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I am submitting herewith a thesis written by John David Davenport, entitled "Development and Evaluation of Two Picker Reels for an Experimental Vegetable Harvester." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Mechanization.

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DEVELOPMENT AND EVALUATION OF TWO PICKER REELS FOR
AN EXPERIMENTAL VEGETABLE HARVESTER

A Thesis
Presented to
the Graduate Council of
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In Partial Fulfillment
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Master of Science

by
John David Davenport
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ABSTRACT

The purpose of this investigation was to evaluate a conical shaped, steel tine picking reel mounted in an experimental helical vegetable harvester for effectiveness in detaching snap beans. Two double helix picking reels, each of a different pitch, were tested. One reel had a pitch of three inches, and the other had a pitch of four inches. Laboratory tests were conducted to determine the effects of helix speed, reel speed, and reel pitch on picking efficiency and pod damage.

The average picking efficiency was 83.2 percent. An average of 31.8 percent of the picked pods were broken and an average of 16.0 percent of the pods were picked in clusters. Statistical analysis of the test results showed that only the interaction between reel speed and reel pitch was significant for the responses percentage of pods broken and percentage of pods picked in clusters.

High speed motion picture films of the picking action were studied to determine the mode of pod detachment. Four modes were observed and grouped into two classes depending on condition of the detached pods. The acceptable group consisted of pods that the tines detached at either the pod-pedicle junction or at the pedicle-plant stem junction. The films indicated pods of the unacceptable group were either broken when one tine accelerated a pod into a second tine or when a tine contacted the pedicle and created tensile stresses within the pod thus removing part of the pod with the pedicle. The helical coil was observed to support the plant stalk and

act on it to aid in pod detachment through application of a force opposite to the picking tine force.

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CHAPTER I

INTRODUCTION AND OBJECTIVES

I. INTRODUCTION

Concentrated, efficient, and timely harvesting is best done mechanically. Since the harvest operation accounts for 1/2 to 3/4 of crop production costs, more efficient harvest methods offer a way to reduce those costs (20). Harvesting is the most difficult area of agricultural mechanization (12). Even so, engineers have produced successful machines to harvest the major field crops. But development of mechanical harvesters for vegetables and fruits has lagged far behind (3). Much expensive hand labor, that is available in unreliable, limited supply, is required for harvesting some of these crops (10). In 1969, only 58 percent of the vegetables produced in the United States were mechanically harvested. This figure is expected to increase to 75 percent by 1975 (18).

Present mechanical snap bean harvesters perform reasonably well, but can be improved. They are tractor mounted, big, and heavy. They are also expensive. A two-row tractor mounted snap bean harvester with hydrostatic drive costs approximately \$18,000. Harvester detaching mechanisms need to be refined to produce less damage to harvested pods. According to Swingle et al. (16), 8.4 percent of the harvested pods were broken when detached by a two-row Hi-Boy model of the Chisholm Ryder Bean Harvester operating at optimum speeds.

Another need for further development of snap bean harvesters is a recent change in cultural practices which introduced high density planting of beans. In this cropping system, beans are planted in rows five to seven inches apart. Since conventional harvesters are designed to pick only rows spaced approximately 36 inches apart, a new machine is required to harvest the high density crop.

A study to develop more efficient methods of harvesting snap beans was organized in the Agricultural Engineering Department at the University of Tennessee. The investigation centered on expanding an idea conceived by A. H. Morgan (14). According to this idea, pods of bean plants could be detached quicker if one force was applied to the pod at the same time another force was applied to the plant stem. The principle was first tested by Richard Shadden (15). The experimental harvester consisted of a cylindrical, open-ended helical coil which travelled parallel to the plant row. The coil rotated through the row of plants to engage the plant stems. When the helix contacted the base of the plant stem, it forced the top of the plant into a cylindrical, fiber bristle brush. The brush rotated in a direction opposite to that of the helix such that the bristles picked the bean pods from the plants (15).

This helical harvester operated with an average picking efficiency of only 70.6 percent in laboratory tests and 80.8 percent in field tests (15). High speed motion picture studies indicated that the fiber bristles of the brush were not stiff enough to penetrate the foliage of the bean plants and readily detach the pods (2).

Also the helix diameter was too small to allow plants to pass through it without clogging. Further difficulties arose because the single coil helix was not stiff enough to maintain its shape when engaging plant stems.

II. OBJECTIVES

The purpose of this study was to evaluate a conical shaped picking reel mounted in a redesigned version of the open-helix harvester for effectiveness in detaching snap bean pods. Specific objectives were:

- (1) To design and build two picker reels for the open-helix harvester utilizing steel tines spaced in a spiral pattern. The two reels were to differ in pitch of the spiral pattern of tines.
- (2) To build a larger model of the open-helix harvester utilizing a three-coil helix assembly made of a stronger, more rigid material.
- (3) To test the revised open-helix harvester with each of the two designs of picker reels for effectiveness in detaching snap bean pods.

Tests were to include determination of the effect of reel speed, reel pitch, and helix speed on the following response variables: 1) percentage of bean pods detached; 2) percentage of detached pods broken; and 3) percentage of pods detached in clusters.

CHAPTER II

REVIEW OF LITERATURE

The snap bean harvester was the second major vegetable harvester developed, preceded only by the sweet corn picker. The original idea for a mechanical snap bean harvester was conceived in 1939 by J. W. Ward. Mr. Ward operated a custom cannery in Veron, New York, and was very aware of the harvesting problems that faced snap bean growers (10). An idea for harvesting snap beans by mechanical means came to him one day when he saw his wife removing snap bean pods in the garden by swinging a steel tooth rake through the plants. Mr. Ward realized that this method of bean harvesting was much faster than the hand picking method. Thus he began to develop a machine that would duplicate the action of the rake passing through the bean plants. Ten years later, in 1949, Mr. Ward revealed his snap bean harvester. Although the machine was not completely satisfactory (1), Yeager (19) reported that it picked two rows of wax beans as fast as the tractor would move. The tractor-mounted harvester picked beans of all sizes and placed them in a bag after removing the leaves. The picking was done by teeth mounted on revolving drums which first sheared away the superfluous top leaves. Observers noted that the machine occasionally missed a bean when the point of attachment was less than four inches above the ground or on a stem so low that the plant lifters missed it (19).

Mr. Ward's snap bean harvester attracted the interest of several manufacturers of vegetable handling equipment. One of the most

interested companies was Chisholm Ryder Company Inc. of Niagara Falls, New York. In 1950 this company bought the manufacturing rights for the bean harvester from Mr. Ward (5). Two years later Chisholm Ryder revealed its first experimental bean harvester. It was tested by Professor W. T. Tapley of New York State Agriculture Experiment Station in a variety test in cooperation with the Alton Canning Company (1).

This machine harvested snap beans by the once-over method. The picking action of the teeth, actually steel tines mounted on a revolving drum, defoliated the plants thus destroying their ability to produce more fruit (4,12). This method of harvesting reduced the yield of beans, but the value of the lost crop was more than offset by the saving in labor cost. The harvester could pick beans of all sizes. This gave the harvester an economic advantage when a premium was paid for small beans. The Farm Research magazine reported that the new harvester picked a high percentage of the pods with very little damage (1). Only two percent of the picked pods were damaged. Most of this damage was in the form of broken pods (4). The operators of the harvester noted that most of the pods which were lost were thrown on the ground after being picked (1).

In snap bean harvester trials conducted in 1959 in Pennsylvania, researchers found that similar machines could harvest $3/4$ to $1/2$ an acre per hour. The quality of the beans picked was very similar to the quality of hand picked beans. A comparison is shown in Table I (7).

TABLE I

QUALITY OF SNAP BEANS

Hand Picked

vs.

Machine Picked

	<u>No. of Pickings*</u>	<u>2, 3, & 4 Percent</u>	<u>Grade of Beans</u>	
			<u>5 & 6 Percent</u>	<u>Culls Percent</u>
Hand Picked	9	69.6	24.4	5.8
Machine Picked	58	66.5	26.0	7.4

*On 225 Acres

Since Chisholm Ryder tested its first harvester in 1950, the company has become the leading snap bean harvesting equipment manufacturer in the world. In 1952 the company built five snap bean harvesters and placed them on the market. By 1954 this number had increased to 20. The popularity of the harvester spread rapidly and by 1956 the machines were being used not only in the United States but in Canada, England, and eight European countries as well (5). The mechanical harvesters have allowed growers to harvest bean crops that would have gone unpicked if only hand labor had been available (7).

Although the development of snap bean harvesters started over 35 years ago with J. W. Ward's idea, there have been very few changes made in the original harvesting principle. All manufacturers use the same method of removing the pods. The snapping or breaking of the pods from the vines is accomplished by using steel tines. The tines are attached to a reel or a chain device and are drawn up through the bean plants. The supporting frame for the reel or chain device moves in a direction parallel to the plant row while the tine path is perpendicular to the row. The tines are positioned in such a way as to start picking the pods and foliage at the top of the plant first, then to act on successively lower levels of the plant. When the pods are detached from the plant, they are thrown onto a conveyor which may or may not pass through a cleaning chamber before depositing the pods in a storage bin or wagon (6).

By 1963 there were eight different manufacturers of snap bean harvesters representing four different countries (5). According to

The American Vegetable Grower, all the European harvesters are tractor drawn except for the Ploeger three-row harvester, while all the American made snap bean harvesters are self propelled. The English, Dutch, and German manufacturers have attempted to design and build their machines to fit local conditions (6). As a result, most of these harvesters are small, relatively low in cost, and can be used in either large or small fields (5).

Mather and Platt Ltd. of London, England has marketed single row harvester and was one of the first developers of a multi-row harvester. The tractor drawn one-row harvester has not been introduced into the United States because its picking device bears certain similarities to the conveyor on a domestic spinach harvester (6). The picking device is different from the typical picking reel used on other makes of snap bean harvesters. It is made up of steel picking tines that are attached to a belt instead of a cylinder. This allows the tines to move straight up through the bean plants instead of making an arc through the plants like the tines of a cylinder (5). This design provides a very narrow picking unit that can pick beans in rows as close as 15 inches (6). Each component of the Mather and Platt harvester is driven by a separate hydraulic motor that is powered by a master hydraulic pump attached to the tractor power take-off. This arrangement makes it possible for the harvester operator to individually change the speeds of the picking belt, conveyor, and fans in order to adapt to varying crop conditions. After the beans have been picked, they are cleaned by a suction fan as a conveyor carries them to a tote bin. The Vegetable Research Station

in Alkmaar, Holland, reported that the harvester did such a good job of cleaning the beans that they could be processed without further cleaning (5). Since the harvester is a pull type, and has an array of hydraulic motor controls, two persons are required to operate it, one to drive the tractor and the other to operate the harvester. The harvester can pick about one-half acre per hour in rows spaced 24 inches apart (6).

Mather and Platt engineers in conjunction with research horticulturists of the Unilever Research Organization at Sharnbrook, Bedfordshire, England, have developed a multi-row harvester to be used on snap beans planted in closely spaced rows. Duncan (27) reported in 1969 that the prototype was clean-cut, trim, relatively quiet, efficient, and large enough to be of commercial interest. This harvester could take advantage of erect high yielding beans planted in high density stands (6).

The Herbort snap bean harvester was introduced in 1962. It was built in Braunschweig, Germany by the August Herbort Factory. It is a one-row, pull type machine and harvests the beans by means of a conventional picking reel aligned parallel to the row. The speed at which it may be operated varies from two and one-half to four miles per hour. The harvesting capacity of the machine is 2,700 pounds per hour. After the beans are picked, they are cleaned at two different locations by air streams. The clean beans then pass into a screening device that separates the clusters of beans from the loose beans. The harvester weighed 2,700 pounds and sold for less than \$5,000 in 1963 (5).

