# Design and Development of a Tree-Shaker Harvest System for Citrus Fruit

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THE Florida citrus industry is searching for new machines and methods to improve the harvesting of citrus fruit. The industry is faced each year with larger production, higher harvesting costs, and chronic labor problems. Cost of picking and hauling Florida citrus to the point of utilization for the 1964-65 season is estimated to be over 60 million dollars. This cost represented 21 percent of the total value of the crop before harvesting. At the peak of the harvest season over 18,000 workers were employed.

Past efforts to mechanize this operation have met with little success. Citrus fruit is still picked by hand labor, one fruit at a time. Picking aids have been studied (2)* and the slight increases in productivity achieved very little economic advantage over present methods. Attempts to develop a machine to harvest citrus mechanically by duplicating the work of hand pickers have not been successful because of the high selectivity required in removing each fruit individually.

The development of frozen, concentrated orange juice has greatly increased the portion of the orange crop that is processed. Approximately 80 percent of the total Florida citrus production for 1964-65 season was processed. This large percentage has greatly increased the possibility of using a mass-removal harvest system, since processing fruit can be handled with less care than handling fresh fruit.

Shaking trees to remove the fruit has been considered for many years. Boom-type shakers designed for harvesting other tree crops proved unacceptable because of their low fruit-removal efficiency (3). A high fruit removal efficiency has been found possible by shaking the tree with an oscillating air blast (4), but it has been accompanied by an objectionably high leaf removal. These early studies indicated that a practical tree-shaker harvest system could be developed for citrus which goes directly to the canneries. The development of such a system and the design requirements of the machine components peculiar to citrus are discussed in this paper.

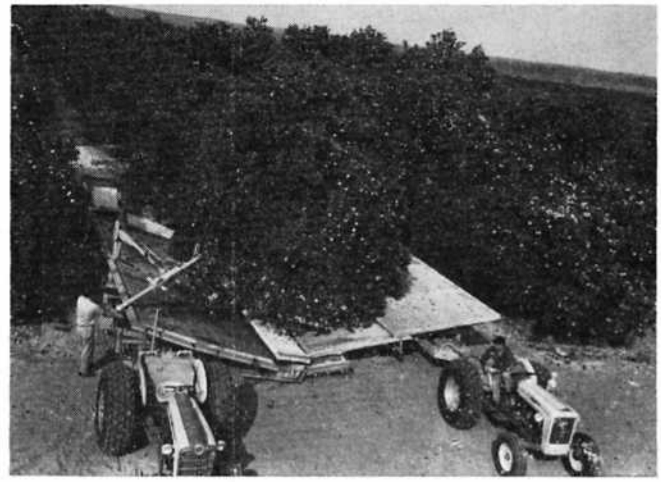

FIG. 1 Front view of tree-shaker harvest system operating in Pineapple oranges. (One of the shakers is hidden by the tree).

### Description of Harvest System

The tree-shaker harvest system shown in Fig. 1 consists of two tractor-drawn catching frames, each equipped with an inertia-type limb shaker. In operation, the two catching frames are pulled into position in opposite sides of a tree and the catching surfaces are extended until they meet and seal around the base of the tree. The shakers detach the fruit by shaking individual tree limbs and the fruit drops onto the catching frame. Conveyors on one catching frame carry the fruit from under the tree into a wire basket carried on the rear section. When the basket is full, it is dropped to one side of the row. The full baskets are picked up later by a lift-boom-type loader and the fruit dumped into a grove truck for transport to a roadside trailer. Empty baskets are spotted to one side of the row before harvesting so they can be set on the frame as needed.

The system requires four men – a combination tractor and shaker operator, a basket tender for the catching frame equipped with fruit-handling equipment, a tractor driver, and a shaker operator on the other frame.

### Limb Shaker

Cable, fixed-stroke, and inertia-type shakers have been tried in citrus. The inertia-type shaker showed greater promise because the reactive forces of the shaker can be readily isolated from the transport unit, and the shaker can be built for greater maneuverability in close planted groves. Adrian and Fridley (1) studied the fundamental vibration theory and design criteria for an inertia-type shaker in deciduous fruits. The basic concept of the inertia shaker is the transmission to the tree of vibrating forces developed by an oscillating mass which is attached to the tree.

