A PERFORMANCE MONITORING SYSTEM FOR A MECHANICAL CANTALOUPE HARVESTER

by

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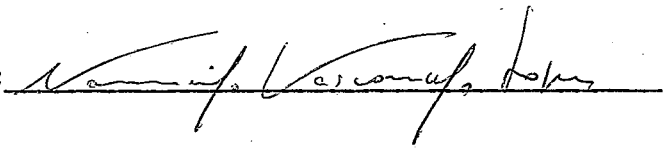
SIGNED: 

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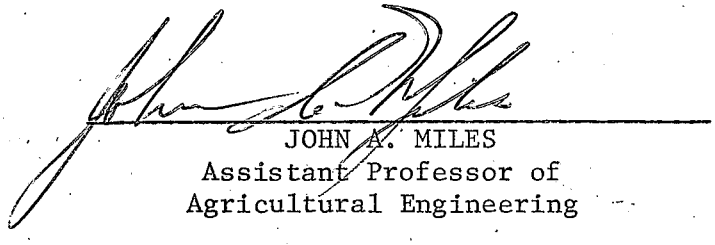

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ABSTRACT

Current practices in the production of cantaloupes rely heavily on an adequate supply of hand labor for the harvest operation.

The Arizona Agricultural Experiment Station has developed a selective cantaloupe harvester that consists of a series of rows of identical rubber rods mounted on a conveyor frame suspended above the cantaloupe bed. It is used as a continuous flexible rake which combs the bed. The frame is angled in relation to the direction of forward travel so that the desired raking motion is always perpendicular to the plant rows.

This study reports work toward the design of a control system that permits the operator to maintain the raking motion perpendicular to the plant rows. To do this, the forward speed of the machine has to be related to the conveyor velocity and the frame angle. The resulting relationship is such that specifying any two parameters automatically fixes the third.

The operator monitors the machine action with an instrument panel where the conveyor speed (rpm) and the angle that the frame makes with the line of travel of the machine are displayed. He must relate these readings with the previously chosen tractor velocity.

Field tests conducted with the device indicated that this is feasible.

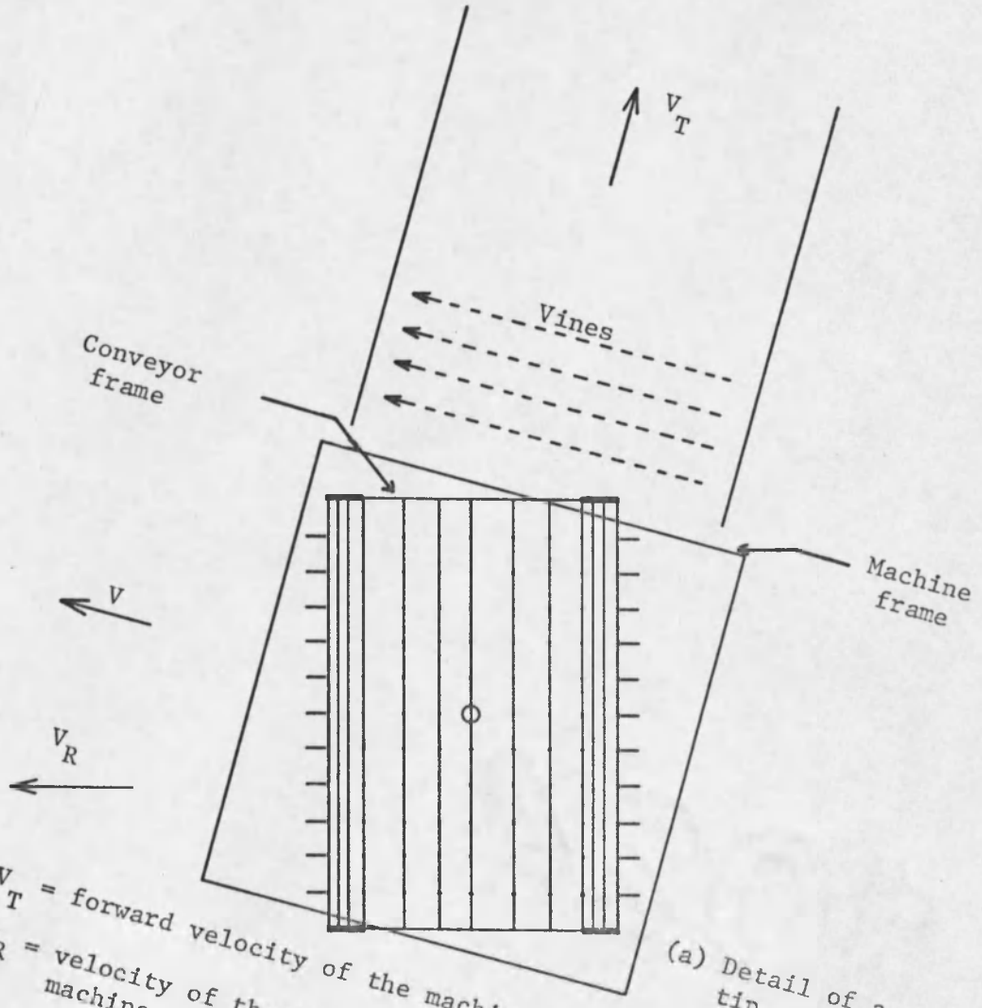
INTRODUCTION

Each year in the United States, over 100 thousand acres of cantaloupes are harvested. The annual farm value of this crop has varied from $60 to $80 million in recent years. Arizona and California contributed about 80% of the total production (Mayes, 3).