There are two different snap bean harvester manufacturers in the Netherlands: The Borga Company and the Ploeger Company. The Borga Company builds a one-row harvester and a two-row harvester, both of which are tractor drawn. The one-row machine was introduced in 1960. The bean pods are picked by a small conventional picking reel that can be adjusted to different row widths (5). This enables the harvester to pick beans planted in rows as close as 17 inches. The beans are cleaned by a pneumatic cleaner as they are carried on a conveyor from the picking area (6). The harvester has a capacity of two and one-half acres per day when harvesting beans planted in rows 24 inches apart. The only power source for the harvester is the tractor power take-off (5).

The Borga two-row harvester was tested in 1968. It featured two picking reels extending from the left side of the machine and rotating in opposite directions. When picked the beans are thrown onto a common conveyor, pneumatically cleaned, and deposited in a box-on hydraulic dump loader (6).

The Ploeger Company of the Netherlands also builds two models of snap bean harvesters. The tractor drawn one-row harvester was named after the farmer who first built it. The machine is light-weight and can be used on rather heavy clay soil. The weight of the harvester was reduced by eliminating most of the cleaning devices. Other than a small picking reel, the machine consists only of a small conveyor belt the width of the reel, a single blower type "precleaner", and a conveyor to carry the beans to a field container. The harvester

can be operated at five and one-half miles per hour in fields with plants in 17-1/2 inch rows yielding two and one-half tons per acre (5).

The self propelled Ploeger three-row harvester was introduced in 1968. According to Ir. Jan van Kanpen, director of the Vegetable Research Station in Alkmaar, Holland, it can harvest three rows spaced 17 inches apart or two rows spaced 34 inches apart. The harvester weighs five and one-half tons thus making it by far the largest European snap bean harvester. After the beans are picked by a conventional reel, they are placed in a box-on bin (6).

There are four different makes of snap bean harvesters manufactured in the United States. These are the Tiura, Pix-All, Hughes, and the Chisholm Ryder machines. All of these harvesters use the conventional picking reel to remove the beans from the plants. The Tiura is a two-row unit that is built on and powered by a Ford 4000 tractor. It features a hydraulic box-over dump loader and a squirrel cage cleaner. The conventional rubber tires on this harvester may be removed and replaced with tracks in order to operate in rugged terrain or in muddy fields. The components of the harvester are driven by either mechanical power or hydraulic power depending upon the buyer's specifications.

Like the Tiura snap bean harvester, the Pix-All is built and powered by a Ford 4000 tractor. This harvester has evolved from a tractor drawn machine. The latest model can be adapted to either 30 to 32 inch or 36 to 38 inch row widths. The harvester has been used to pick southern peas and lima beans as well as the snap beans (5).

This company is now owned by Manny Llop, the president of Chisholm Ryder Company (6).

The Hughes Company has built and tested a two-row snap bean harvester mounted on a Ford 5000 diesel tractor. The harvester can be removed thus freeing the tractor for other jobs. The harvester is powered by five separate hydraulic motors. The oil flow for the motors is provided by a central hydraulic pump driven by the tractor power take-off. The picking, conveying, and cleaning principles of this harvester are very much like the Chisholm Ryder two-row harvester (6).

The Chisholm Ryder Company has several models of snap bean harvesters in use. All the models are self propelled and designed to pick beans planted in 30 to 36 inch rows. The major change in the Chisholm Ryder harvesters has been the power plant. It has changed from a Farmall Super C tractor in 1952 to an IH 656 with hydrostatic drive in 1969. Other refinements of the Chisholm Ryder harvesters include a pickup brush to feed plants into the front of the reel and an automatic scrow height control. Since many of the bean fields are muddy at harvest time, the company has started equipping the C-R 656 harvester with large flotation tires on the rear and heavily ribbed tires on the front. This not only reduces the compaction of the soil but aids in eliminating stuck harvesters and hard steering (6). The harvesters have been perfected to the point that they pick the pods clean without burising them and separate the leaves from the pods. It is not uncommon for the

harvesters to recover 90 to 95 percent of the bean pods on the plants (5). Yields of three tons per acre have been obtained in a once-over picking (9).

Since introduction of the mechanical harvester for use in snap bean production, it has been necessary to somewhat alter and adapt the cultural practices and type of plants to suit mechanical harvesting. The Raw Products Research Committee of the National Canners Association was one of the early promoters in the mechanical harvesting phase of snap bean production. This group met with plant breeders and drew up specifications for the type of plant thought to be most suitable for mechanical harvesting (10). It was realized that the efficiency of the mechanical harvesters depended mainly on the plant characteristics (4). The group noted that there was a definite correlation between the height and concentration of pods and picker efficiency (13). It was also known that extreme plant branching would reduce picker efficiency (1). With these things in mind, plant breeders have been working to develop varieties of snap beans that will set most of their pods at one time near the top of the plant. Other plant characteristics desired are a longer, upright stalk, fewer low branches, and less crossing of upper branches (10). Researchers have found that pod concentration and placement can also be improved by obtaining uniform seed germination and by close spacing of the plants in the row. The close spacing of the plants in the row tends to aid in the high placement of the pods on the vine. It is recommended that six to eight seeds be planted per foot (5). The seeds should be planted in rows approximately 36 inches apart if a two-row mechanical harvester is to be used to harvest the crop (9).

Because uniformity of emergence, uniformity of seedling growth, and evenness of maturity are extremely important with crops such as snap beans that are harvested only once (10), the appropriate field culture practices must be used. The field should be level and clear of stumps, stones, and other obstacles that would interfere with crop production (7). The soil should be fertile and well drained. Cultivation should be held to a minimum. If the crop is cultivated, no ridges should be left along the row (4). If the ridges are formed, the harvester will pick up the soil and mix it with the picked beans. The use of chemical weed control is one means of eliminating the need for extensive cultivation (13). Under the proper cultural conditions, snap beans are ready to be harvested when the pods snap readily and have pliable tips. This occurs about 46 days after planting for early maturing varieties and 72 days after planting for late maturing varieties (17).

As the agriculturist strives to obtain more yield per acre, it is becoming apparent that the old traditional, and at the present time, standard, 36 inch row width is no longer needed. When this row was established, there had to be enough room between the rows for the mules or horses to walk through and pull the farm implement. Today the idea of a 36 inch row width is rapidly giving way to the idea of narrow row spacing (11).

According to researchers in England and at Oregon State University Vegetable Research Farm, higher yields of snap beans are possible at high plant densities if drought, disease, low fertility, and insects can be controlled. At Oregon State University yields between

14-1/2 and 21-1/2 tons per acre in a single once-over harvest have been obtained using a planting arrangement of six inches by six inches for Tendercrop varieties and five inches by five inches for OSU Bush Blue Lake varieties (6). This yield can be compared to the average three tons per acre that is obtained by planting the same varieties in the conventional 36 inch row width and harvesting with a two-row mechanical harvester.

The obstacle to narrow row planting of production acreage has been lack of a means of harvesting the crop. The answer was partly provided by the Mather and Platt Company of London, England, when it introduced the multi-row harvester previously described. Although the machine lacked high efficiency, it created interest when it was brought to the United States and tested at the Oregon State University (11).

One firm that became very interested in this type of harvesting system was the Chisholm Ryder Company. After observing the demonstration of the Mather and Platt multi-row harvester, it began a project under the direction of A. Lee Towson and Virgil Jarred to study and develop a multi-row machine. The result of the project was the Multi-D harvester (11). This machine can harvest up to 11 narrow spaced rows at one time. The harvester has been tested in the Willamett Valley of Oregon for the past two years. It uses a brush to align the plants and guide them into the picking reel. The plants are picked of their pods and foliage by a series of metal "fingers" that are attached to a rotating reel (8). The reel is located in a position perpendicular to the rows. After the pods are harvested,

they are conveyed to a storage bin on the machine. The beans are cleaned by pneumatic fan units before being dumped into the bin. The harvester has a device at the initial elevation conveyor to separate the clusters. The storage bin is self contained and dumped by means of a hydraulic lift system. The harvester is eight feet in width and suitable for road travel. According to the Chisholm Ryder Company, the new harvester has the following advantages (11):

- (1) It is a self-contained unit.
- (2) The operator has a complete view of his work.
- (3) Fields can be "spot" harvested.
- (4) The harvester increases productivity by about 15 percent.
- (5) The harvester may be used for harvesting pods of snap beans, lima beans, peas, and southern peas.

The new multi-row harvester, like the preceding single and two-row machines, employ metal tines, or fingers, sweeping through the plant structure to detach the pods. Although beans picked by this method are generally acceptable for processing, broken pods are still present which render machine picked beans undesirable for fresh market packs without extensive grading. Also harvesting efficiency is not consistently at the 90 to 95 percent level as optimistically reported by Duncan in 1963 (2, 5).

To gain insight as to the reasons for pod breakage and to uncover hints on how to further improve harvesting efficiency, the specific mechanism of pod detachment by moving tines was investigated by Bledsoe and Morgan at the University of Tennessee (2).

High speed motion picture films of the picking action of a model 544 Chisholm Ryder Hi-Boy harvester were analyzed in the study. Two general classes of tine action were identified: one in which the tine strikes the pedicel (pod stem) between the pod and stalk; another in which the tine strikes the pod itself. Action of the tine on the pedicel results in failure of this pod attaching stem primarily as a result of high flexural stress induced by the concentrated bending loads applied. This is the ideal detaching action, the pod being untouched by the metal tine. The class of detaching action where the tine strikes the pod is subdivided into two cases. One case occurs when the tine strikes the pod near its stem end and exerts primarily tensile force on the pod. The detachment occurs by breaking of the pedicel, the pedicel-stem junction, the pedicel-pod junction, or the end of the pod. The second case occurs when the tine strikes the pod at a point more distantly removed from the pedicel end; transverse shear and bending forces dominate, and cause breakage of the pod (2).

A survey of a 60 pod random sample from four, two-row Chisholm Ryder harvesters operating in the bean fields on the Cumberland Plateau in Tennessee in 1970 showed 62 percent of the pods were detached with the pedicel intact, 12 percent were detached at the pod-pedicel junction, and 26 percent had the ends of the pods broken off. The last class of pods is undesirable for processing as well as for fresh market, because unless moved rapidly from the field to the processing plant, discoloration of the broken ends takes place.

As stated in Chapter I, an approach to improved efficiency of harvesting was originated by Morgan (14) and evaluated by Shadden

and Morgan (15). Since the harvester needed to be improved, further studies were conducted. From analysis of the films of the helix-brush action, it appeared a cooperative helix-tine action would give a more effective picking action. This observation prompted the investigation reported herein.

CHAPTER III

TEST EQUIPMENT AND PROCEDURE

I. TEST EQUIPMENT

The machine built for this study consisted of a frame, a helix assembly, a picking reel (two designs tested), a suspension system, and a power supply. It was a once-over, one-row harvester. For tests it was supported by a stationary suspension system. Figure 1 shows the frame, helix, reel, and suspension system. The power supply for the harvester consisted of two hydraulic motors driven by a hydraulic pump which was powered by a tractor power take-off shaft.

The frame of the machine was constructed of 1 x 2 x 1/8 inch rectangular steel tubing. It was 40-1/2 inches high, 28-3/4 inches long, and 38-7/8 inches wide. The front of the frame was 1-1/4 inches lower than the rear so that the front points of the helix coils would be as close to the ground as possible. The frame narrowed to 6-9/16 inches at the bottom and formed a 4-9/16 inches wide by 18-3/4 inches long slot for the plants to enter and pass through the helix. A 3/4 inch diameter steel rod was bent into a 180 degree arc and welded into the rear of the slot to deflect the plant skeletons from the harvester after they were picked.