The shape and fruiting habits of citrus trees indicate that a design requirement of a suitable tree shaker should be characterized by a long stroke, low frequency, and a high degree of maneuverability. In general, fruit removal is associated with long strokes and leaf removal is associated with high frequencies. Other machine design requirements for the shaker are length and weight balance to permit the operator to control it from outside the periphery of the catching frame, and a limb clamp with controlled clamping pressure capable of clamping onto limbs up to 7 in. in diameter.

The tree shaker shown in Fig. 2 was developed for citrus using a slider-crank mechanism. In this arrangement, the boom is the slider and the housing assembly, crank, and driving motors provide the reciprocating weight

Paper No. 66-130 presented at the Annual Meeting of the American Society of Agricultural Engineers at Amherst, Mass., June 1966, on a program arranged by the Power and Machinery Division.

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* Numbers in parentheses refer to the appended references.

**Author's Note:** This paper is approved as a contribution to the Florida Agricultural Experiment Station's journal series No. 2430, and is a report of cooperative research by the Florida Citrus Experiment Station, Florida Citrus Commission, and USDA.

This article is reprinted from the TRANSACTIONS of the ASAE (vol. 11, no. 3, pp. 339, 340, 341 and 342, 1968), the Transactions of the American Society of Agricultural Engineers, Saint Joseph, Michigan

to excite the tree. The housing assembly extends from the operator's handle to a slip bearing located about one-third the length of the boom from the crank. A hydraulically-powered limb clamp is an integral part of the boom. The complete shaker is balanced and pendulously hung from a positioning mechanism by a swing link attached to the housing assembly. The design permits 360 degrees rotation of the shaker about its longitudinal axis for aligning the clamp with the limbs. This design permits the catching frame to absorb some of the reactive force of the shaker without causing excessive vibration of the frame when the shaker is operating under long stroke conditions. In effect, this is the same as adding more reciprocating weight to the shaker. The operation of a shaker designed in this manner is analogous to a fixed-stroke shaker mounted on a tractor, if the tractor is considered as an extremely heavy reciprocating weight.

Two hydraulic motors power the shaker, as shown in the cutaway section of Fig. 2. Their speed can be varied by the operator from 0 to 350 rpm. Once the shaker is in operation, the operator can control only the frequency of shaking.

TABLE 1. ENGINEERING SPECIFICATIONS AND MECHANICAL PERFORMANCE OF LIMB SHAKER

| | | |
|---|---|---|
| Specifications: | | |
| Total weight | | 400 lb |
| Reciprocating weight | | 230 lb |
| Stroke of reciprocating weight relative to boom | | 6 in. |
| Length of shaker (operator's handle to center of clamp) | | 18 ft |
| Pivot point (from operator's handle) | | 8 ft |
| Length of pendulum arm | | 12 in. |
| Drive motors: | | |
| Flow | | 0 to 10 gpm |
| Speed | | 0 to 350 rpm |
| Power (at 1300 psi and 350 rpm) | | 5.3 hp |
| Torque (at 1300 psi) | | 963 in-lb |
| Clamping cylinder: | | |
| Stroke | | 12 in. |
| Diameter | | 2 in. |
| Pressure | | 500 psi |
| Speed | | 4 in. per sec |
| Performance: (Typical operating condition in Pineapple oranges) | | |
| Frequency | avg | 297 cpm (range 248 to 333) |
| Displacement of clamp | avg | 3.71 in. (range 2.7 to 5.2) |
| Acceleration | avg | 34 g's (range 20 to 57) |
| Limbs clamped per tree | avg | 8 (4 to 12) |

The limb clamp is an important component of the shaker, and has been given special design consideration to eliminate possible damage to the tree bark. The limb clamp used consists of a C-type frame with two pivoted rubber pads, one stationary and the other attached to the rod end of a hydraulic cylinder. The pads pivot to conform to the shape of the lamb as they are hydraulically pushed together. The clamp action is remotely controlled from the operator's handle through a solenoid valve and a pilot-operated check valve in the hydraulic system prevents the clamp from loosening when the shaker is in operation. The clamping pressure on the limb is controlled by an adjustable relief valve.

The engineering specifications and mechanical performance of the shaker are given in Table 1. Shaker performance was evaluated by attaching an accelerometer to the limb clamp and measuring its acceleration under typical operating condition in "Pineapple" oranges. The frequency and displacement were computed from the accelerometer responses. Variations in values reflect the effect of different angles of attachment, points of attachment, and limb characteristics.