Cantaloupe harvesting in the Southwest currently requires large amounts of hand labor during a relatively short harvest period. Standard harvest methods require workers to walk through the fields, pick the ripe fruit and carry the melons in bags to field trailers.

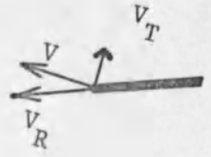
Harriott and Foster (1) have developed a cantaloupe harvester that consists of a series of rows of rubber rods mounted on a conveyor frame suspended above the cantaloupe bed and is used as a continuous flexible rake across the bed (Fig. 1). On the current machine, the rubber rods are seven inches long and 7/8 inches in diamemter. They are mounted four inches apart in the rows with eight inches between the rows. The conveyor frame is angled in relation to the direction of travel such that, when properly adjusted, the raking motion is always perpendicular to the plant row. Adjustments in height, pitch, rake angle, and rake velocity are provided to accommodate changes in forward speed and bed angle to vary the agressiveness of the raking action.

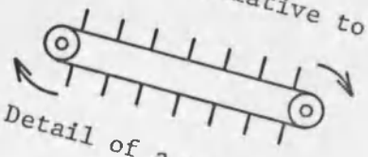
In harvesting, the flexible fingers rake through the vine area and come into contact with the melons. As the melons reach full slip stage (complete maturation), they are detached, rolled out of the vine area, and placed in the irrigation furrow adjacent to the bed. Green



V_T = forward velocity of the machine.
V_R = velocity of the rakes relative to the machine.
V = velocity of the rakes relative to ground.

(a) Detail of a rake tip.





(b) Detail of a conveyor row.

Fig. 1. Sketch of the cantaloupe harvester.

melons remain attached to the vine for later harvest because abscission has not developed and the rubber rods flex to move over or around the melons. The major drawbacks with this harvesting system are:

1. Reduction of vine cover for fruit. The raking action removes some leaves from the vines during each harvest operation. This exposes the ripening fruit to increasing amounts of sunlight and results in sunburned melons that will not maintain market quality during transit periods (Harriott, Foster and Park, 2).

2. The need to match harvester speed, conveyor velocity, and rake angle so that the perpendicular rake motion and the desired aggressiveness of harvesting action are maintained regardless of direction and speed of travel. The desired aggressiveness refers to the rake's motion such that the mature melons are removed without removing so many leaves.

The design problem of this thesis was to remove this second drawback by providing means for the operator to preselect, monitor, and control the forward velocity of the machine, the rake angle, and the conveyor speed in order to get an optimum machine performance. The required control system was designed, and in addition a visual display system was designed to allow the operator to monitor and control all these relationships from the operator's station.

Statement of the Problem

The goals in the development of devices that will permit the operator to control machine performance are:

1. To determine the mathematical relationship between the conveyor velocity, the harvester speed, and the rake velocity such that the rake tips travel perpendicular to row.

2. To give the operator an easy method of determining proper settings when the ground speed of the machine is known.

3. To develop a monitor system and a visual display system to provide the operator knowledge of these relationships.

INVESTIGATION

Objectives

Due to the importance of selecting correct rake angles, the first objective of this investigation was to determine the mathematical relationship among the conveyor velocity, the harvester speed, and the rake velocity.

A second objective was to define ranges for forward speeds, conveyor velocities, and rake angles.

The principal objective was to design a monitor system which allows the operator to control effectively all three variables, and an instrument panel which shows to the operator the machine behavior during operation.

The final objective was to check the performance of the controls and devices used in the system.

Design

The Mathematical Relationship

The relationship between the various velocity vectors are shown graphically in Fig. 2. From Fig. 2 and according to vector mechanics:

$$(I) \qquad \vec{V}_R = \vec{V}_T + \vec{V}$$

where: V_R = velocity of the rakes relative to the machine,

V_T = velocity of the machine relative to the ground,

V = velocity of the rakes relative to the ground (fps).

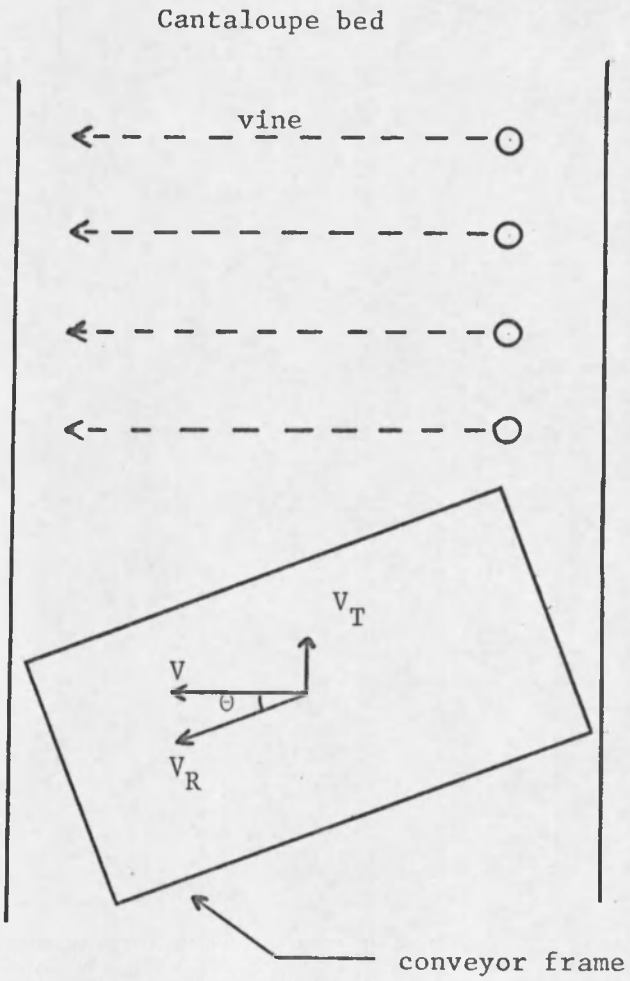


Fig. 2. Sketch showing the conveyor frame position on the bed, the velocities and the rake angle θ.