Plant lifters were installed on the front of the harvester on each side of the slot. They were made of round steel rods 5/8 inches in diameter and bolted to the frame. The lifters were positioned so

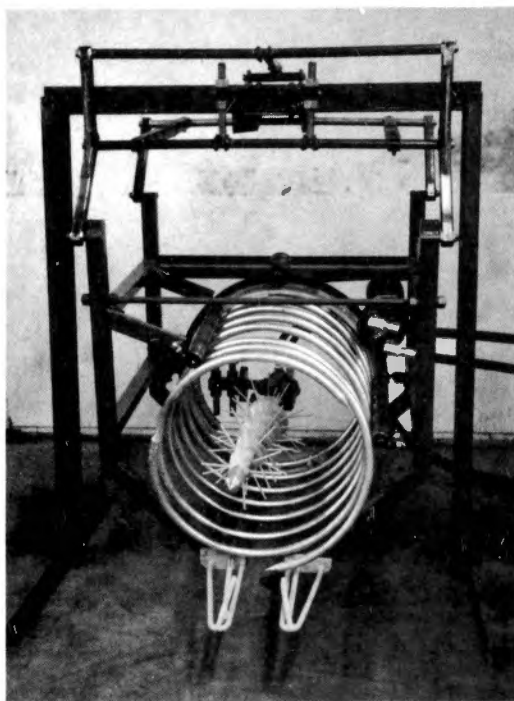


FIGURE 1. COMPONENTS OF HARVESTER INCLUDING FRAME, HELIX, REEL, AND SUSPENSION SYSTEM

they would lift and guide the plants into the slot to be engaged by the helix front points. The plant guides are shown in Figure 2.

Preliminary investigations revealed that snap bean plants were 15 to 22 inches in height. To accomodate this plant height and prevent clogging during picking, an inside diameter of 24 inches was chosen for the helix. The helix assembly consisted of three helical coils each 30 inches long and with a pitch or lead of 12 inches. Each coil was made from seamless steel tubing of 1 inch outside diameter and 0.1196 inch wall thickness. The coils were bolted to a hub that was constructed from a 6 inch length of 26 inch outside diameter by 9/16 inch wall thickness black steel pipe. A steel ring with a 1/2 x 1-1/2 inch cross section was cut and welded around the center of the hub to provide a means of support. The ring was mounted on grooved rollers which were supported by the frame. Vees for a 1-7/8 inch wide poly V-belt were machined in the back side of the hub to provide a sheave for the drive belt. The lead end of each coil was plugged with a tapered rounded tip to produce a pointed end. To prevent plants from clogging at the junction of the coils and hub, metal fillets made of 5/8 inch thick steel were bolted at the junction points. The completed helix assembly, shown in Figure 2, had a pitch of 4 inches and a lead of 12 inches.

The helix was positioned parallel to and directly over the slot in the frame. Since the helix assembly had to turn freely, the front of the coils were supported by three 2 inch diameter steel rollers spaced 120 degrees apart. The rollers were 20 inches in

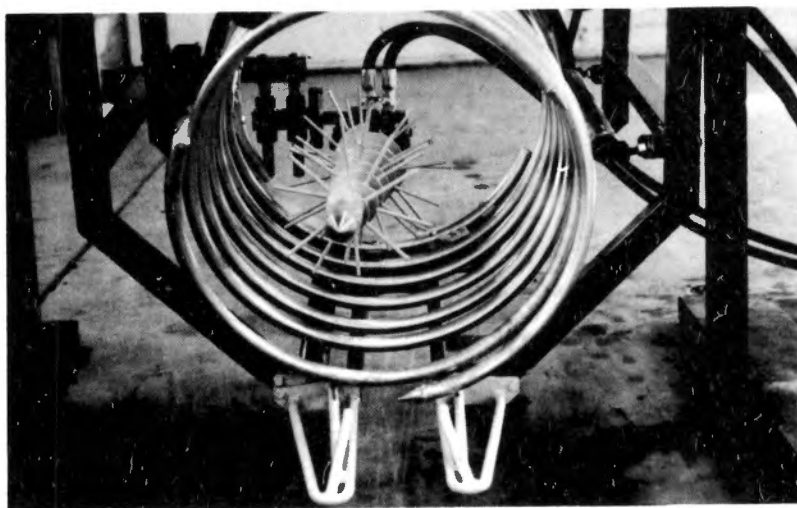


FIGURE 2. FRONT VIEW OF HARVESTER SHOWING PLANT LIFTERS
AND HELIX ASSEMBLY

length and were made from thick wall, high pressure steam pipe, fitted with ball bearings at each end. The bearings were mounted on 5/8 inch cold rolled steel shafts which were in turn held by pivot blocks made from 1/4 inch angle iron. Each pivot block was welded to a 2-1/2 x 1/2 inch cap screw and bolted to support assemblies that were fastened to the main frame. This construction permitted the rollers to be adjusted to align the front of the helix assembly with the slot in the main frame.

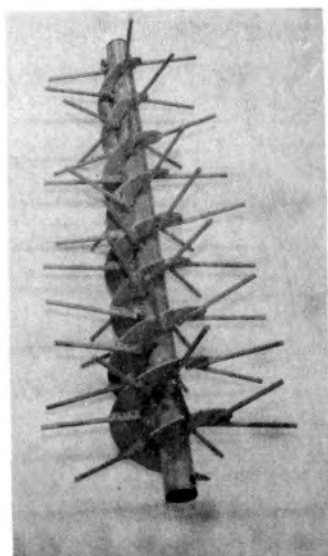
The rear of the helix assembly was supported by the hub ring which rested on three steel rollers placed 120 degrees apart. The rollers were 3-1/2 inches in diameter and had a 9/16 x 1/2 inch groove in which the hub ring rotated. The rollers were mounted on 1 inch cold rolled steel shafts that were placed in holes drilled in the machine frame. This arrangement not only supported the helix assembly but aligned it within the frame. The helix assembly was driven by a Hydreco hydraulic motor through a poly V-belt. The helix drive is shown in Figure 3.

The picking reel for the harvester consisted of a tubular shaft, tapered auger flights, and picking tines. Two reel designs were used. Each had a core comprised of two right hand wound, tapered auger flights welded to a 1-1/2 inch diameter tubular shaft. The flights were made from No.11 gage steel sheet. The flights were assembled 180 degrees apart on the shaft to form tapered double helical edges. The flights of one core had a lead of 6 inches, which produced an assembly with a 3 inch pitch. The flights for the other core had a lead of 8 inches giving the assembly a 4 inch pitch. Each

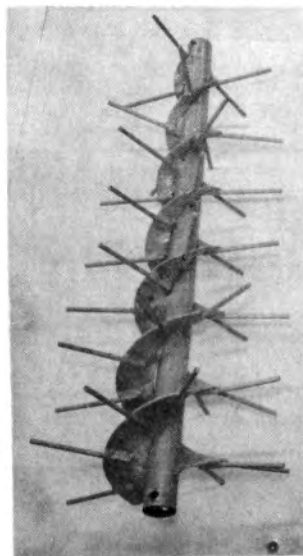
of the conical shaped cores were 27-1/2 inches long with a diameter ranging from 2 inches at the small end to 6 inches at the large end. Picking tines, five inches long, were made from 1/4 inch diameter mild steel rod and welded on each of the double helix cores. The tines were positioned on the back side of the auger flights so they would extend 3-3/8 inches beyond the flight edge. The tines were placed at 2-1/2 inch intervals along the entire length of the flights. The completed reels, shown in Figure 4, had an overall diameter of 9 inches at the small end and 12-3/4 inches at the large end.

The picking reel was mounted inside the helix assembly on a 1-1/4 inch steel drive shaft and held in place by a 3/8 inch bolt at the rear. This method of mounting provided for a quick change of reels during the tests. The front of the tubular reel shaft was plugged with an aluminum cone. The picking reel drive shaft assembly was supported as a cantilever beam by two pillow block bearings placed near the rear of the shaft.

The bearings were bolted to a support frame with four built-in adjustments: pitch angle movement of 45 degrees; horizontal movement of 4 inches in the transverse plane of the helix assembly; vertical movement of 3 inches in the vertical plane; longitudinal movement of 4-3/4 inches along the axis of the helix. One inch diameter threaded rods and a flanged joint provided the required movements (Figure 5). With the exception of the flange plates which could be bolted together at one degree intervals, the various adjustments were held by lock nuts.



3 Inch Pitch



4 Inch Pitch

FIGURE 4. DOUBLE HELIX PICKING REELS

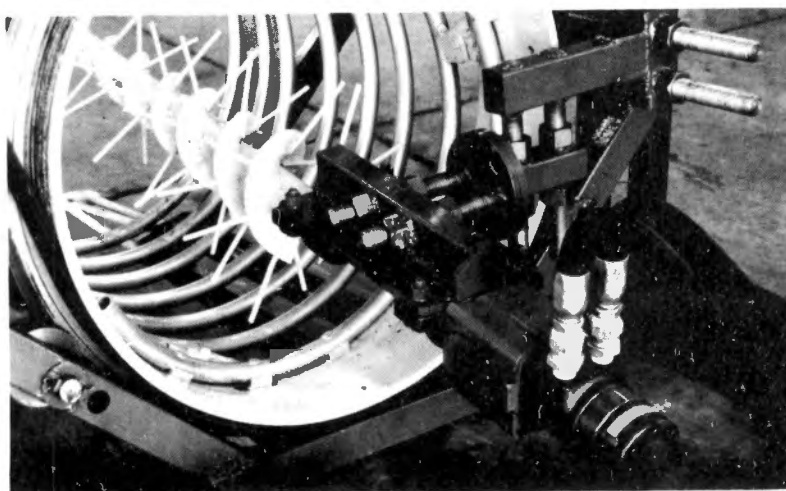


FIGURE 5. PICKING REEL MOTOR AND ADJUSTMENTS FOR POSITIONS

The picking reel was driven by a Char-Lynn Orbit motor which was attached at the end of the drive shaft and latched to the reel support assembly as shown by Figure 5.

Operation of the harvester proceeded as follows. Viewed from the front, the clockwise rotating helix assembly engaged the plants, supported them, and forced them into the counter clockwise rotating picking reel. The tines of the reel passed up through the plants and removed the foliage and bean pods.

Since all the tests were to be conducted in the laboratory, the harvester was supported by a stationary suspension system that provided adjustment of the height and pitch of the machine. Front and side views of the suspension system are shown by Figures 1 (page 20) and 6 respectively. Height could be varied 6 inches and the pitch changed by 15 degrees.

Open construction was used throughout the harvester assembly to allow a clear view of the picking operation. Since this was an investigation of pod removal from the plant, no attempt was made to develop a materials handling system for the detached pods.