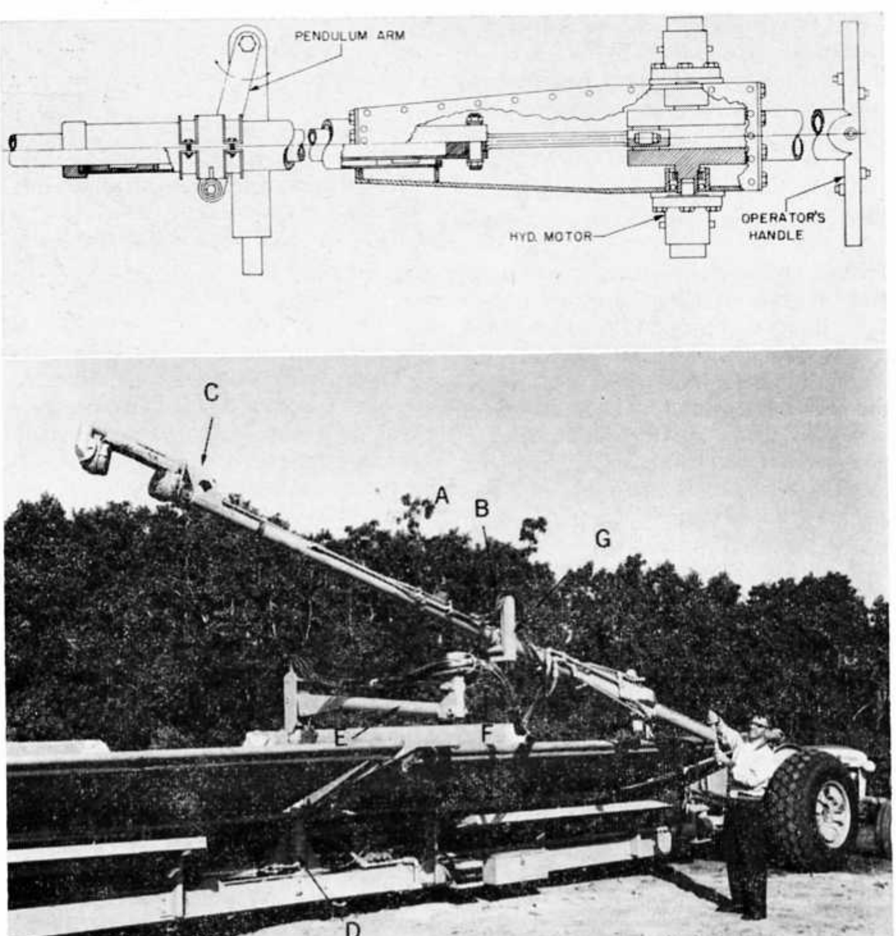


**FIG. 2 Inertia tree shaker and positioning mechanism mounted on catching frame: (A) slip bearing, (B) pendulum arm, (C) boom with integral limb clamp, (D) turret, (E) parallel-linkage lift arm, (F) floating arm, and (G) flooding pivot arm.**

An effective shaker positioning mechanism is one of the most important design requirements of a tree shaker. Shaker position has more effect on performance than any other single factor. A desirable positioning mechanism should permit the shaker to clamp onto a limb at about one-third the length of the limb from its base, perpendicular to the axis of the limb and in a position so that fruit can be shaken vertically. Unfortunately the optimum position for shaking cannot always be obtained because of machine-design limitations, tree structure, and tree shape. Clamping the limb away from its base improves the vibration characteristic of the limbs and dampens some of the vibrations before they reach the tree roots where possible damage might occur.