Fig. 3 shows the conveyor components and dimensions. Fig. 3 shows:

$$\text{(II)} \qquad \vec{V}_R = \frac{\pi D N}{60} \quad \text{(fps)}$$

$$D = 1.0 \text{ ft.}$$

where: D = sprocket diameter (ft.)

N = conveyor drive shaft (rpm)

As shown in Fig. 2, Θ is equal to rake angle for a chosen V_T and for a calculated V_R.

$$\text{(III)} \qquad \Theta = \arcsin \frac{\vec{V}_T}{\vec{V}_R}$$

The mathematical relationships are plotted in Fig. 4 for the machine velocities of: 0.5, 1.0, 1.5, 2.0, 2.5, and 3.0 mph. These are reasonable harvesting speeds that might be anticipated for a commercial machine.

An upper limit of 200 rpm on the conveyor drive shaft is a practical limitation considering the acceleration of components and the velocity of the rakes through the vine. Low rake velocity provides a gentle harvest action that does little damage to vine but may not remove many of the desired fruit. High rake velocities may remove fruit that is too green as well as many of the leaves. Hence a compromise must be reached depending on crop and market conditions.

A maximum rake angle of 40° is a physical constraint considering the size of the conveyor and the area of vines to be covered.

Making V_T = 0.5, 1.0, 1.5, 2.0, 2.5, and 3.0 mph and calculating V_R for different values of N,

$$N = 10, 20, 30, \ldots 200 \text{ rpm}$$

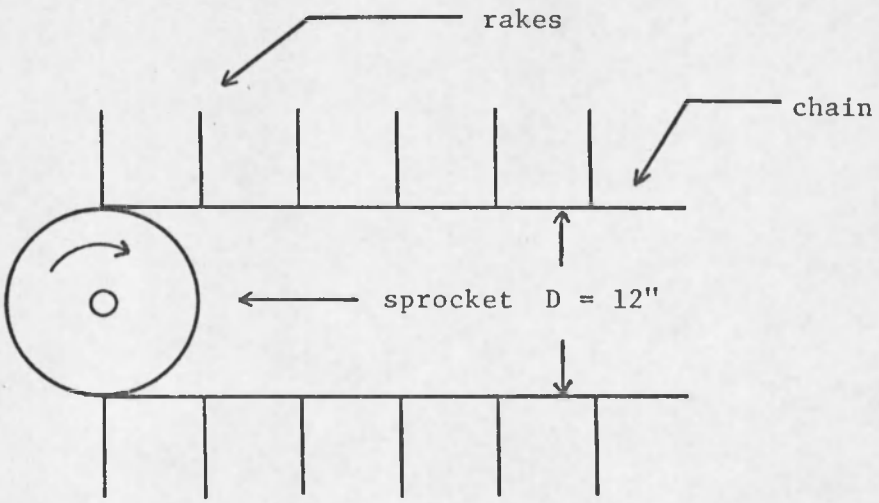


Fig. 3. Sketch of conveyor components and dimensions.

it is possible to construct Table 1. Fig. 4 is constructed taking the ordinates for the rake angles in degrees and the abscissas for the conveyor velocity represented by the conveyor rpm. For example,

considering $V_T = 1.0$ mph $= \frac{5280}{3600} = 1.467$ fps

and $N = 50$ rpm

from Equation (II),

$$V_R = \frac{\pi\ (1.0)\ 50}{60} = 2.617 \text{ fps}$$

from equation (III),

$$\Theta = \text{arc sin } \frac{1.467}{2.617} = 34.00$$

In order to get a point for the curve of $V_T = 1.0$ mph on the ordinate there is an angle of 34.00 degrees and on abscissa a conveyor rpm equal to 50 rpm.

The Monitor System

In order to properly operate the machine, the following variables must be controlled: harvesting velocity, conveyor rpm and rake angle.

The forward velocity can be controlled by monitoring the speedometer of the tractor or through the position of the throttle for a selected gear. The conveyor speed and the rake angle have to be displayed to the operator in a very simple way. A display panel is located at the operator's station and in front of him. The conveyor speed can be monitored using a tachometer directly coupled on the conveyor drive shaft, transmitting the speed in rpm to the panel. Speed in rpm is related to V_R according to Equation (II).

