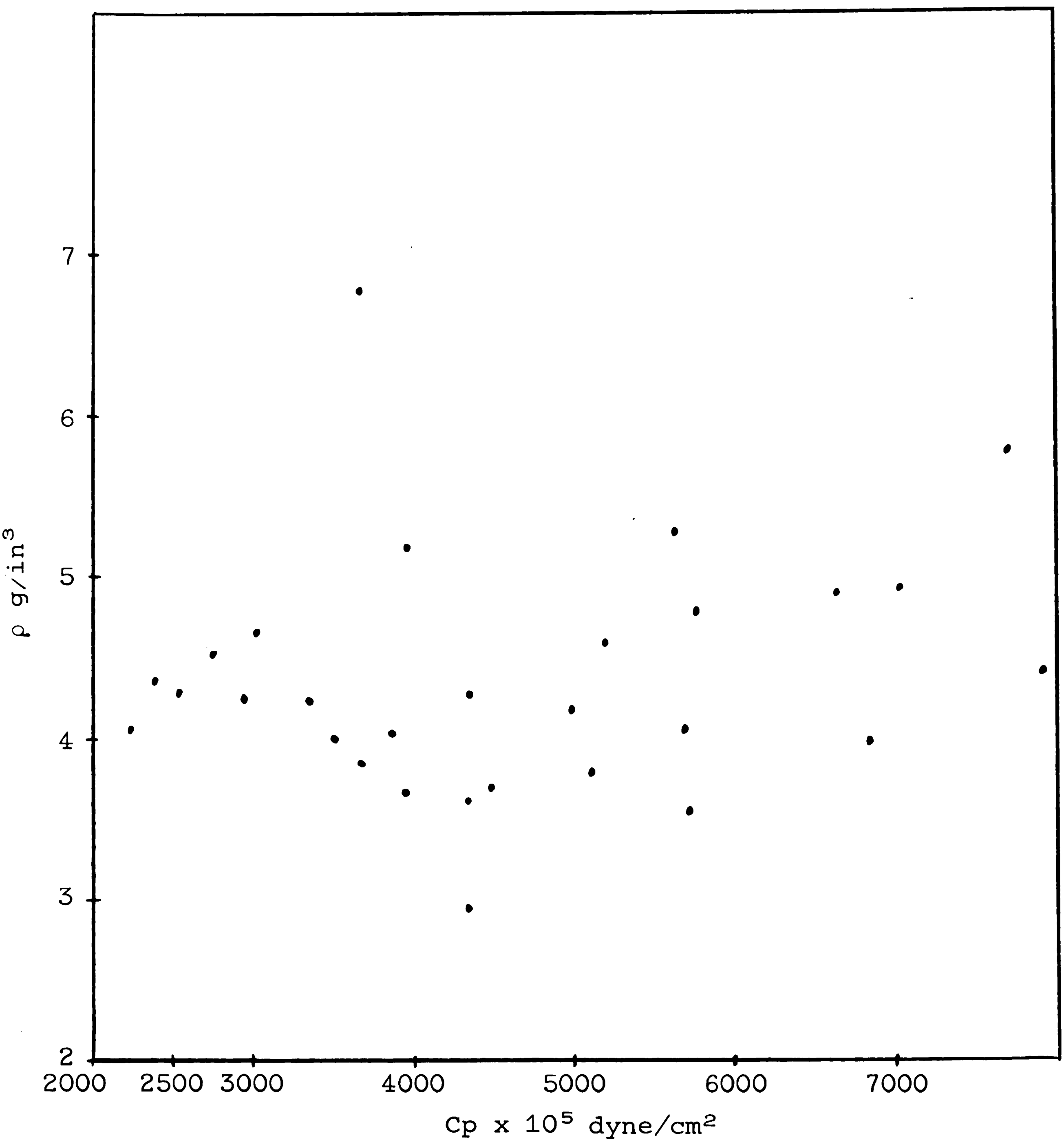

Figure 8. Density vs. compressibility factor.