Hydraulic power was chosen for the harvester to provide a wide range of speed adjustments. A separate unit was constructed to produce the oil flow which drove the hydraulic motors on the harvester. The unit, shown in Figure 7, was mounted on a tractor by a three-point hitch and driven from the tractor power take-off shaft. It consisted of a frame, a 40 gallon reservoir, a Hydreco gear type hydraulic pump, and two sets of control valves. The frame was constructed of 1 x 2 x 1/8 inch rectangular steel tubing and was

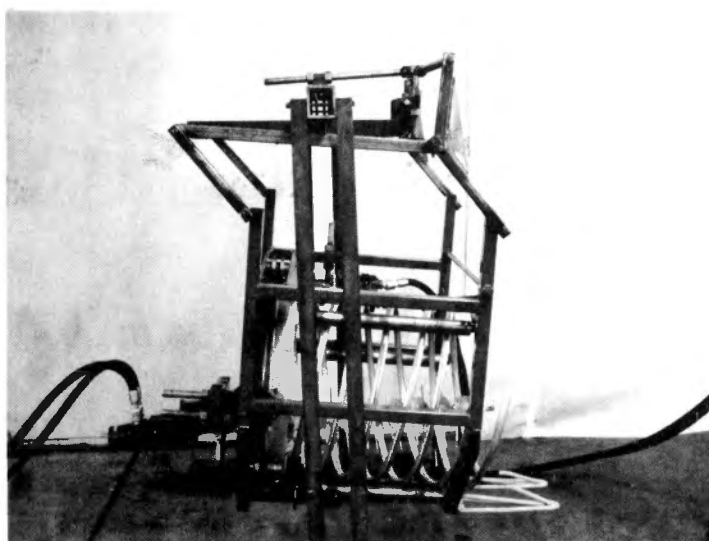


FIGURE 6. SIDE VIEW OF SUSPENSION SYSTEM

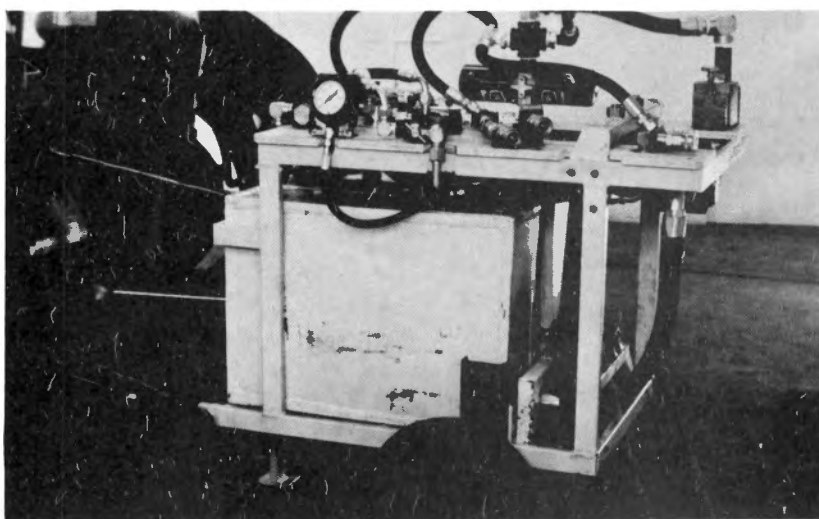


FIGURE 7. HYDRAULIC POWER SUPPLY MOUNTED ON THE TRACTOR

28 inches high, 39-1/2 inches long, and 25-7/8 inches wide. To make the unit self-supporting during operation, size 4.00 x 8 inch tires were mounted on each side of the frame. The U-shaped reservoir was constructed from No.11 gage cold rolled steel sheet and was 19-5/8 inches high, 28 inches long, and had an overall width of 23-5/16 inches. The hydraulic pump was mounted on a pump support assembly behind the reservoir at the rear of the frame. Two 1 x 8-1/4 inch threaded rods were welded to the pump support assembly and mounted to a beam. The beam was positioned above a poly V-sheave on the counter shaft which was connected to the power take-off shaft of the tractor. A poly V-belt connected the pump drive shaft to the counter shaft. Belt tension was adjusted by nuts on the threaded rods connecting the pump support assembly to the beam (Figure 8).

A mounting board cut from 3/4 inch thick exterior plywood and bolted to the top of the frame provided a mounting surface for the hydraulic oil circuit components, (Figure 8). The circuit was arranged so the pump would produce a continuous flow. The pump drew oil from the reservoir and sent it through a flow divider which directed the oil into two identical sets of valves. Each set consisted of: 1) a direction control valve that either directed the oil flow through a motor or back into the reservoir; and 2) a variable flow control valve which controlled the volume of oil pumped to the motor. This arrangement made it possible to change the speed of the driven motors through a wide range. Both motors were connected to their respective set of controls by two hydraulic hoses equipped with quick detachable couplings. One hose carried the oil flow to the motor and the other

returned it to the reservoir. By using the detachable couplings, the harvester and power supply could be readily separated. The harvester and the power supply are shown connected in Figure 9.

II. TEST PROCEDURE

Each of the two picking reels were mounted in the harvester and evaluated for effectiveness in detaching snap beans (Slender-white and Tender X varieties) in the laboratory. A completely randomized experimental design with factorial treatment arrangement was used. Independent variables were helix speed (HS), reel speed (RS), and reel pitch (RP). In all tests, the forward velocity of the machine (V_m) was held constant at 88 feet per minute. Three replications were run for each treatment combination. Six plants were included in each replication.

Since the harvester construction was not completed until the first of October, very few plants were available for the tests. Most of the test plants were taken from Stokeley Van Camp's bean fields around Newport, Tennessee. These fields had already been picked, and the plants obtained were ones that the harvesters had missed or could not pick due to wet soil conditions. Although the area had not experienced frost, it was expected any night. To hurriedly remove the plants from the field where frost might occur, they were pulled from the ground and placed in large plastic bags. The bags of plants were brought back to the laboratory and stored in a walk-in cooler until the tests were conducted. During the tests, it was noticed that plants which had been in the cooler for two days had lost some of their shape and were somewhat crisp.

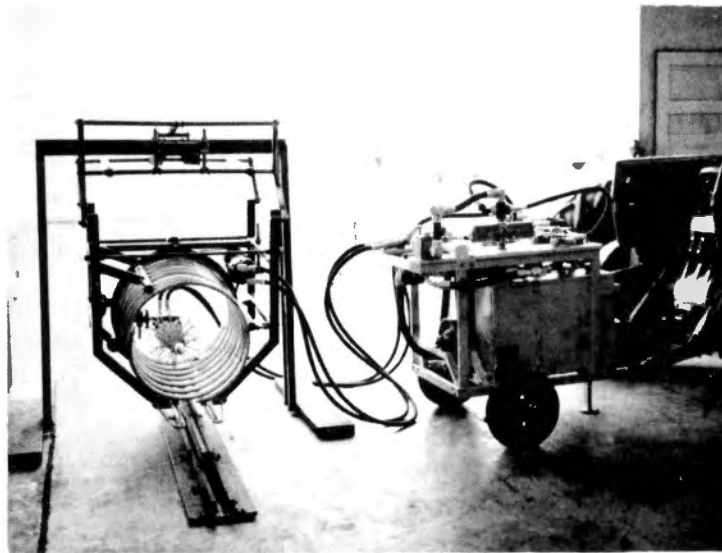


FIGURE 9. HARVESTER AND POWER SUPPLY

Since the tests were conducted in the laboratory, the plant holding carriage shown in Figure 10 was constructed for simulating forward motion of the harvester. The carriage was positioned under and parallel to the center line of the plant slot in the harvester frame. Bean plants were mounted between two 1 x 6 inch wooden boards that comprised the carriage. The boards were lined with 1/8 inch thick fabric to reduce injury to the plant stems. Six plants were mounted between the boards on 4 inch centers; the boards were then bolted together to clamp the plants in an upright position. A cable attached to the end of the carriage was wound around a winch drum as shown by Figure 11. The drum was rotated by an electric motor to wind up the cable and pull the carriage through its guides. Relative motion of the carriage with respect to the harvester, equivalent to that of the harvester moving down a row of stationary plants, resulted. An idler pulley clutch was used to disengage the drum winch to allow repositioning of the carriage for the start of another test. A rheostat and voltmeter were used to adjust the carriage velocity to 88 feet per minute for each test.

With the carriage track positioned under the harvester, the suspension system was adjusted such that the front of the helix was 2-1/8 inches above the top of the carriage boards and the rear of the helix was 4-1/4 inches above the boards. This gave the harvester frame a 6 degree forward tilt and a clearance of 2 inches between the rear of the frame and the top of the carriage. This clearance was necessary to enable the plant skeletons to pass from under the harvester after the pods had been picked from them.

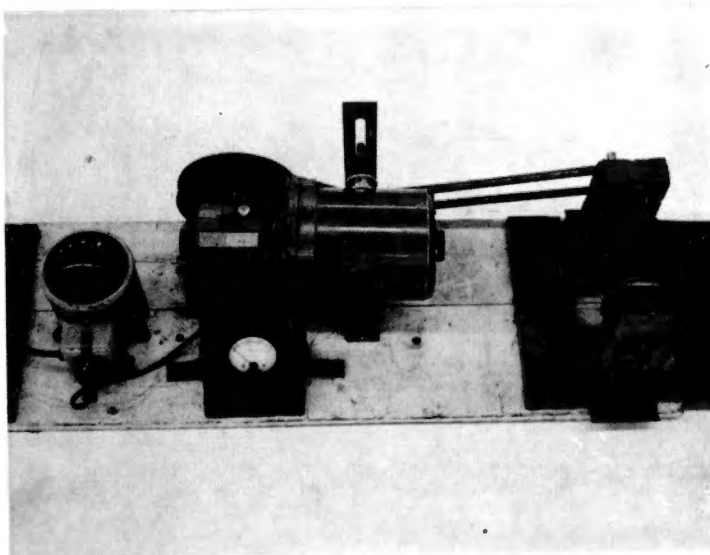


FIGURE 11. CABLE WINCH AND SPEED CONTROLS FOR PLANT HOLDING CARRIAGE

Preliminary studies had indicated the plants could be picked of pods best by starting detachment at the top and working down to successively lower plant levels. To enable the reel to accomplish this top to bottom detaching action, the reel assembly was adjusted to a 13 degree upward inclination with respect to the center line of the harvester frame. This adjustment gave the reel assembly an inclination of 5 degrees with respect to a horizontal plane. The center line of the reel assembly was positioned $2\frac{7}{8}$ inches to the right of the center line of the plant slot in the harvester frame.

The reel assembly was placed such that its front was $14\frac{1}{2}$ inches above the top of the carriage boards. The rear end of the reel was 12 inches above the top of the carriage. With respect to the longitudinal dimensions of the helix assembly, the front of the reel was one inch behind the front points of the helix. Thus the helix engaged the plants before the reel started detaching pods.

A $2 \times 2 \times 2$ factorial treatment arrangement resulted in eight treatment combinations. Levels of the independent variables were: helix speed, 88 and 97 revolutions per minute; reel speed, 196.5 and 328 revolutions per minute; reel pitch, 3 and 4 inch pitches. The desired speed for each of the components was obtained by adjusting the oil flow control valve in the hydraulic circuit supplying the motor which drove the component. The speed of the helix and of the reel was checked by using a hand held tachometer. The two levels of reel pitch were obtained by changing reels. The treatment combinations that were tested are summarized in Table II.

TABLE II

CONDITIONS FOR TESTS

Treatment	Simulated Velocity of Machine Vm (ft/min)	Helix Speed HS (rpm)	Reel Speed RS (rpm)	Reel Pitch RP (inches)
HS _I RS _A RP ₁	88	88	196.5	3
HS _I RS _B RP ₁	88	88	328	3
HS _I RS _A RP ₂	88	88	196.5	4
HS _I RS _B RP ₂	88	88	328	4
HS _{II} RS _A RP ₁	88	97	196.5	3
HS _{II} RS _B RP ₁	88	97	328	3
HS _{II} RS _A RP ₂	88	97	196.5	4
HS _{II} RS _B RP ₂	88	97	328	4

Each test run proceeded as follows: 1) the treatment combination was selected at random by drawing a number from a container containing numbers for all combinations; 2) the appropriate reel was mounted in the harvester; 3) reel and helix speeds were adjusted to the required levels; 4) the number of bean pods per plant was counted and recorded; 5) the carriage drive was engaged to pull the plants through the harvester; 6) after the plants passed through the harvester, counts were made and recorded for: the number of whole pods remaining on each plant, the number of pods picked unbroken, and the number of pods picked in clusters. Only pods that were completely intact were considered unbroken. If one or more pods were still attached to a stem segment after picking, they were counted as being picked in a cluster.