Table 1. Rake angles corresponding to each selected conveyor rpm and forward speed.

rpm (Rake)	Θ	rpm (Rake)	Θ
V_{T1} = 0.5 mph = 0.733 ft/sec		V_{T2} = 1.0 mph = 1.466 ft/sec	
10	--	10	--
20	44.50	20	--
30	27.80	30	69.00
40	20.50	40	44.50
50	16.30	50	34.00
60	13.50	60	27.80
70	11.50	70	24.00
80	10.00	80	20.50
90	9.00	90	18.10
100	8.00	100	16.30
110	7.30	110	14.80
120	6.70	120	13.50
130	6.20	130	12.50
140	5.70	140	11.50
150	5.40	150	10.80
160	5.00	160	10.00
170	4.70	170	9.50
180	4.50	180	9.00
190	4.20	190	8.50
200	4.00	200	8.00
V_{T3} = 1.5 mph = 2.2 ft/sec		V_{T4} = 2.0 mph = 2.93 ft/sec	
10	--	10	--
20	--	20	--
30	--	30	--
40	--	40	--
50	57.20	50	--
60	44.50	60	69.00
70	37.00	70	53.20
80	31.60	80	44.50
90	28.00	90	38.50
100	25.00	100	34.00
110	22.50	110	30.60
120	20.50	120	27.80
130	19.00	130	25.50
140	17.50	140	23.50
150	16.30	150	22.00
160	15.20	160	20.50
170	14.30	170	19.50
180	13.50	180	18.00
190	13.00	190	17.00
200	12.00	200	16.30

Table 1. (continued)

rpm (Rake)	Θ	rpm (Rake)	Θ
V_{T5} = 2.5 mph = 3.66 ft/sec		V_{T6} = 3.0 mph = 4.4 ft/sec	
10	--	10	--
20	--	20	--
30	--	30	--
40	--	40	--
50	--	50	--
60	--	60	--
70	--	70	--
80	61.00	80	--
90	51.00	90	69.00
100	44.50	100	57.20
110	39.50	110	49.80
120	35.70	120	44.50
130	32.60	130	40.30
140	30.00	140	37.00
150	27.80	150	34.00
160	26.00	160	31.70
170	24.30	170	29.50
180	23.00	180	28.00
190	21.50	190	26.20
200	20.50	200	25.00

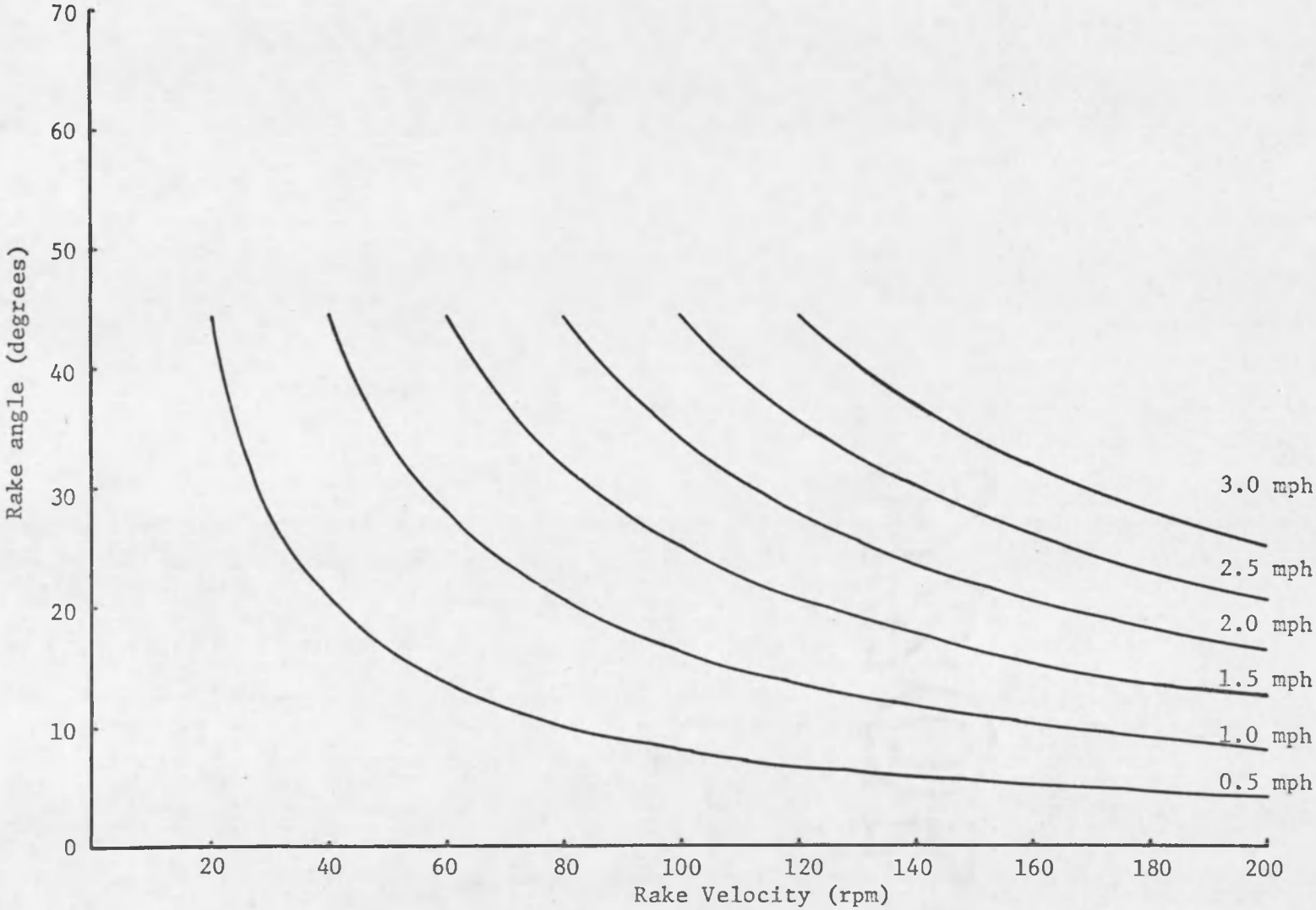


Fig. 4. Graph relating frame angle to the forward velocity of the machine and conveyor rpm.

