Development of a Limb Shaker for Harvesting Florida Citrus

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BY 1971, Florida citrus plantings totaled 824 thousand acres of which 76 percent, or 624 thousand acres, were planted to orange varieties. About one half of the orange acreage was planted to early and midseason varieties, primarily 'Hamlin' and 'Pineapple'. The other half was planted to a late season orange, the 'Valencia' variety (reference 6). Following the development of frozen concentrated orange juice about 25 years ago, the percentage of the Florida orange crop going into processed products has been rapidly increasing. By 1972, it had reached 92 percent of the total orange production (reference 5).

Harvesting has continually been a major problem because of heavy reliance by the industry on seasonal labor, and decline in the number of workers willing to do this type of work. Harvesting cost has been rising much faster than cost of production. For the 1971-72 season, harvesting cost the Florida Citrus Industry over 160 million dollars.

Attempts to mechanize citrus harvesting have met with varying degrees of success (Coppock 1969). The emphasis in Florida has been on harvesting oranges for processing. This fruit does not have to be handled with the care required for fresh market fruit, and represents the bulk of Florida's orange production.

A limb shaker-pickup harvest system seemed to have considerable potential for processed oranges. In this system, fruit removal is separate from the fruit collection operation. This offers a potential for increasing the rate of removal and the efficiency over previously tried systems using catching frames which inhibited the removal operation.

Article was submitted for publication in August 1973; reviewed and approved for publication by the Power and Machinery Division of ASAE in January 1974. Presented as ASAE Paper No. 73-118.

Cooperative research by the Florida Department of Citrus, AREC, University of Florida, Lake Alfred, and U.S. Department of Agriculture.

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FIG. 1 Trailer mounted shaker requiring two operators.

This paper covers the development and performance of a limb shaker to operate in a shaker-pickup harvest system for processed oranges.

DEVELOPMENT OF MACHINE REQUIREMENTS

The machine design requirements were developed over four harvest seasons (1968-72), and included three major machine alterations. First, a limb shaker similar to the one reported by Coppock and Hedden (1968) was mounted on a tractor-drawn trailer, Fig. 1. The shaker was of the inertia type employing 230 lb of reciprocating weight, a 6-in. stroke of the limb clamp, relative to the reciprocating weight, and a variable frequency up to 350 cpm. Total weight of the shaker was 400 lb. It was pendulously hung from a 3-dimensioned positioning mechanism controlled remotely at the operator's handle on the shaker. This mounting arrangement required an operator for the shaker, and one for the tractor. Inadequate communication between operators was a problem which continuously affected the operation. Having to move fruit on the ground to prevent the trailer wheels running over it, was another serious problem. Mainly because of these factors, the anticipated increase in the rate of fruit removal was not obtained.

The next season (1969), the machine was self-propelled by installing a third wheel at the trailer hitch point, and an automotive rear axle to replace the straight one. A hydrostatic drive was connected to the axle differential to propel the machine using the hydraulic system already available for powering the shaker. A remote control was added to the shaker operator's handle so the operator could shuttle the transport unit back and forth to find suitable openings in the tree canopy for inserting the shaker boom and clamp onto the limb. The pendulum hanger arm on the original shaker was replaced with the spring supported, slotted, bracket shown in Fig. 2. This reduced the force that was transmitted to the transport unit from the shaker, and increased the operator's visibility in the area above the shaker.

The performance of the self-propelled machine was superior to that of the trailer type machine. One man could operate the shaker and the propelling unit. The problem of running over fruit was mostly overcome by backing the machine down the middle and shaking the trees on each side. This allowed the fruit to fall on the ground behind the machine where it was not disturbed until the pickup operation was begun.

To minimize fruit damage, the top

This article is reprinted from the TRANSACTIONS of the ASAE (Vol. 17, No. 2, pp. 262, 263, 264, 265, 1974)
Published by the American Society of Agricultural Engineers, St. Joseph, Michigan

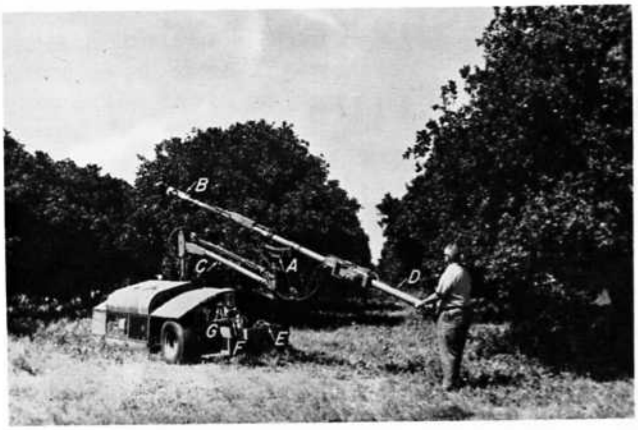

FIG. 2 Self-propelled limb shaker requiring one operator: [A] Slotted bracket supports shaker mechanism, [B[boom with integral limb clamp, [C] turret lift arm—rotates 90 deg to each side of transport unit, [D] opérator's handle—contains electrical controls to shuttle, lift, rotate and clamp, [E] shaker mechanism speed control valve, [F] operator's seat for transport, and [G] Ground speed control and mode switch.