III. HIGH SPEED MOTION PICTURE STUDY

The detaching action of the harvester was recorded on 16 mm film. A Red Lake Laboratories Hy-Cam high speed motion picture camera was used to expose the film. Camera speeds of 1500 and 2400 frames per second were used. Two 650 watt quartz bromide lamps and a 1000 watt quartz iodine lamp were used to provide light for the filming. A Honeywell Spotmeter was used to check light intensity and determine camera adjustment for each film action sequence. A timing light generator placed a mark on the film every millisecond for a time reference. Six 100 foot rolls of film were used. Five of the films were taken viewing the front of the harvester, and one was taken viewing the rear of the harvester.

The films were analyzed by first viewing them repeatedly at normal projector speed (16 frames per second). This projector speed gave a slow motion interpretation of the detaching action. Film sections showing pod detachment clearly were selected and studied frame by frame, using a Recordak microfilm reader. The reader magnified the image 20 times. From the frame by frame study, specific frames were chosen that illustrated successive phases of the detaching action recorded by the particular film sequence. Enlarged photographs were made from the selected frames.

The distance between successive timing marks on the films was measured. This data was subjected to regression analysis to determine elapsed time between each of the selected frames.

CHAPTER IV

RESULTS AND DISCUSSION

I. MACHINE PERFORMANCE

The number and percentage of bean pods detached, pods broken when picked, and pods detached in clusters for each test replication are shown in Table III. The pods removed from the six plants in each replication, shown in Table III, ranged from 64.4 percent to 100.0 percent with the mean being 83.2 percent. The mean effect of the levels of each independent variable on percentage of pods detached is diagrammed in Figure 12.

An analysis of variance for the percentage of bean pods detached, Table IV, showed there was no significant difference among treatments at the 10 percent of probability. It followed that the main effects of helix speed, reel speed, or reel pitch were not significant. No interaction terms were significant at the 10 percent probability level. Although not statistically significant, reel speed and the two factor interaction between helix speed and reel pitch had the greatest effect on variation in percentage of pods picked. Figure 13 shows that as the helix speed increased, the picking efficiency of the reel with a three inch pitch increased while the picking efficiency of the reel with a four inch pitch decreased. The higher level of helix speed tilted the plants forward into the path of the conical shaped reel to cause more aggressive contact between the reel tines and the bean plants. With more tines

TABLE III
PICKING REEL EFFICIENCY AND DAMAGE TO SNAP BEANS

Treatment	Replication	Number of Pods Available	Number of Pods Detached	Number of Pods Broken	Number of Pods Detached in Clusters	Percent of Pods Detached	Percent of Pods Broken	Percent of Pods Detached in Clusters
HS _I RS _I ARP ¹	1	55	39	3	2	70.9	7.7	7.7
	2	62	47	19	2	75.8	40.4	6.4
	3	58	40	13	3	69.0	32.5	17.5
HS _I RS _B RP ¹	1	39	37	12	4	94.9	32.4	13.5
	2	58	51	21	6	87.9	41.2	21.6
	3	50	33	9	6	66.0	27.3	24.2
HS _I RS _A RP ²	1	56	49	21	5	87.5	42.8	18.4
	2	43	31	8	4	72.1	25.8	19.4
	3	55	49	22	4	89.1	44.9	16.3
HS _I RS _B RP ²	1	63	60	19	8	95.2	31.7	26.7
	2	39	31	9	5	79.5	29.0	19.4
	3	43	37	6	2	86.0	16.2	5.4

TABLE III (continued)

Treatment	Replication	Number of Pods Available	Number of Pods Detached	Number of Pods Broken	Number Pods Detached in Clusters	Percent of Pods Detached	Percent of Pods Broken	Percent of Pods Detached in Clusters
HS _{II} RS RP _A 1	1	52	44	7	4	84.6	15.9	18.2
	2	60	49	11	4	81.7	22.4	10.2
	3	56	52	19	6	92.8	36.5	19.3
HS _{II} RS RP _B 1	1	64	62	25	8	98.4	40.3	22.6
	2	66	58	29	3	87.9	50.0	8.6
	3	70	56	20	5	80.0	35.7	28.8
HS _{II} RS RP _A 2	1	66	62	19	10	93.9	30.6	22.6
	2	52	44	11	6	84.6	25.0	27.1
	3	45	29	13	1	64.4	44.8	3.4
HS _{II} RS RP _B 2	1	69	50	13	3	72.5	26.0	14.0
	2	58	58	17	3	100.0	29.3	6.9
	3	50	41	14	2	82.0	34.1	4.9

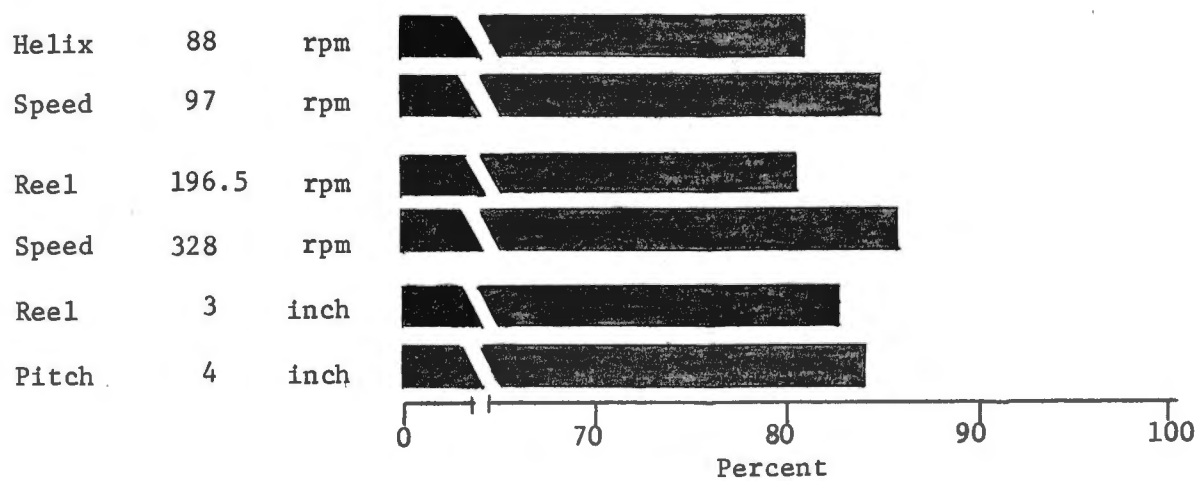


FIGURE 12. MEAN EFFECT OF VARIABLES ON PERCENTAGE OF PODS DETACHED.

TABLE IV
ANALYSIS OF VARIANCE FOR PERCENTAGE OF PODS DETACHED
BY PICKING REELS

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	F-Ratio	Prob > F
Corrected Total	23	2435.4297	105.8882		
Replications	2	296.3211	148.1605	1.3231	0.2976 N.S.
Treatments	7	571.3429	81.6204	0.7289	0.6523 N.S.
Helix Speed (HS)	1	99.8376	99.8376	0.8915	0.636 N.S.
Reel Speed (RS)	1	169.8676	169.8676	1.5169	0.237 N.S.
Reel Pitch (RP)	1	12.0558	12.0558	0.1077	0.746 N.S.
HS x RS	1	29.4152	29.4152	0.2627	0.621 N.S.
HS x RP	1	221.6160	221.6160	1.9790	0.179 N.S.
RS x RP	1	11.6901	11.6901	0.1044	0.749 N.S.
HS x RS x RP	1	26.8605	26.8605	0.2399	0.636 N.S.
Error	14	1567.7657	111.9833		

N.S.=Not significant at the 10 percent level of probability.

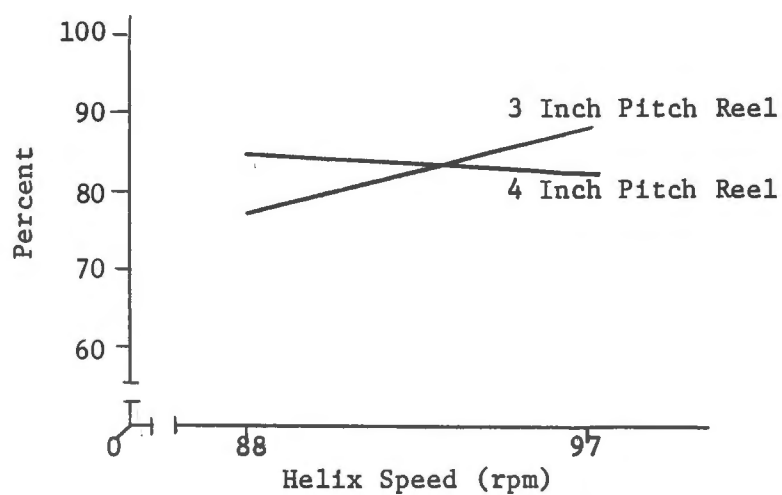


FIGURE 13. EFFECT OF INTERACTION BETWEEN HELIX SPEED AND REEL PITCH ON PERCENTAGE OF PODS DETACHED.

per unit length along its axis, the narrow, three inch pitch reel possibly was able to produce a more vigorous detaching action than the four inch pitch reel. Figure 14 indicates that picking efficiency is increased at the higher reel speed.

The pods that were broken during detachment ranged from a low of 7.0 percent to a high of 50.0 percent (Table III). The mean was 31.8 percent. Mean effect of the independent variables on the percentage of broken pods is shown in Figure 15. The analysis of variance for the percentage of pods broken, Table V, showed there was no significant difference among treatments. The only component of the treatment sum of squares having a statistically significant effect was the reel speed - reel pitch interaction. Figure 16 is a graph of this interaction. As the reel speed increased, the reel with the more closely spaced tines, consequently the greater number of tines, broke a greater percentage of the pods.

The bean pods detached in clusters ranged from 3.4 percent to 28.8 percent, Table III. The mean was 16.0 percent. Figure 17 shows the effect of the independent variables on the percentage of the pods removed in clusters. The analysis of variance for pods detached in clusters, Table VI, showed there was no significant difference among treatments. The interaction between reel speed and reel pitch resulted in a significant difference at the 10.2 percent level of probability. Figure 18 shows the interaction. As the reel speed increased, the more closely spaced tines of the three inch pitch reel picked more of the pods in clusters than the four inch pitch reel. The tines had a tendency to break the plant stems to which

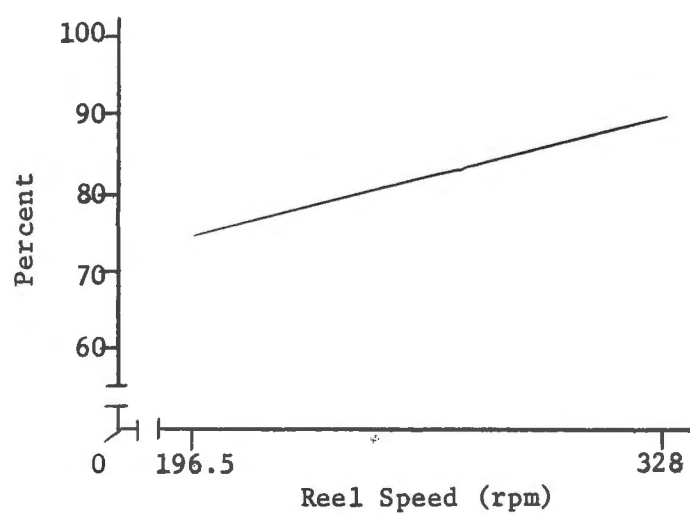


FIGURE 14. EFFECT OF REEL SPEED ON PERCENTAGE OF PODS DETACHED.