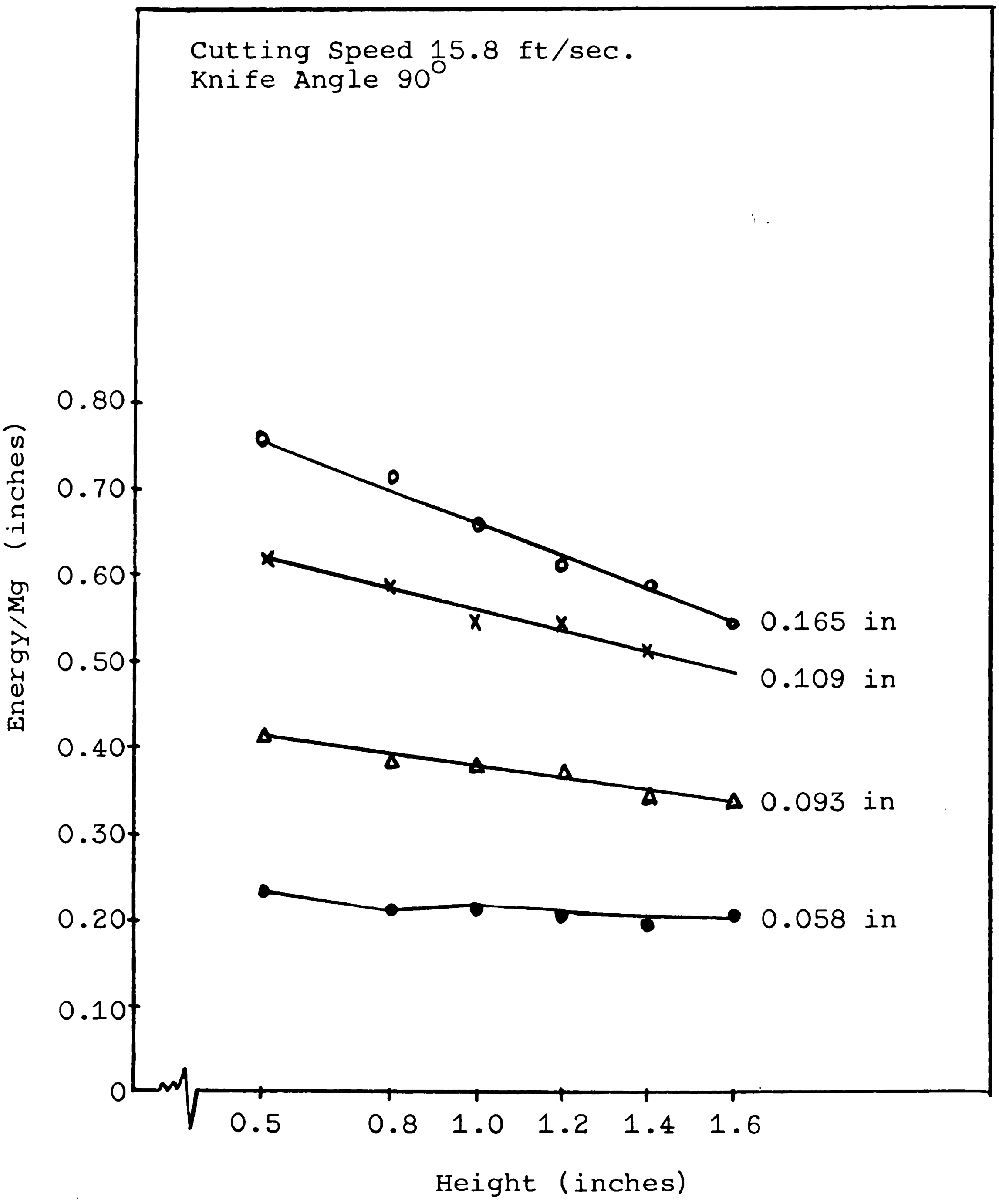

Figure 9. Energy vs. cutting height.