As is shown in Fig. 5, the rake angle (Θ) is equal to the angle (α) formed by the center line of the machine frame and the center line of the conveyor since:

$$\Theta = 90 - \beta \qquad \text{and } \alpha = 90 - \beta$$

From this point the rake angle (Θ) will be referred to as frame angle, and will be monitored through lamps located on the panel.

Operating the system is easy since all the decisions are made before operation starts. The operator chooses the suitable harvesting speed and an angle from the possible angles for the selected harvesting speed. Choice of the angle also fixes the conveyor rpm.

The harvesting velocity is controlled by setting the throttle and gear. The frame angle is set by means of a hydraulic cylinder activated by a lever on the operator's station. The conveyor is powered by a hydraulic motor whose control is located at the operator's station.

The display panel includes:

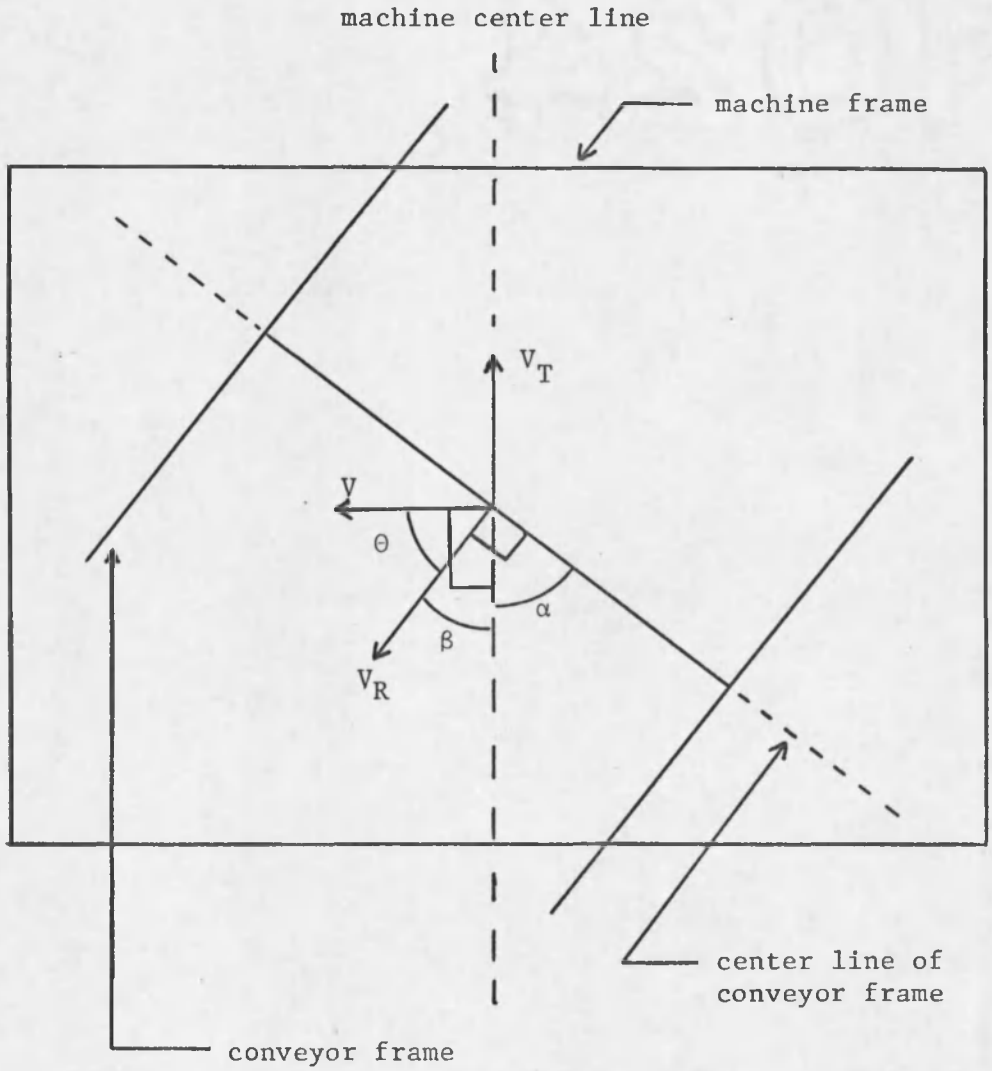
(a) The tractor speedometer which indicates the forward velocity (V_T),

(b) The tachometer display which indicates the conveyor rpm and thus the velocity of the rakes relative to the machine (V_R),

(c) The lamps which indicate the frame angle (Θ).

The Tachometer

A tachometer is attached to the rear part of the conveyor frame and coupled directly to one of the conveyor shafts. The tachometer (see Fig. 6) selected was a ZERO-MAX (ZERO-MAX IND., Minneapolis, Minn.). It



θ = rake angle
α = frame angle

Fig. 5. Sketch showing the relationship between the angle (α) formed by the machine frame and the conveyor frame, and the rake angle (θ).

