Reprinted from *Proc. Int. Soc. Citriculture.* 2:407-412. 1977.

MECHANICAL REMOVAL OF FRUIT FROM CITRUS TREES[1, 2]

J. D. WHITNEY
University of Florida, Institute of Food and Agricultural Sciences, Agricultural Research and Education Center, Lake Alfred, FL 33850

H. R. SUMNER
United State Department of Agriculture, Agricultural Research Service, Agricultural Research and Education Center, Lake Alfred, FL 33850

Additional index words. Shaker, harvesting, abscission.

Abstract. **Removal of citrus fruit has been dependent on hand labor. Aids for the hand picker have not gained industry acceptance. Several mechanical fruit removal devices have been developed in Florida over the past 2 decades. Contact devices have not gained acceptance because they have not demonstrated a reasonable potential in existing groves. Limb, foliage, trunk, air, and water shakers (with the aid of abscission chemicals) have gained some acceptance for removing early and midseason oranges for processing. Limb and foliage shakers generally achieved fruit removal efficiencies of 85 to 95% at fruit removal rates of 1800 to 5400 kg/hr. These shakers depended less on the fruit loosening by abscission chemicals and have inherently low operational reliabilities. Trunk, air, and water shakers depended on the fruit loosening by abscission chemicals to achieve fruit removal efficiencies of 85 to 95% at fruit removal rates of 9000 to 36000 kg/hr. Their operational reliability was inherently high. Generally shaker effects on subsequent yields of early and midseason citrus have been minimal. In 'Valencia,' however, shakers have reduced subsequent yields up to 40 or 50% and this reduction remains a major deterrent to the acceptance of shakers as removal devices in mechanical harvesting.**

The harvesting of citrus fruit has been dependent on hand labor. During the 1950's, the Florida citrus industry became concerned that manual labor to accomplish harvesting might soon be unavailable and/or excessive in cost. As a result, a concerted research effort was begun to mechanize the harvesting of citrus fruit. Initially, time and motion studies were made on manual harvesting methods (15). Information from these studies suggested that partial mechanization in the form of aids to the picker might be feasible. It was found that aids such as a mobile platform can increase a picker's productivity (9, 20). However, the productivity increase has not been commensurate with the capital expenditure for the platform. Overall, the potential for aids to alleviate anticipated harvesting problems has been rather limited, and investigations into mechanical methods of citrus fruit removal began in the early 1960's. This paper discusses the state-of-the-art of mechanical devices for citrus fruit removal as they have been developed over the past 2 decades.

Mechanical Removal

General Principles

Separation of citrus fruit from the tree requires that the forces exerted on the supporting stem exceed the bonding strength between the stem and fruit. The type or mode of separation affects the magnitude of required force. As the direction of force changes from parallel to perpendicular with respect to the fruit axis, the required forces decrease (1, 8). Twisting of the stem can also slightly reduce the separation force (1).

Mechanical removal devices exert forces on the fruit-stem system by several means to accomplish fruit separation. Forces may be applied to the fruit: (a) by direct contact much the same as in manual harvesting; (b) through the tree structure that supports the fruit (non-contact); and (c) by a combination of (a) and (b). Mechanisms which principally utilize direct fruit contact (a) have been generally classified as contact devices. Those which remove fruit by the 2 latter means (b and c) have been classified as shakers.

With regard to problems in mechanical removal, citrus cultivars are harvested under 2 distinctly different conditions. Some cultivars (early and midseason) are harvested before bloom when the only crop on the tree is a mature one. With these cultivars, fruit bonding strength gradually decreases as the harvest season progresses, thus requiring less removal force. Another cultivar (late season 'Valencia') is harvested after the bloom when 2 crops (mature and young) are on the tree. With this cultivar, fruit bonding strength does not decrease as the harvest season progresses. Mechanical removal of the fruit from 'Valencia' is most difficult because the mature fruit must be removed without causing significant damage to the young fruit. A more detailed discussion of the problems can be found elsewhere (6, 8).

Because of the high forces generally required to separate mature citrus fruit from the tree, it was recognized early that an abscission chemical to reduce the fruit bonding strength could be an aid to mechanically removing the fruit (14). As a result, development of mechanical fruit removal devices and abscission chemicals has been a joint effort in Florida. Abscission chemicals have played a significant role in the types of mechanical removal devices which have been tested and used in the field. In this paper, abscission chemicals will be discussed only as they have influenced the development of mechanical removal devices. A more detailed discussion of abscission chemicals can be found elsewhere (33).

Contact Devices

Some of the first attempts to mechanize the removal of citrus fruit dealt with contact devices. Most of these devices accomplished fruit separation by a combing action of the branches in the tree. The picking head usually consisted of some array of long fingers or rotating surfaces with sufficiently large physical dimensions between them to allow passage of the foliage and young fruit, but not large enough to allow mature citrus fruit to pass (Fig. 1). Such devices have included rotating rubber rollers and cones (4), flexible hooks (3), vacuum cups (19) and rubber spindles (4). Further investigations (17, 22) were made to optimize the geometry and components of the spindle or auger picking head for efficient fruit removal. Field data indicated that a maximum fruit removal efficiency of 65 to 75% could be achieved in trees that were less than 4 m high and had

[1]Florida Agricultural Experiment Stations Journal Series No. 515.