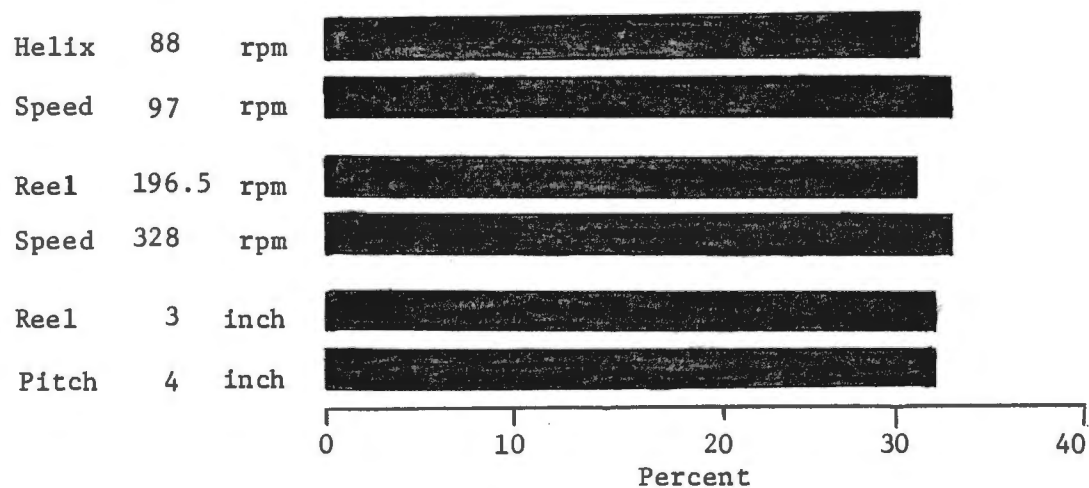


FIGURE 15. MEAN EFFECT OF VARIABLES ON PERCENTAGE OF PODS BROKEN.

TABLE V
ANALYSIS OF VARIANCE FOR PERCENTAGE OF PODS BROKEN
BY PICKING REELS

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	F-Ratio	Prob > F
Corrected Total	23	2389.3159	103.8833		
Replications	2	139.1520	69.5760	0.6627	0.535 N.S.
Treatments	7	780.2103	111.4586	1.0615	0.436 N.S.
Helix Speed (HS)	1	14.8680	14.8680	0.1416	0.713 N.S.
Reel Speed (RS)	1	23.5422	23.5422	0.2242	0.647 N.S.
Reel Pitch (RP)	1	0.1717	0.1717	0.0016	0.967 N.S.
HS x RS	1	133.1517	133.1517	1.2682	0.279 N.S.
HS x RP	1	16.5834	16.5834	0.1579	0.698 N.S.
RS x RP	1	590.7360	590.7360	5.6262	0.031*
HS x RS x RP	1	1.1572	1.1572	0.0110	0.914 N.S.
Error	14	1469.9536	104.9967		

N.S.=Not significant at the 10 percent level of probability.

*Significant difference at the 5 percent level of probability.

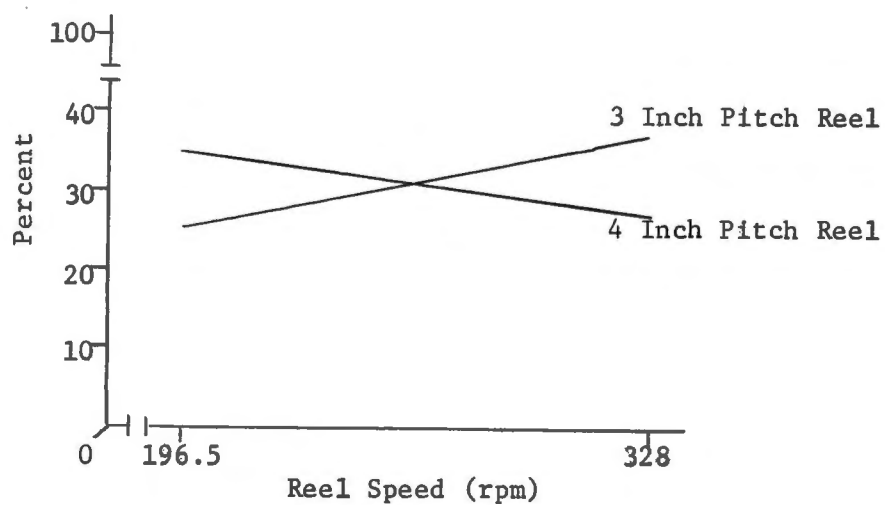


FIGURE 16. EFFECT OF INTERACTION BETWEEN REEL SPEED AND REEL PITCH ON PERCENTAGE OF PODS BROKEN.

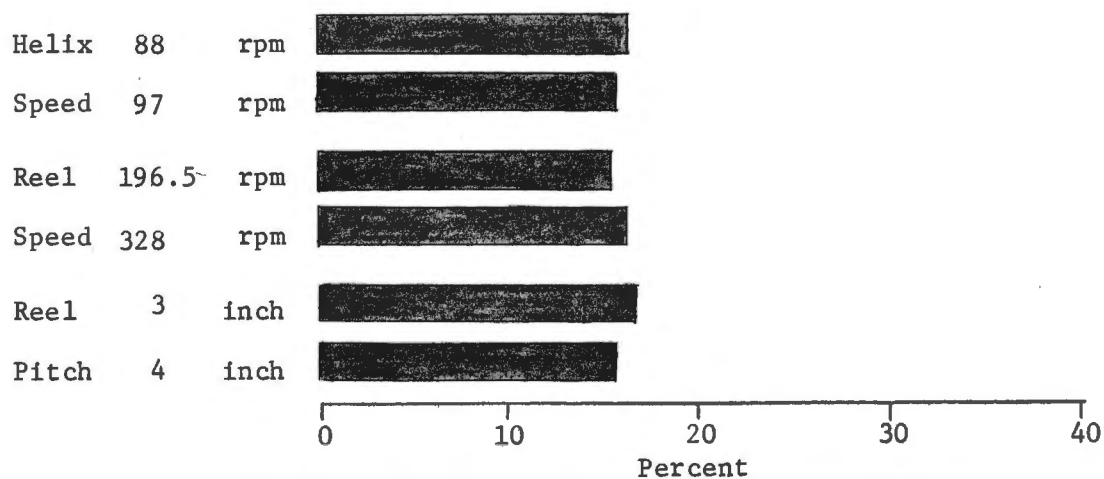


FIGURE 17. MEAN EFFECT OF VARIABLES ON PERCENTAGE OF PODS DETACHED IN CLUSTERS.

TABLE VI
ANALYSIS OF VARIANCE FOR PERCENTAGE OF PODS DETACHED
IN CLUSTERS BY PICKING REELS

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	F-Ratio	Prob > F	
Corrected Total	23	1371.6044	59.6350			
Replications	2	47.3254	23.6627	0.3473	0.717	N.S.
Treatments	7	370.4081	52.9154	0.7766	0.618	N.S.
Helix Speed (HS)	1	3.8560	3.8560	0.0566	0.810	N.S.
Reel Speed (RS)	1	4.0344	4.0344	0.0592	0.806	N.S.
Reel Pitch (RP)	1	8.2134	8.2134	0.1206	0.733	N.S.
HS x RS	1	68.0067	68.0067	0.9981	0.664	N.S.
HS x RP	1	77.6161	77.6161	1.1392	0.305	N.S.
RS x RP	1	204.9842	204.9842	3.0086	0.102**	
HS x RS x RP	1	3.6974	3.6974	0.0543	0.814	N.S.
Error	14	953.2709	68.1336			

N.S.=Not significant at the 10 percent level of probability.

**Significant difference at the 10.2 percent level of probability.

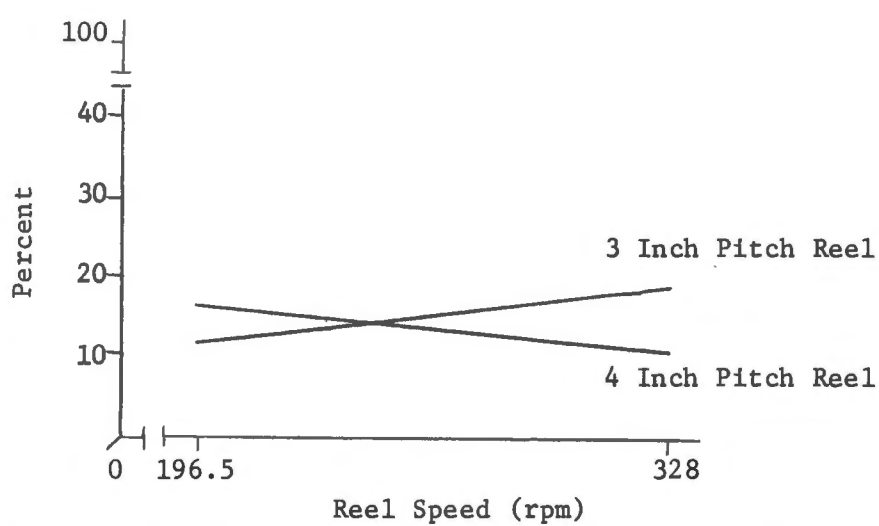


FIGURE 18. EFFECT OF INTERACTION BETWEEN REEL SPEED AND REEL PITCH ON PERCENTAGE OF PODS DETACHED IN CLUSTERS.

more than one pod was attached before the individual pods could be detached from the same stem. An identical effect, to a lesser degree, resulted from increased helix speed (Figure 19). As the helix speed increased and tilted the plants into the reel, the more closely spaced tines were unable to pass through the inclined pods and remove them one at a time as done when the plants were in an upright position.

II. TYPE OF DETACHMENT AND ANALYSIS OF PICKING ACTION

The harvested pods were grouped according to point of detachment: 1) in pod, 2) between pod and pedicel, 3) between pedicel and stem, 4) and in stem. Pods detached at points two and three are acceptable to commercial canners. Examples of pods in these two groups are shown in Figure 20. Point one detachment resulted in broken pods while point four detachment gave clusters made up of one or more pods still attached to a portion of the plant stem. Figure 21 shows examples of these two groups.

Analysis of detaching action observed in the high speed motion picture films made of the harvester in operation identified frame sequences that showed pods being detached, being broken, and the action of the helix on the plant during pod removal.

All except one of the front view films were made with the harvester operating at the tabulated test speeds. The one exception, the film showing a pod being broken, was made at a helix speed of 92.8 revolutions per minute, the mid point between the helix speeds used in the tests. This helix speed was chosen, after the tests had been

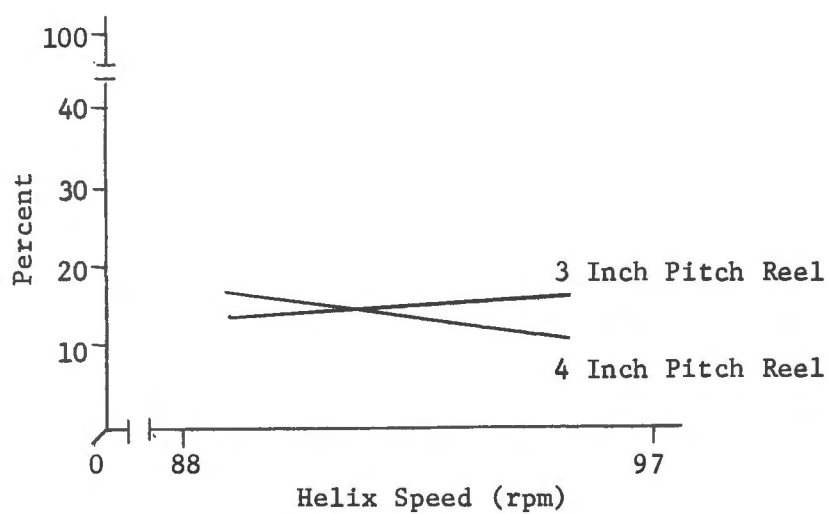


FIGURE 19. EFFECT OF INTERACTION BETWEEN HELIX SPEED AND REEL PITCH ON PERCENTAGE OF PODS DETACHED IN CLUSTERS.