TABLE 1. SPECIFICATIONS OF MACHINE COMPONENTS FOR SELF-PROPELLED LIMB SHAKER

Transport Unit	3-wheel
Tires	11.00-16
Engine	40 hp
Hydraulic drive motors	2-high torque
Max Flow	20 gpm
Max press	1 350 psi
Ground speed	
Shuttle (in shake mode)	44 ft per min
Transport mode	88 ft per min
Torque on wheels, Max	50 800 lb-in.
Positioning Mechanism	
Turret height above ground	7 ft
Turret lift arm length	9 ft
Rotation speed at end of lift arm	12 in. per sec
Lift speed at end of arm	6 in. per sec
Shaker Mechanism	
Reciprocating wt	230 lb
Total wt	400 lb
Length of stroke of reciprocating wt	8-in.
Length of shaker (operator's handle to clamp)	18-ft
Balance point from operator's handle	7.5-ft
Length of slot in slotted bracket	22 in.
Hydraulic drive motors	2-high torque
Max flow	26 gpm
Max press	1 500 psi
Max speed	270 rpm
Max torque	3 000 lb-in.
Clamping Cylinder	
Stroke	14-in.
Dia	2-in.
Closing time	2 sec
Clamping press	750 psi
Accumulator capacity	1 pt

surface of the transport unit was padded. Several types of padding materials were investigated. The most practical was 1-in. thick polyurethane, open-cell foam covered with nylon cloth coated with a chlorosulphonated polyethylene (Hypalon). This padding was durable and minimized fruit bouncing.

Tests of the self-propelled shaker under varied grove (orchard) conditions showed the relationships among length of stroke, frequency, and tree structure to be important. In tall trees with long, limber limbs, and high skirts (without low limbs) where the limbs could be easily clamped about one-third of the way out from the trunk, the original shaker mechanism (6-in. stroke, 350 cpm) was adequate. However in groves with trees that branch out at about one-third of the way out on the trunk, it was not possible to attach on limbs at this point because of their closeness to each other. The stroke of the reciprocating weight was increased to 8 in., and the maximum frequency reduced to 270 cpm. This change allowed more effective shaking action to be produced when limbs were clamped farther out from the trunk where they were more accessible. A marked increase in the rate and efficiency of fruit removal was obtained in groves having this type of tree.

In 1971, a completely new machine was constructed incorporating all of the desirable features from the previous machines, Fig. 2. It was used in a complete shaker-pickup harvest system evaluation study (Deason et al. 1973).

DESIGN OF SELF-PROPELLED SHAKER

Drawing from the knowledge gained in the previous work, several general design parameters were established: (a) One operator must be able to shake trees on both sides of the row middles in groves with tree spacings up to 25 x 25 ft. (b) The transport unit must be such that it can be shuttled back and forth in the row middles, so the operator can find a convenient opening in the tree canopy to insert the shaker boom. (c) The transport unit must have a low profile to allow it to pass under low-hanging limbs, and its top must be padded to reduce damage to falling fruit. (d) Ground speed must be 1 mph for intra-grove travel. (d) Provisions must be made for towing between groves.

In addition, one man must be able to operate the machine in the following manner: Move in the row middle between two tree rows. Shift hydraulic system from ground drive to shaker drive. Grasp the operator's handle, unhook shaker boom and swing, lift or shuttle transport unit as required to position the boom, and to clamp on a limb. Then by a control located away from the shaker mechanism (a safety feature), operate it to shake limbs at necessary frequencies for optimum fruit removal. This positioning and shaking procedure is repeated until a high percentage of fruit is removed. When the end of the row middle is reached, the hydraulic system is shifted to ground drive to move to another row middle. For long distance transport, the hydraulic drive motors are disconnected; a drawbar attached, and the machine towed to a new location.