Table 2. The Cp vs. ρ for Different Cross Section Area

Dia. x 10^{-2} in.	ρ g/in^3	Cp x 10^{-5}dyne/cm^2
8.90	3.849	3651.96
9.18	4.969	7067.91
9.18	3.958	3642.72
10.25	4.456	7900.00
10.65	4.296	2521.10
10.65	3.664	3920.68
10.60	4.918	6602.75
10.93	4.259	4312.22
10.53	4.086	5680.80
11.00	4.331	3621.47
11.30	4.302	2909.90
11.38	2.949	4302.43
11.33	5.817	7677.00
11.40	5.357	5359.39
11.43	4.385	2388.64
11.60	4.106	6820.76
11.70	2.618	5266.04
12.15	3.566	5669.85
12.08	4.197	4952.23
12.28	6.822	3561.78
12.48	4.510	2732.15
12.43	4.082	2238.51
12.60	4.293	3344.53
12.83	4.692	5184.09
12.83	4.663	3001.49
12.93	4.212	3343.00
12.50	4.808	5759.13
13.20	5.215	3931.32
13.68	4.738	13670.36
13.00	4.042	3840.42
14.18	3.778	4471.64

The result shows the relationship between the cutting energy and cutting height is pure linear. The cutting energy is decreased as the height increases, and the linear graph line becomes steeper as the cross section area increases. Actually, as the cutting height becomes larger, the bending movements increase, requiring less energy to cut. Like Chancellor states: "As the knife strikes farther from the point of support (cutting height larger) the amount of energy required to cause a given deflection at point of cutting is decreased." Russian scientists did work some physico-mechanical properties of Agricultural Crops. Burmistrova investigated the cutting forces on the oil plant, sunflower. He reported that the cutting forces decreased as the cutting height increased.

Table 3. The Cutting Energy Under Different Cutting Height and Different Cross Section Area

	Inches			
Height (inches)	Energy/mg (D=0.058 in)	Energy/mg (D=0.093 in)	Energy/mg (D=0.109 in)	Energy/mg (D=0.165 in)
1.60	0.205	3.4	4.9	5.4
1.40	0.195	3.49	5.2	5.9
1.20	0.210	3.75	5.49	6.15
1.00	0.215	3.80	5.5	6.6
0.80	0.215	3.80	5.8	7.1
0.50	0.230	4.15	6.2	7.6

Effect on the Velocities

The results are shown in Figure 10.

The result states the relationship between cutting energy and velocity of cutting is a nonlinear curve. As the velocity increased, the cutting energy decreased. Compared with Professor Prince's investigation on oats, it shows that the energy decreases with a nonlinear relationship to the velocity increase.