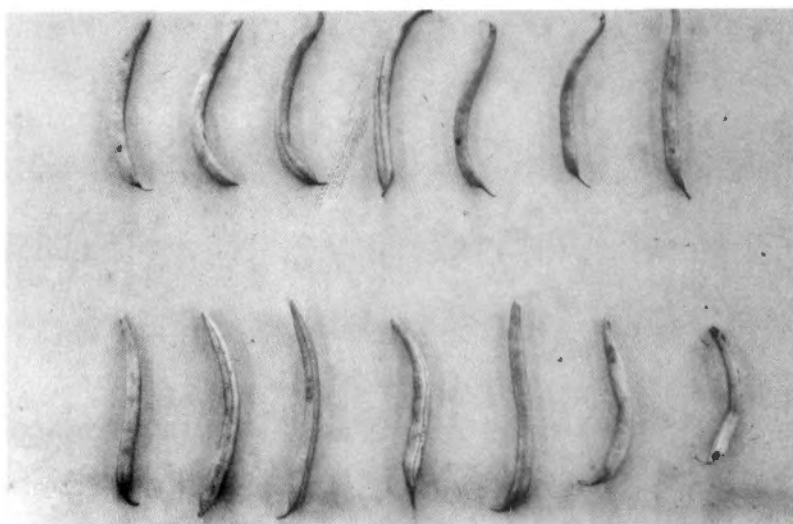
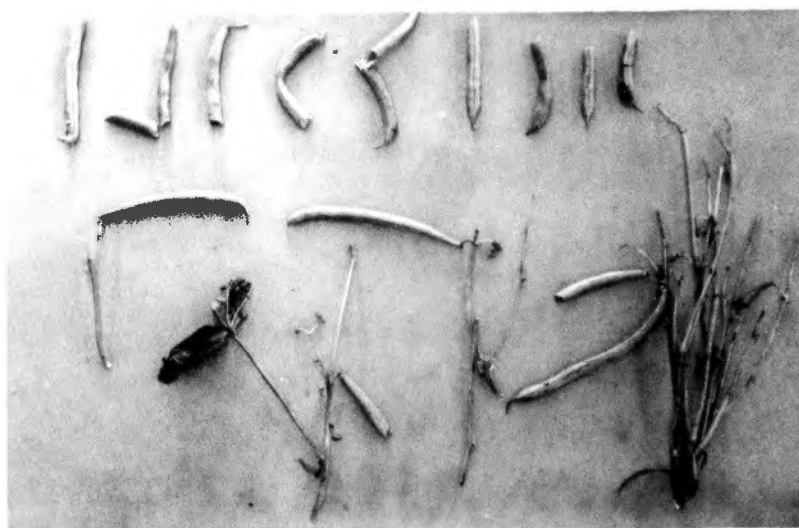


FIGURE 20. ACCEPTABLE DETACHED PODS

Broken Pods



Pods Detached in Clusters

FIGURE 21. UNACCEPTABLE DETACHED PODS

conducted, to determine by viewing the film, if there was any difference in the picking action at the different helix speeds. No difference was observed.

Figure 22 shows a pod, marked by an "O", that has been detached with the pedicel intact. The position of the pod indicates that it was detached a few milliseconds before the picture was made. The pod had rotated such that the pedicel can be clearly seen against the light colored background of the reel. The plant structure blocked the view of the pod when it was detached; therefore frames showing the actual detaching action were not part of the sequence.

Figure 23 shows a series of photographs in which the pod is detached and the pedicel remained with the plant stem. At frame 0, the tine identified by an "X" is approaching the pedicel of the pod marked by an "O". At frame 10 (7.1229 milliseconds later) the tine appears to have come in contact with the pedicel but the pod position is the same as in frame 0. In frame 20 (14.2444 milliseconds), the tine is lifting the pod and the pedicel has begun to fail. By frame 30 (21.3659 milliseconds after frame 0), the pedicel has failed, the pod is detached without the pedicel and lifted upward. Note that the detachment process took place in a little more than 1/500 of a second.

Two sequences of photographs that indicated the detachment of unacceptable pods were identified. In Figure 24, the pod is picked but the stem end of the pod is broken during the process. In frame 0, the tine marked by an "X" is behind and approaching the pedicel of pod "O". Notice the pointed shape of the stem end of the pod.

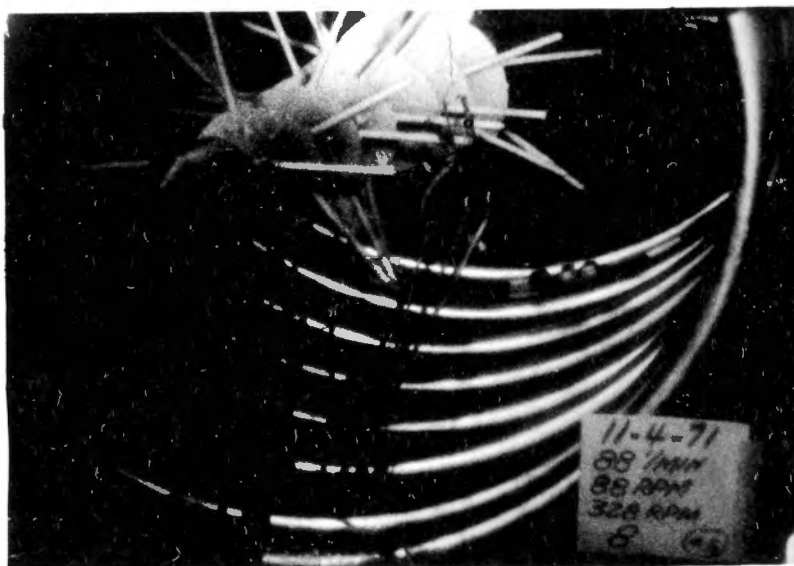
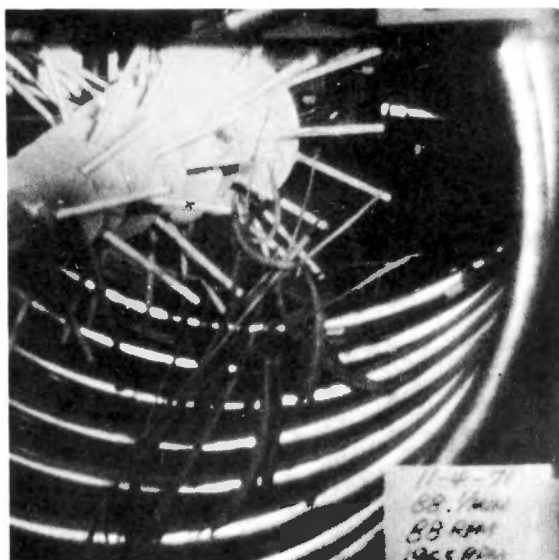


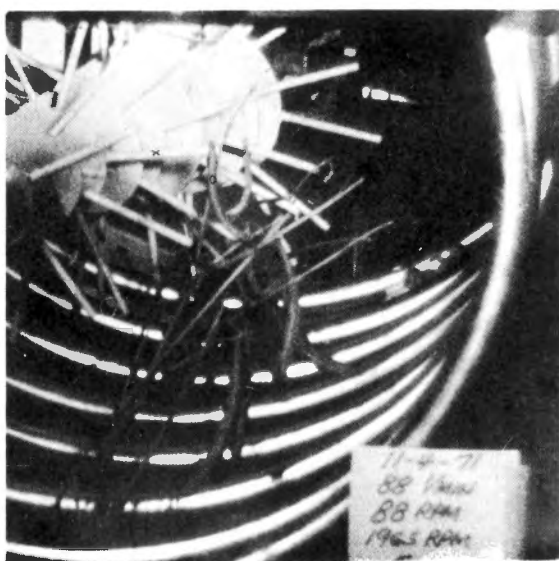
FIGURE 22. PHOTOGRAPH OF A FRAME FROM THE HIGH SPEED MOVIE FILM SHOWING POD DETACHMENT WITH PEDICEL REMAINING ON THE POD



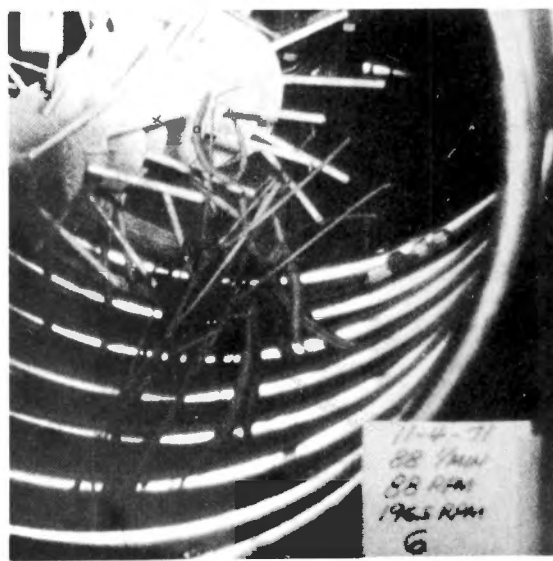
Frame = 0
Time = 0 Millisec.



Frame = 10
Time = 7.1229 Millisec.



Frame = 20
Time = 14.2444 Millisec.

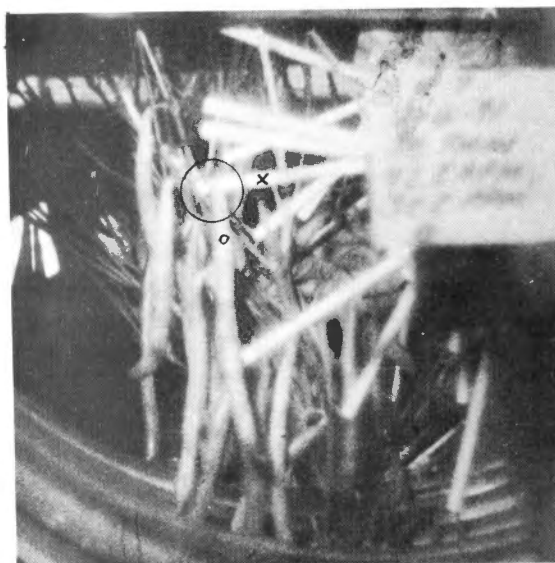


Frame = 30
Time = 21.3659 Millisec.

FIGURE 23. PHOTOGRAPHS OF INDIVIDUAL FRAMES FROM THE HIGH SPEED MOVIE FILM SHOWING POD DETACHMENT WITH PEDICEL REMAINING ON PLANT STEM (camera speed = 2400 frames per second)



Frame = 0
Time = 0 Millisec.



Frame = 25
Time = 11.0889 Millisec.



Frame = 29
Time = 12.8883 Millisec.