Table 1 gives specifications of the machine components and Fig. 2 shows the completed machine. Components in Fig. 2 are referenced by letters. A 3-wheel transport configuration was selected because of its simplicity, and its ease of maneuvering in close groves. The single front wheel, which steered, was slightly castered to facilitate towing. The rear wheels were hydraulically powered through an automotive axle, and differential. A clutch was provided between the differential and the drive motors to disconnect them when the machine was towed. The power requirements of the shaker mechanism and the ground drive were about equal. Thus a single hydraulic system was provided with a mode switch to shift from transport mode (ground drive) to shake mode (shaker mechanism drive) of operation. The mode switch, which was located in conjunction with the ground speed control, (G) was electrical and

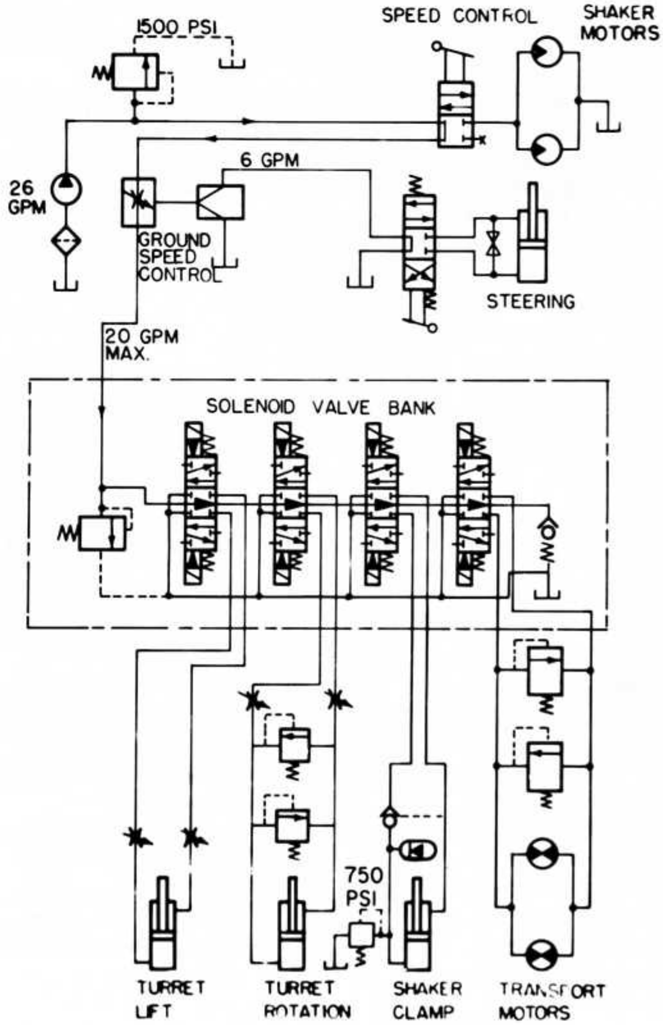

FIG. 3 Graphic hydraulic diagram.

operated a solenoid valve (Fig. 3) to accomplish the mode shift. For the transport mode of operation, a seat (F) was provided for the operator within reach of ground speed control (safety feature). For the shake mode, a speed control (E) was located on the transport frame to assure that the operator released the shaker mechanism before operating it.

The positioning mechanism consisted of: a turret which could rotate 90 deg to each side of the center of the transport unit, a parallel linkage, turret lift arm (C), and a spring cushioned slotted bracket (A) to support the shaker mechanism. The turret lift arm, along with transport shuttle, and clamp cylinder were hydraulically powered, but electrically controlled at the shaker operator's handle (D). The transport shuttle was engaged when the machine was in shake mode. It operated the transport unit in the same manner as when the machine was in transport mode, but at a slower ground speed, and was controlled from the operator's handle (D).

The shaker mechanism used a slider-crank in which the boom (B) was the slider, and the housing assembly, crank and driving motors provided the reciprocating weight to excite the limbs. The mechanism was powered by two hydraulic motors whose speed could be varied from 0 to 270 rpm. It was suspended from the reciprocating weight rather than from the shaker boom to keep the weight displacement to a minimum when transmitting a long stroke to the limb.

A graphic diagram of the hydraulic system is given in Fig. 3. The solenoid valves were electrically controlled from the shaker operator's handle by a 12-v system. To change from shake mode to transport mode of operation, an interlock was provided between the mode change switch and the ground speed control valve. This prevented shifting modes at high speed settings, because the mode change switch could be operated only when the speed setting was the lowest. The flow going to the solenoid valve bank was reduced to 10 gpm when the machine was shifted from transport mode to shaker mode of operation. The pressure in the shake clamp circuit was set at 750 psi to minimize bark damage when clamping on limbs. An accumulator and pilot operated check valve was used to compensate for valve and cylinder leakage during the shaking operation.