The positioning mechanism shown in Fig. 2 consists of a 5-ft high turret, a 7-ft parallel linkage lift arm, a 2-ft free floating arm, and a free-pendulum pivot arm. The turret and lift arm are powered hydraulically and are controlled by switches located on the operator's handle. The shaker is positioned and clamped onto a limb by means of the controls located on the operator's handle and the operator then releases the handle before operating the shaker. The floating arm and the pendulum

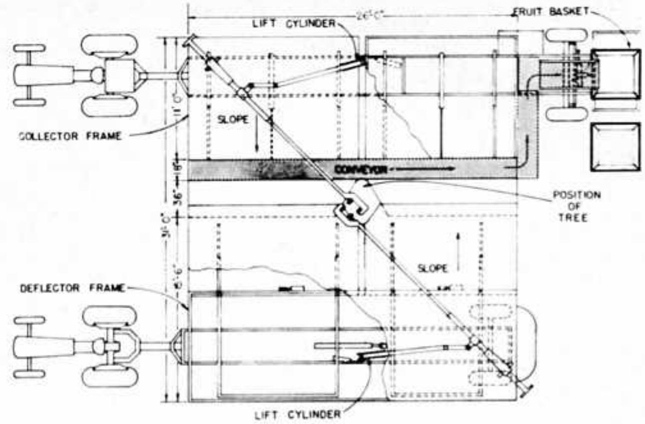


**FIG. 3 Plan view of catching frames designed for the tree-shaker harvest system.**

pivot arm are free to be moved manually, giving the operator a better "feel" of the shaker when clamping on the limbs. The turret rotates the lift arm 180 degrees to one side of the center of the catching frame as shown in Fig. 3. This movement plus the free movement of the floating arm, enables the operator to stand along the edge of the catching frame. Limbs as high as 15 ft can be reached by using the lift arm. When moving from one tree to another, the shakers are positioned and clamped to the catching frames parallel to the direction of travel. The same hydraulic system powers both the shaker and the positioning mechanism since they are never operated simultaneously.

### Catching Frames

The function of the catching frames in the harvest system is to decelerate and collect the falling fruit and deliver it into a suitable container for transportation out of the grove. This must be accomplished with minimum damage to the fruit. The general design requirements of a catching frame for citrus are:

(**a**) Catch fruit falling from trees having a periphery up to 25 ft in diameter without puncturing the peel

(**b**) Be built as low to the ground as possible to reach under low limbs

(**c**) Form a seal between frames and around the base of the tree

(**d**) Be retractable and extendible so frames can be moved from tree to tree

(**e**) Be highly maneuverable in soft, sandy soils

(**f**) Turn within a 25-ft distance at end of grove

(**g**) Fold to within a 10-ft width for travel between groves.

A plan view of the catching frames designed for the tree-shaker harvest system is shown in Fig. 3. Each catching frame is semimounted by a clevis hitch arrangement on a medium-size farm tractor (35 hp) equipped with sand tires. The clevis is slotted to permit vertical movement between the frame and tractor. The catching surface on the collector frame is cradled between the tractor and the trailer axle. This permits the transport frame to be built low to the ground. Increased maneuverability is obtained by making the trailer axle steerable on both frames. A hydraulic system driven by the tractor PTO shaft powers all components on each catching frame.

The narrow, catching-surface panel next to the conveyor on the collector frame is mounted parallel to the ground to form a seal as low as possible on the tree. Fruit collected on the panel is dumped into the conveyor when the frame is retracted. The conveyors are 3-ply nylon belting, 18 in. wide, moving at 140 fpm. The elevator is 24 in. wide and moves at 110 fpm.

Designing the frames to form an effective seal around the base of the tree presented a problem because many citrus trees grown in Florida branch out close to ground level leaving little or no trunk. No really effective solution was found though the sealing arrangement shown in Fig. 4 was tried and found to be acceptable when the low lateral limbs were removed. It consists of a semicircular opening in the center and toward the inside edge of both catching frames. When the frames are extended, the circular openings surround the group of limbs extending from the base of the tree about 12 in. above ground. Padded flaps are attached to the edge of the semicircular openings and pushed between the limbs to reduce fruit loss when the frames are extended.

The slope of the surface of both catching frames is adjustable to compensate for differences in terrain. A slope of 20 deg is adequate for fruit drainage. The catching surface of the frames is covered with a fabric material stretched across a tublar frame. All points of contact between the frame and fabric are padded with a plastic foam having a density of 1.29 lb per cu ft.

The cover material must be strong and resistant to citrus peel oil and hot, humid climatic conditions. A woven "Saran" plastic material was tried and found to be too fragile to withstand the abuse of tree limbs dragging over it. It was replaced by a nylon fabric coated with a chlorosulphonated polyethylene (Hypalon) which lasted extremely well under severe field conditions.