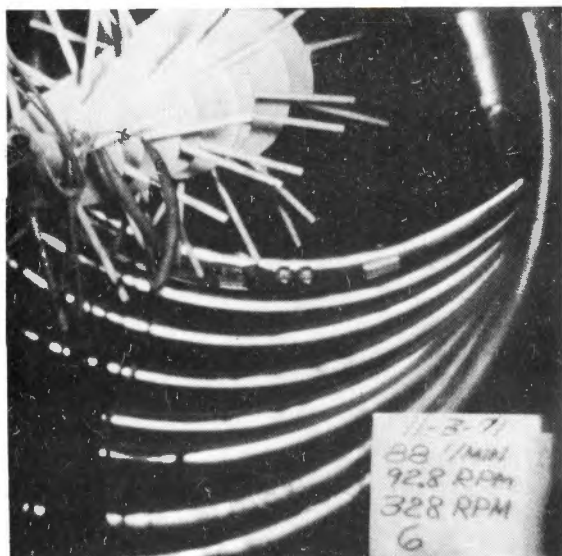
Frame = 30
Time = 13.3381 Millisec.

FIGURE 24. PHOTOGRAPHS OF INDIVIDUAL FRAMES FROM THE HIGH SPEED MOVIE FILM SHOWING DETACHMENT BY BREAKING THE STEM END OF THE POD (camera speed = 1500 frames per second)

Twenty-five frames later (11.0889 milliseconds), the tine is seen as it begins to break the pod, within the circle, instead of separating the pedicel-pod junction. The completed separation of the pod is seen in frame 29 (12.8883 milliseconds after frame 0). Notice the blunt end of the larger portion of the pod, within the circle, that has resulted from the pod breakage. In frame 30 (13.3381 milliseconds elapsed time), the broken end of the pod is seen passing over the top of the tine as indicated by the circle.

Pods are sometimes broken when they are accelerated by the rotating reel and thrown against a tine. This type of pod damage is seen taking place in Figure 25. In frame 0, the stem of pod "0" is caught by the upward rotating tine marked by an "X". Notice the natural curved pod shape. At frame 5 (3.9925 milliseconds), when the pedicel failed to break, the pod is thrown back against tine "XX" and begins to straighten out. In frame 10 (7.6546 milliseconds after frame 0), the pod, still attached to the plant, is bending around tine "XX" and is beginning to break. By frame 15 (11.3167 milliseconds elapsed time), the pod is broken completely in two due to its impact with the tine.

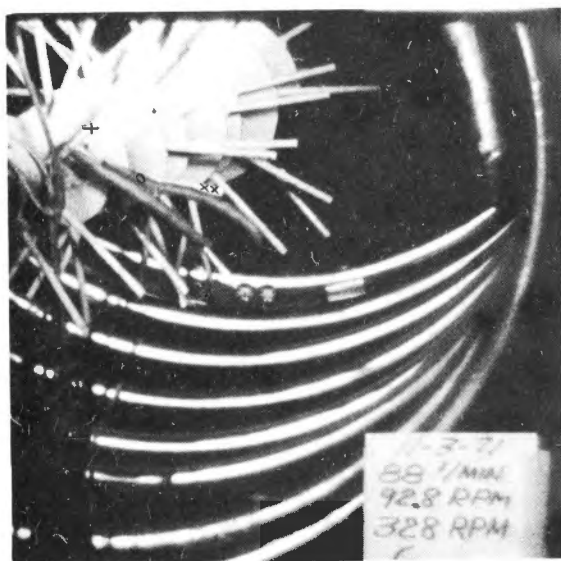
The film showing a rear view of the harvester presented evidence of the helix acting on the plant structure while pod detachment took place. In Figure 26, frame 0, the right hand rotating helical coil marked by an asterisk is rotating against the plant stalk marked by the arrow. While the helical coil is supporting the plant stalk, the reel tine marked with an "X" is behind and moving up under the pedicel of the bean pod marked with an "0". Notice the slightly



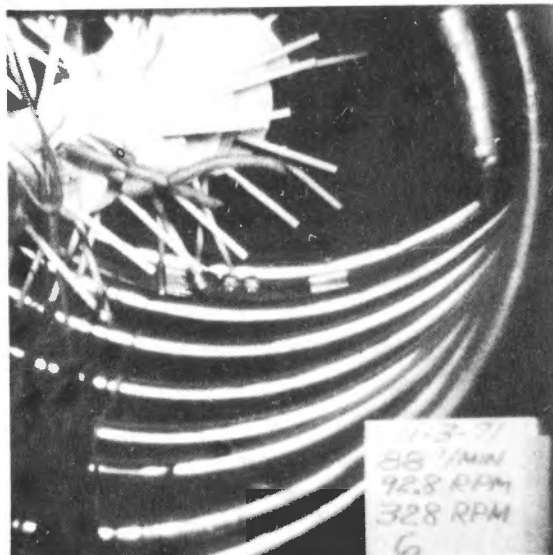
Frame = 0
Time = 0 Millisec.



Frame = 5
Time = 3.9925 Millisec.

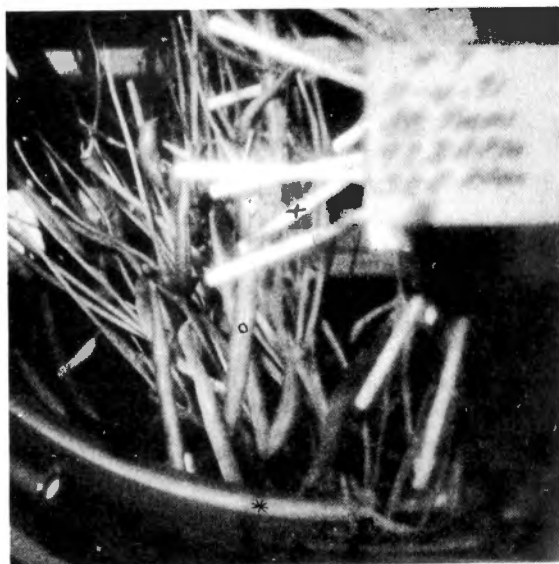


Frame = 10
Time = 7.6546 Millisec.



Frame = 15
Time = 11.3167 Millisec.

FIGURE 25. PHOTOGRAPHS OF INDIVIDUAL FRAMES FROM THE HIGH SPEED MOVIE FILM SHOWING AN ACCELERATED POD BEING BROKEN BY IMPACT WITH A TINE (camera speed = 1500 frames per second)



Frame = 0
Time = 0 Millisec.



Frame = 10
Time = 4.2113 Millisec.



Frame = 20
Time = 8.4274 Millisec.



Frame = 30
Time = 12.6436 Millisec.

FIGURE 26. PHOTOGRAPHS OF INDIVIDUAL FRAMES FROM THE HIGH SPEED MOVIE FILM SHOWING THE HELIX SUPPORTING THE PLANT STALK AND APPLYING A FORCE OPPOSING THE TINE FORCE DURING POD DETACHMENT (camera speed = 1500 frames per second)

inclined position of the pod. In frame 10 (4.2113 milliseconds later) the tine with the "X" has contacted the pedicel and started lifting the pod marked "O". Notice that the position of the pod has changed to an angle of inclination opposite that of its original position. Also notice that even though the upward rotating reel is tilting the plant stems to the left, the helical coil is holding and supporting the plant stalk, thus applying a force to the plant that acts in a direction opposite to that of the force applied by the tine "X" to the pedicel of pod "O". In frame 20 (8.4274 milliseconds), pod "O" has been detached and moved upward by the momentum of the rotating tine "X" while the helix holds the plant stalk in place. By frame 30 (12.6436 milliseconds after frame 0), the detached pod, marked with an "O", is struck by tine "XX" and is being pushed away from the reel.

CHAPTER V

SUMMARY AND CONCLUSIONS

The object of this study was to evaluate a conical shaped picking reel mounted in an experimental helical vegetable harvester for effectiveness in detaching snap beans. The influences of speed of the helix (HS), speed of the reel (RS), and pitch of the reel (RP) on the percentage of pods detached, pods broken, and pods detached in clusters were studied. The reels and harvester were constructed in the Department of Agricultural Engineering Research Shop, The University of Tennessee at Knoxville, and were tested with Slenderwhite and Tender X varieties of snap beans provided by Dixie Garden Farms, Crossville, Tennessee, and Stokely Van Camp Company of Newport, Tennessee.

The harvester was tested in the laboratory using two levels of HS, two levels of RS, and two levels of RP. The simulated forward speed of the machine (V_m) was held constant at one mile per hour. Analysis of variance showed there was no significant difference among treatments for the response percentage of pods detached.

An analysis of variance for broken pods showed there was no significant difference among treatments. The interaction between reel speed and reel pitch was significant at the 5 percent level of probability.

A third analysis of variance, for the percentage of pods detached in clusters, showed no significant difference among treatments.

The interaction between reel speed and reel pitch was significant at the 10.2 percent level of probability.

The lack of significant difference among treatments may have been due to the poor condition of the test plants. The extreme variation in the condition of the bean plants was indicated by the large experimental error mean square term in the analysis of variance. The F ratios in the percentage of pods detached analyses indicated the difference among replications was greater than the difference among treatments. Large error terms resulted for the responses percentage of pods broken and of pods detached in clusters.

Throughout the tests, it was observed that the picking reel failed to detach many pods that were attached to lower branches of the plants. The rear of the harvester had been raised so the plant skeletons could pass from under the frame. The results suggest that the rear of the harvester should be closer to the ground. This change would require considerable alteration of the helix hub and lower part of the frame.

Another component of the harvester that would need extensive development studies is a conveying system for the detached pods. After being picked, the pods were thrown out both sides of the harvester. A materials handling system for the machine would have to catch and remove pods from both sides of the detaching unit. Also the conveying system would need to be very compact since the bottom of the harvester must be close to the ground.

Probably the major disadvantage of the helix-reel design is that it does not lend itself to multi-row harvesting. The helix and

reel can operate on only one row at a time. This restriction may be a serious problem if future work is directed toward multi-row harvesting.

Even though the lack of significant differences for the mean effects of independent variables prevented specific conclusions, the following trends were observed: (1) An increase in helix speed resulted in an increase in picking efficiency for the three inch pitch reel while the efficiency of the four inch pitch reel was increased slightly; (2) the three inch pitch reel benefited from an increase in reel speed more than the four inch pitch reel for the response percentage of pods detached; (3) an increase in helix speed resulted in the three inch pitch reel picking a greater percentage of the pods in clusters than the four inch pitch reel.

The following conclusions were based on detachment and film studies. (1) Reel tines picked undamaged pods when they contacted the pedicel, and detachment occurred at either the pod-pedicel junction or the pedicel-plant stem junction. (2) Reel tines broke pods when a tine contacted the pedicel or plant stem, no detachment occurred, the tine accelerated the pod in one direction, and the pod was impacted by another tine with a force acting in another direction; when a tine acted on a pod in a manner to develop tensile stress within the pod, the stem end of the pod was detached with the pedicel. (3) The helical coil aided pod detachment by supporting the plant and applying a force that was opposite to the force applied by the picking tine.

Based on the analysis of mean response values for the various factor levels used in the experiment, the following conclusions were made about machine performance: (1) The conical shaped, steel tine type picking reel detached pods more effectively than the fiber bristle brush used in the original helical harvester. (2) As the reel speed increased, the rate of change in the percentage of pods broken by the two picker reels was significantly different. (3) As the reel speed increased, the rate of change in the percentage of pods detached in clusters by the two picker reels was significantly different.

Suggested areas for future study are:

- (1) Additional laboratory tests using good quality snap bean plants, and
- (2) The study of harvesting other crops such as green peppers with the machine.

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VITA

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