TABLE 2. PERFORMANCE CHARACTERISTICS OF THE SELF-PROPELLED LIMB SHAKER IN EARLY AND MIDSEASON ORANGES

Factors	Grove conditions*		
	Hamlin A	Pineapple B	Pineapple C
Fruit yield, boxes per tree	7.07	11.47	5.81
Avg harv rate†, trees per hr	8.6	6.1	9.3
Avg harv rate, boxes per hr	58	67	51
Fruit removal eff, percent	90	90	89
Split fruit on ground, percent	4.3	1.8	6.8
Fruit removed with stems, percent	24	16	9
Increased harv rate, boxes per hr w/15 ppm CHI‡, percent	15	15	70
Increased removal eff w/15 ppm CHI, percent	2.2	0.7	3.0
Reduction of fruit with stems w/15 ppm CHI, percent	75	60	92
Time and motion, percent of total time (without CHI)			
Positioning boom	43	60	54
Moving transport	10	4	6
Raking fruit	7	5	13
Shaking limbs	40	31	27
Avg no. clamps per tree	6.0	8.7	4.0

* Hamlin A - Hamlin variety, 20 x 24-ft spacing, 18 to 20-ft tree height, middles hedged, level terrain, 3-ft tree skirts

Pineapple B - Pineapple variety, 25 x 25-ft spacing, 16 to 20-ft tree height, middles hedged, level terrain, 3-ft tree skirts

Pineapple C - Pineapple variety, 25 x 25-ft spacing, 20 to 25-ft tree height, foliage canopied over in top, level terrain, 8-ft tree skirts

† Sustained harvest rate (does not include delays, minor repairs or turning time).

‡ CHI - Cycloheximide abscission chemical

PERFORMANCE

The shaker's mechanical performance met the general design parameters. Some overheating of the hydraulic system was experienced in hot weather, but this could probably be overcome by using dual pumps, one for the shaker and propelling motors, and one for the positioning cylinders.

Table 2 summarizes the performance data for the shaker when operated in three different groves. The conditions were typical of those found in early and midseason orange groves with trees in the 20 to 50-year age range. Plots in each grove were sprayed with the abscission chemical, cycloheximide, to study its effect on the shaker's performance.

Without the aid of an abscission chemical, the harvest rate (sustained rate) in trees per hour, ranged from 6.1 to 9.3. The rate in boxes per hour ranged from 51 to 67, with the highest box rate in the grove where the trees per hour rate was the lowest, a reflection of the higher per tree fruit yields in that grove. Fruit removal efficiency was about 90 percent in all groves. The abscission chemical increased the per box harvest rate and fruit removal efficiency. The increase in harvest rate ranged from 15 to 70 percent, depending to a large degree on tree height, and degree of fruit loosening obtained. Increase in removal efficiency ranged from 0.7 to 3.2 percent. This small increase was attributed in part to the inability of cycloheximide to loosen all the fruit on the trees enough for it to be removed easily. Also, it could be that the tree structure prevented the shaking force from reaching more than 90 percent of the fruit. A very significant benefit from the abscission chemical was the large reduction in the fruit coming off the tree with stems attached. Fruit detached with stems becomes a handling problem at the processing plant. Fruit split in falling to the ground ranged from 1.8 to 6.8 percent, varying with the height of the fall.

Positioning the shaker boom consumed a large part of the operational time (43 to 60 percent). Improvements in this area offer the greatest potential for increasing the harvest rate.

The shaker was also tested in 'Valencia' oranges. This variety has the next year's crop, in the form of young fruit, on the tree at harvest time. The weight of the young fruit increases over the harvest season from 2 to 40 gm (1). Loss to the next year's crop resulting from removing some young fruit ranged from 5 to 50 percent, depending on the size of the young fruit at harvest time, and the severity of shaking action used.

The removal efficiency for mature 'Valencia' fruit was about the same as that for early and midseason oranges. Extra time was required to position the shaker boom because of the denser tree canopy.

SUMMARY

A self-propelled limb shaker was developed as a component of a shaker-pickup harvest system. The development progressed from a trailer-mounted unit with two operators, to a self-propelled unit with one operator. Tests were conducted in three different groves of early and midseason oranges. The harvest rate averaged from 6.1 to 9.3 trees per hr or, in these groves, from 51 to 67 boxes per hr. Fruit removal efficiency was about 90 percent in all groves. Cycloheximide, an abscission chemical, increased the harvest rate between 15 to 70 percent, varying with tree height and degree of fruit loosening obtained.

Tests in 'Valencia' oranges showed a reduction in the next year's crop of from 5 to 50 percent resulting from the removal of some of the young fruit at harvest time. The mature fruit removal efficiency was about the same as that obtained in early and midseason oranges.

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