### Performance of Harvest System

The system was tested throughout the 1965-66 harvest season in early and midseason oranges ("Hamlin" and "Pineapple"), grapefruit and late season oranges (Valencia). Trials were made using these fruits at four harvest dates spaced over the normal harvest period for each fruit type. The data from these trials given in Table 2 show that an average removal efficiency of 90 percent and above was obtained in all fruit types.

A special problem was encountered in harvesting Valencia oranges which are the only citrus-fruit type grown in Florida that always has the next season's crop (in the form of immature fruit) on the tree at harvest time. A large amount of this immature fruit was removed along with the mature fruit when the trees were shaken and, as expected, the amount removed increased with the size of the immature fruit. Efforts to remove the mature fruit with the tree shaker and leave the immature fruit were not successful. Another problem associated with Valencia oranges is that of excessive bark damage caused by the limb clamp. This damage occurs because Valencia oranges are harvested in the spring of the year when the bark is very succulent. These problems may seriously hamper the adaptation of the tree-shaker harvest method for Valencia oranges.

The rate of harvest with the shaker harvest system was essentially the same in oranges and grapefruit. An average of 12 trees per hr were harvested, re-

**FIG. 4 Catching frames in position around the base of a grapefruit tree. (Many of the trees do not have a single trunk).**

TABLE 2. FRUIT REMOVAL EFFICIENCY OF HARVEST SYSTEM

| Fruit type | Harvest season | Seasonal average removal, percent |
|---|---|---|
| Valencia oranges | April 1 to June 15 | 91 |
| Hamlin oranges | November 1 to January 15 | 94 |
| Pineapple oranges | December 15 to March 1 | 90 |
| Marsh grapefruit | December 15 to March 15 | 97 |

gardless of fruit yield, by a four-man crew. At this rate, four men on the machine can do the work of 10 to 15 pickers by hand. An average of 3.8 min were required per tree for shaking and 1.2 min to move from tree to tree.

The maneuverability of the catching frames was satisfactory, but trouble was encountered in forming a good fruit seal around the base of the tree and in preventing fruit from rolling off the catching surface when operating on sloping terrain. Fruit losses from these sources ran as high as 5 percent of the tree yield.

The operator had some trouble in swinging the shaker through the tree canopy to attach onto the limbs and in positioning the shaker when operating on sloping terrain. Long, slender limbs in the center of the trees were difficult to shake because of their vibration-damping characteristic.

Some corrective pruning of the trees will be necessary to use this harvest system. Tree skirts must be raised in most cases to permit the movement of the catching frames under the trees. The tree must have about 18 in. of clearance at the base and 3 to 4 ft at the periphery of the tree. It is also advantageous to prune an access hole in the tree canopy for the tree shaker to reach the main scaffold limbs of the tree. Providing the operator with a view of the main limbs increases the harvesting efficiency and reduces bark damage. Pruning for fewer scaffold limbs to reduce the number of shaker attachments necessary would, no doubt, increase fruit removal efficiency and increase the harvest rate.

Tree size is not a limiting factor with the harvest system as long as the tree is large enough to provide an attachment for the tree shaker clamp, and there is enough room under the tree for catching equipment. Fruit damage may be increased in large trees due to the fall through the tree foliage.

Personnel operating this equipment must have some aptitude for operating farm machinery. Two men on the harvest crew could be eliminated if the deflector frame was self-propelled or if the fruit were conveyed directly into a truck.

The effect of tree shaking on subsequent yields and on fruit damage are under study. Preliminary results indicate that reduction in yield in "Hamlin" and "Pineapple" oranges, and "Marsh" grapefruit will not be a problem. Fruit harvested by this system is limited at present to cannery utilization.

## Summary

A tree-shaker harvest system consisting of two catching frames each equipped with an inertia-type limb shaker was developed for the purpose of establishing some of the machine-design requirements peculiar to citrus. The mechanism for positioning the shaker was a major factor affecting the shaker's performance. An acceptable shaker was characterized by a long stroke, low frequency, and high power requirements.

The harvest system showed promise in harvesting Hamlin and Pineapple oranges and Marsh grapefruit for cannery utilization. It was limited to harvesting in older groves and on fairly level terrain. An average of 12 trees per hr were harvested, regardless of fruit yield, by a four-man crew. Fruit removal efficiency was 90 percent and above in all fruit types harvested.

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