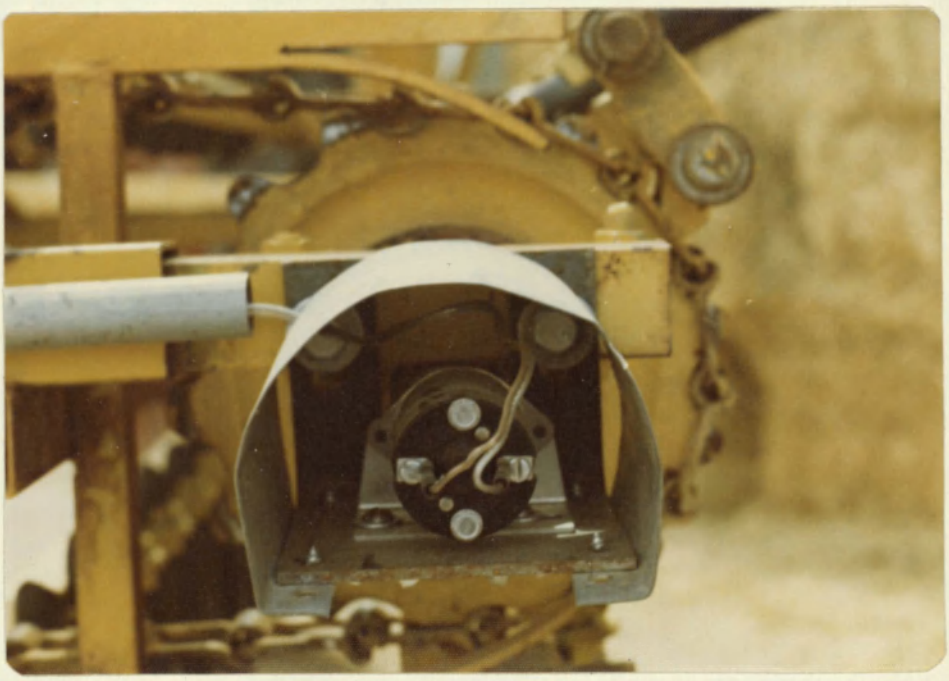


Fig. 6. A close-up of the tachometer and conveyor sprocket.

consists of a small generator which induces a voltage proportional to rpm. The display is calibrated directly into rpm.

The tachometer has two ranges: 0-100 rpm with increments of 2 rpm and 0-500 rpm with increments of 10 rpm. The dial of the tachometer moves only clockwise but the conveyor can rotate in both directions, so a switch was put on the panel in order to provide a change of the direction of current flow to correspond with the direction of the conveyor rotation.

The Switches Sector

A series of switches are placed on a sector of circle with radius equal to 14 5/8 inches and placed on the conveyor frame (see Figs. 7 and 8). A roller placed on the stationary frame of the machine activates the switches at each selected frame angle. Each pair of switches corresponds to one defined angle determined from Fig. 4. Each switch of the pair is used for the corresponding angle for each side of the sector depending on the direction of rotation of the conveyor, which changes with the direction of displacement of the machine. The sensing-switches (POTTER & BRUMFIELD - 19B660) are directly connected to lamps placed on the panel. Thus the operator can see, directly from the operator's station that he has the proper frame angle. A metallic plate was placed beneath the switches sector in order to avoid entanglement of the wires and the vines that can be carried by the rubber rods.

The Instrument Panel

A panel (Figs. 7 and 9) is placed in front of the operator at the operator's station. The tachometer display is situated at the center