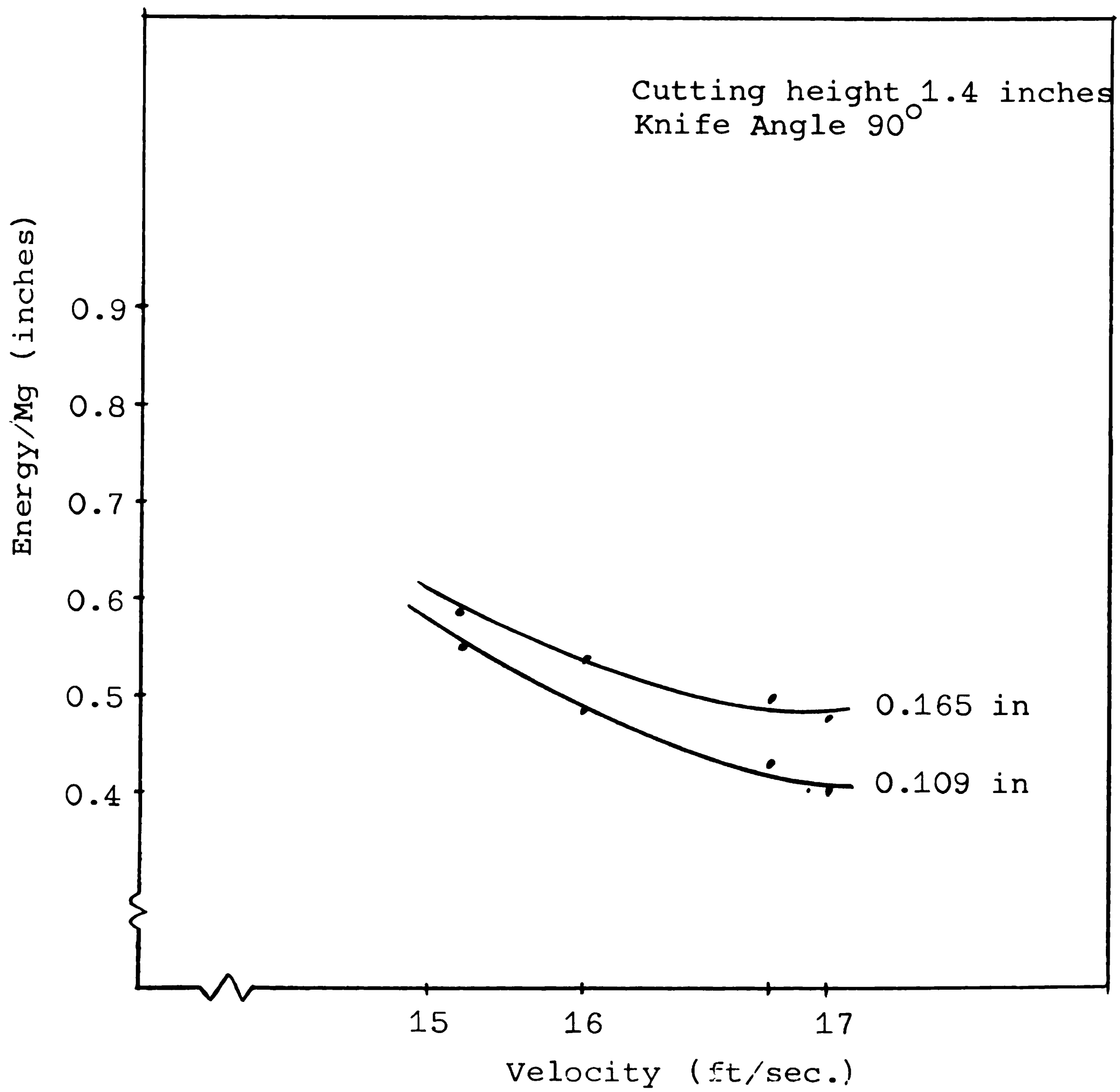

Figure 10. Energy vs. cutting velocities.

CONCLUSIONS AND RECOMMENDATION

Referring to the formula:

$$E = v^2 \rho A^{3/2} f_1 \left(\frac{Cp}{v^2 \rho}\right) f_2 (L/A^{\frac{1}{2}})$$

From the results given preceding we know:

1. The cutting energy is linear to the cross section area.

2. The cutting energy is linear to the cutting height.

3. The cutting energy is nonlinear to the velocity.

4. The densities of samples in this study fall in the range of 3.5 to 5.5 g/in^3.

From 1 and 2, we can conclude that f_2 is a linear function because $A^{3/2} \cdot A^{-\frac{1}{2}} = A^{\frac{3-1}{2}} = A$. So we can rewrite the formula as:

$$E = v^2 \rho \; AL \; f_1 \left(\frac{Cp}{v^2 \rho}\right)$$

It is strongly recommended as further research that this formula be completed by investigating the relationships between E and Cp and ρ and v^2.

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