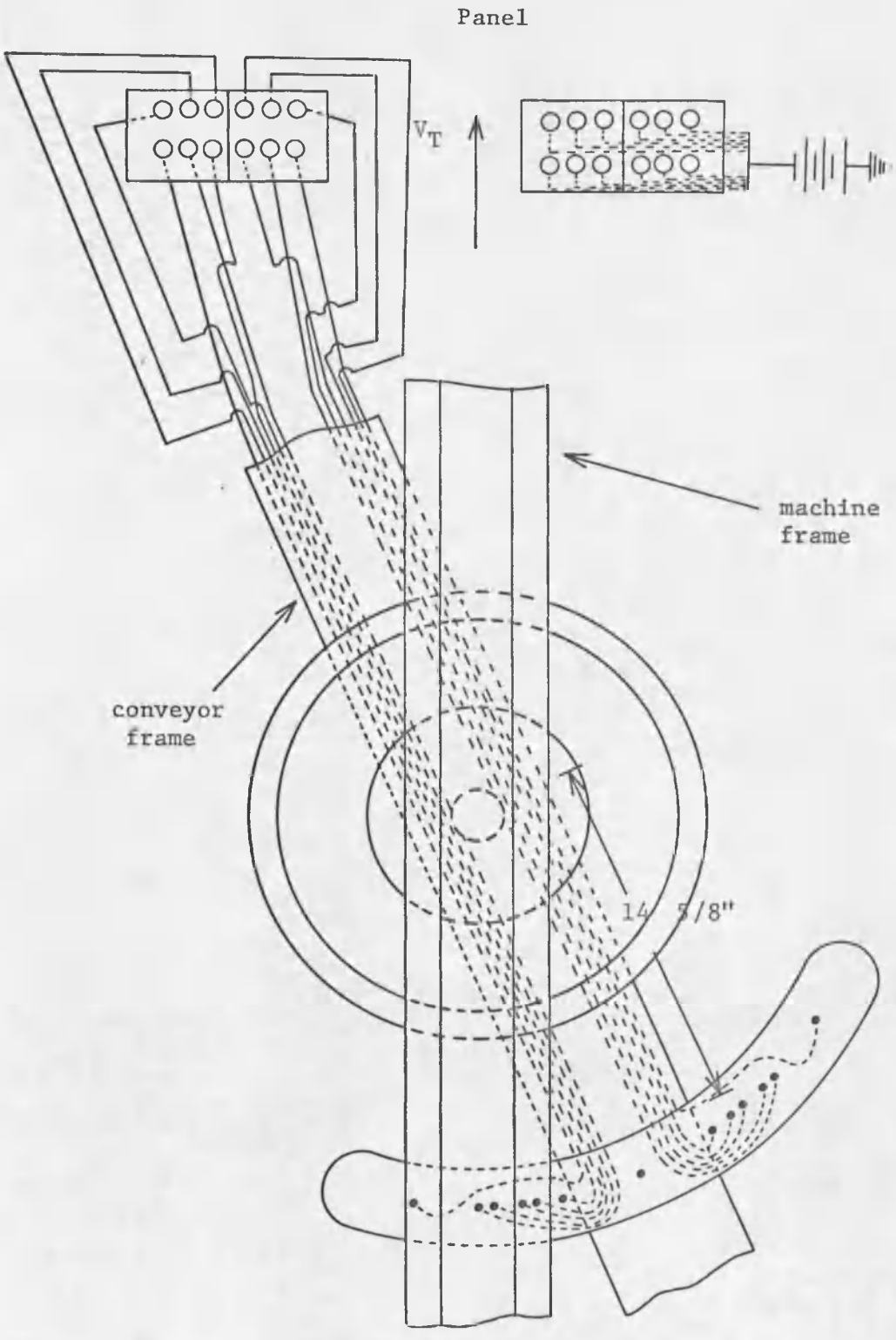


Fig. 7. Sketch of the wiring of the switches.

Fig. 8. The sector of circle containing the switches.

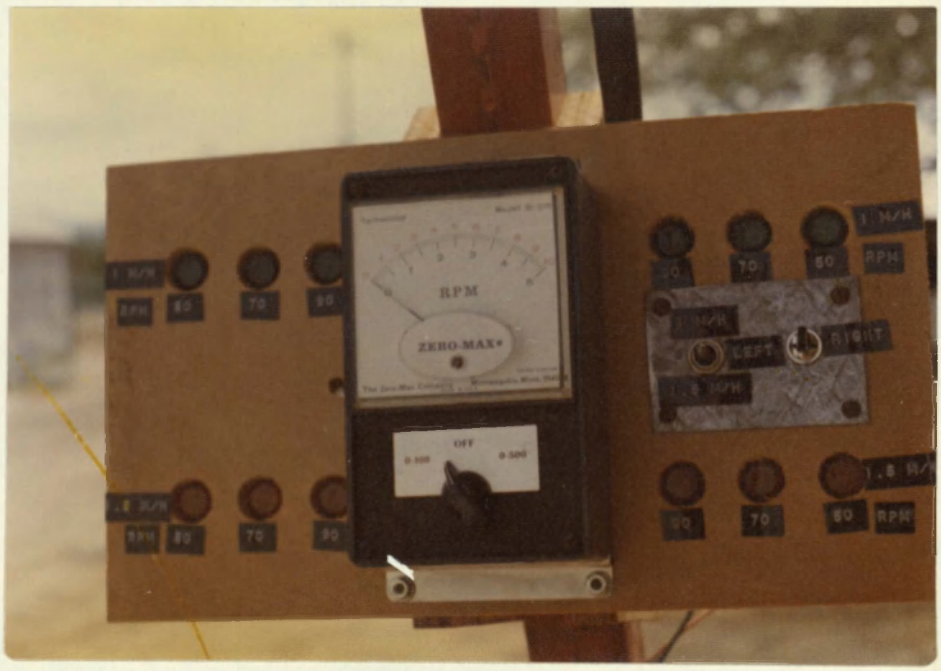


Fig. 9. Complete view of the panel showing tachometer display, lamps which indicate frame angle, and switches.

of the panel. Two lines of lamps, divided in two sections each, are disposed at the sides of the tachometer display. The upper line with green lamps is for the machine velocity equal to 1.0 mph. The lower line with red lamps is for machine velocity equal to 1.5 mph.

The two sections show the same frame angles. Each angle is represented at each section of the same line (see Fig. 9). The use of each section depends on which side of the machine the melons are being placed. For example, if the center red light of the left side of the panel is turned on, this means that the velocity of the machine is 1.5 mph, the frame angle is approximately 37^{o}, the conveyor velocity is 70 rpm, and the melons are placed to the left side of the machine.

Two switches complete the panel. The first has three positions: a central position for neutral (off), the upper position for the green lamps on (1 mph) and the lower position for the red lamps on (1.5 mph). The second switch also has three positions: a central position for neutral (off), the right position which will turn on when the conveyor is turning counter clockwise and the melons are placed to the right side, and the left position when the conveyor is turning clockwise and the melons are placed to the left side of the machine.

Field Tests

Field tests were conducted at River Road Farm in Tucson, Arizona on July 20, 1974 and January 2, 1975.

Two harvesting velocities (1.0 and 1.5 mph) were chosen for field testing.

The conveyor speeds were chosen avoiding fractional numbers and very low (0 - 40 rpm) or very high (160 - 200 rpm) conveyor rpm.

Using Fig. 4 and the chosen harvesting velocities (1.0 and 1.5 mph) and using conveyor rpm inside the chosen range (50 - 100 rpm), the display was set for the following conditions:

(a) harvesting velocity 1.0 mph

Conveyor rpm	Frame angle (degrees)
50	34.00
70	24.00
90	18.10

(b) harvesting velocity 1.5 mph

Conveyor rpm	Frame angle (degrees)
50	--
70	37.00
90	28.00

Throttle and gear selection were made for travel at 1.0 and 1.5 mph.

Following this, the frame angle and the correspondent conveyor rpm were adjusted. As cantaloupes ready to be harvested were not available, the machine was tested on a clean soil surface by observing the marks made by the rubber rods on the soil (Fig. 10).

During the tests, distances equal to 300 ft. were covered for both velocities, 1.0 and 1.5 mph.

The machine required two hydraulic pumps, one to move the hydraulic motor and another to be used on the cylinder which changed

Fig. 10. A view of the marks produced by the rakes over the ground.

the frame angle. As only one hydraulic pump was available, it was used to move the hydraulic motor, and an adjustable beam was used in place of the hydraulic cylinder.

The machine was adjusted to work at 1.0 mph with the conveyor turning at 70 rpm and with a frame angle equal to 24^{o}.

Rod marks perpendicular to the direction of travel of the machine were observed ($\theta + \beta = 90^{o}$). The variation of this angle was observed only at the mark's tips, since the tip speed increases as it goes around the sprocket.

RESULTS AND DISCUSSION

Sensing Switches Evaluation

When the frame angle was set the sensing switches worked as was expected, turning the lights on as they were contacted by the roller set in the stationary machine frame (Fig. 11).

Since the lights turn on a little before the exact frame angle and delay to turn off a little after the cited angle, this variation was measured and found a maximum variation of $\pm 2^{\circ}$.

Tachometer Evaluation

As movement was started in the conveyor without contact between the rubber rakes and the ground, rpm was steady, but when forward movement of the machine was started and contact was made between rubber rods and the soil, the tachometer read a velocity variation of $\pm$ 10 rpm. This variation is more frequent when the forward velocity is 1.0 mph, probably due to insufficient power available at the hydraulic motor which drives the conveyor. For this reason the operator must be always ready to readjust the position of controls that changes conveyor rpm. In spite of small rpm and rake angle variation, no significant loss of efficiency was observed upon the machine performance.

Instrument Panel Evaluation

The size of the panel and the distribution of lamps, switches, and tachometer through the panel did not produce any problems. However,

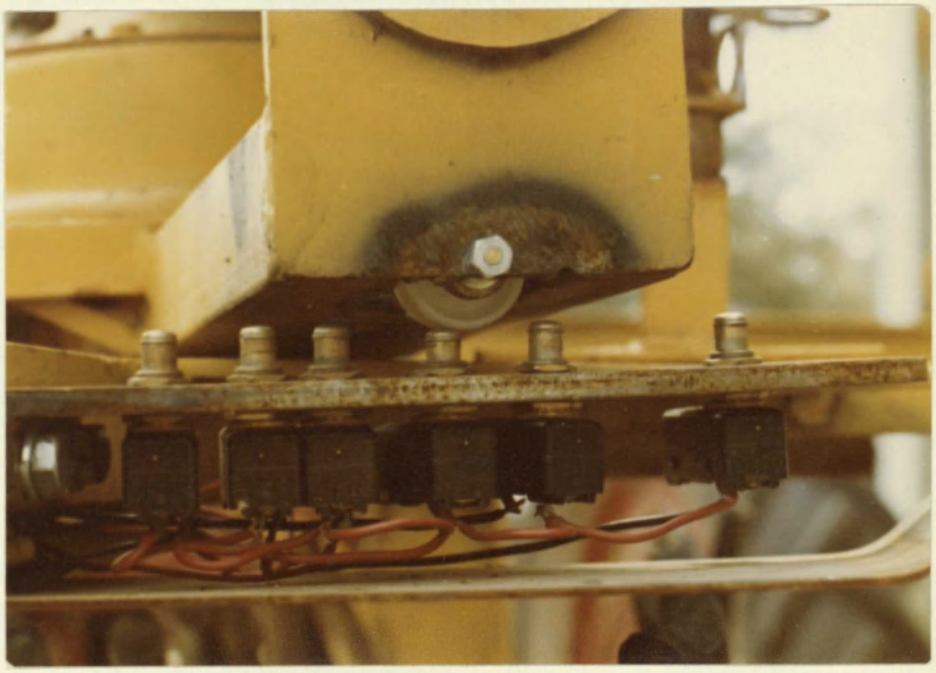


Fig. 11. Detail of the roller located on the machine frame which activates the switches.

the positioning of the panel to the left front side of the operator while the hydraulic controls (valves for moving the machine up and down, valves for changing the frame angle, and controls for the hydraulic motor) are placed to the right side it is anticipated that this would cause a loss of operator efficiency after several hours of work.

CONCLUSIONS

1. Although the controls as reported here certainly cannot be considered ready to be used on a production mechanical cantaloupe harvester, the results of the tests show that they solve some of the operator's problems. He can now finish a row and start another without need of getting off the machine in order to make adjustments. All the adjustments can be made and monitored directly from his seat on the operator's station.

2. The roller which contacts the sensing switches has a diameter larger than necessary for turning on the lamps as close as possible to the desired frame angle.

3. A better performance, i.e., less conveyor rpm variation, was observed when the forward velocity of the tractor was 1.5 mph, probably due to the higher engine speed, and thus making power available to the hydraulic motor which drives the machine conveyor.

4. The instrument panel should not be positioned at the left side of the operator while all controls are placed on his right side.

RECOMMENDATIONS

1. The roller which contacts the sensing switches must have a smaller diameter in order to increase the accuracy of the frame angle.

2. A more accurate control for the hydraulic motor which drives the conveyor has to be used in order to reduce rpm variation. This will avoid frequent adjustments and provide better conditions for the operator to observe and correct general performance of the machine.

3. The position of the instrument panel should be changed from the left to the right side of the operator making his task more comfortable.

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