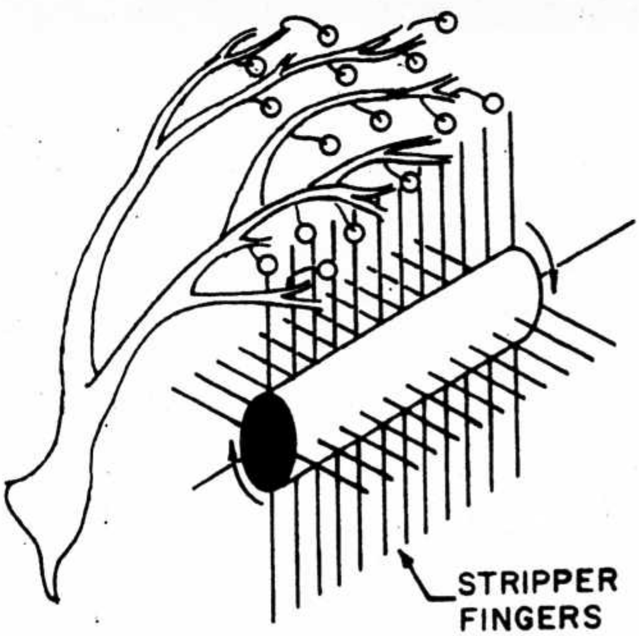

Fig. 1. Principle used to remove fruit with contact devices.

quire that the picking head be positioned in the fruit bearing zones of the tree. Also, the direction of penetration should be perpendicular to the tree canopy surface to achieve maximum penetration. The positioning mechanism for the picking head must have considerable flexibility and is usually complex and expensive. Positioning for fruit removal in the top zone of the tree canopy has been most difficult.

Depth of penetration inside the periphery of the tree canopy has been generally limited to approximately 1 m. Deeper penetrations of the normal tree canopy have been prohibited because of the presence of large and rigid limbs. This situation has been prevalent in bearing Florida citrus because many groves are on a regularly scheduled hedging and topping program which results in large limb sizes near the outer canopy of the tree.

Contact devices have generally been characterized by low fruit removal rates and efficiencies, high capital investment, and limited adaptability to different shapes, structures, and sizes of trees. The use of abscission chemicals has not particularly improved the performance of contact devices. Interest in contact devices continues mainly as a means of mechanically removing fresh market fruit. They also have some merit in selectively removing mature 'Valencia' oranges on the basis of fruit size. These devices have not demonstrated a reasonable potential in existing grove conditions and, therefore, have not been generally accepted.

Shakers

The shaker or mass removal approach to mechanical fruit removal appeared to offer fruit removal rates commensurate with cost and was adaptable to a wide variety of trees as evidenced by its use in other tree crops. Although greater fruit damage (compared to that with contact devices) was expected in the removal process, it was felt that the compromise for greater damage could probably be tolerated, particularly in Florida, where a high percentage of the citrus crop was processed.

Limb shakers. A limb shaker can generally be described as a device which accomplishes fruit removal by applying an oscillating unidirectional force to the main scaffold limbs of a tree. The force is generated by an unbalanced mass and transmitted to the limb by a boom and clamp. Two general principles are used to develop the shaking forces (Fig. 2). In one, an unbalanced mass is oscillated by a slider-crank mechanism, while in the other, eccentrically mounted masses are rotated about a shaft to develop the oscillating force. Generally, the slider-crank type of shaker can develop larger net shaking forces for a given total weight of the shaker. The slider-crank is better suited for long stroke, low frequency shaking while the eccentrically mounted mass is better suited for short stroke, high frequency shaking. The eccentrically mounted mass is a simpler mechanism.

The slider-crank shaker was first tested on citrus without abscission chemicals. A 10-cm stroke at 16 hz removed 50 to 60% of the oranges (4). Subsequent tests (10, 11, 18) with longer shaking strokes (15 to 17 cm) were found to achieve orange removal efficiencies of 80 to 90%.

One of the immediate concerns about using limb shakers (as well as other shakers) for citrus fruit removal was their effect on subsequent yields. A five-year study (12) showed that 15-cm stroke limb shaker effects on early and mid-season citrus yields (including grapefruit) were insignificant, while yields of late season ('Valencia') oranges were reduced up to 40%. Subsequent yield losses in 'Valencia' oranges were due to excessive numbers of young fruit being damaged or removed as a result of the high shaking energy required to remove the mature fruit.

Because abscission chemicals were not available to loosen mature 'Valencia' oranges satisfactorily, shaking strokes of 10, 15, and 20 cm at various frequencies were investigated as shaker adjustments to minimize young fruit removal at reasonably high mature fruit removal efficiencies (5). Subsequent yield reductions over the harvest season ranged between 8 and 28% at an average mature fruit removal efficiency of 81%. The optimum shaker adjustment was a 20-cm stroke at 2.5 hz.

Abscission chemicals affect the fruit removal performance of limb shakers. In early and midseason oranges, fruit loosening by abscission chemicals increased the fruit removal rate of a self-propelled manually positioned limb shaker (slider-crank type) from 2700 to 4000 kg/hr (7). Fruit removal efficiency was increased by only one or two percentage points in the 90% range. Remotely positioned limb shakers (rotating mass type) have generally demonstrated fruit removal rates of 3600 kg/hr without abscission chemicals and 5400 kg/hr with abscission chemicals (23).

Limb shakers have been mounted for positioning in two ways—manual and remote. Manually positioned shakers re-

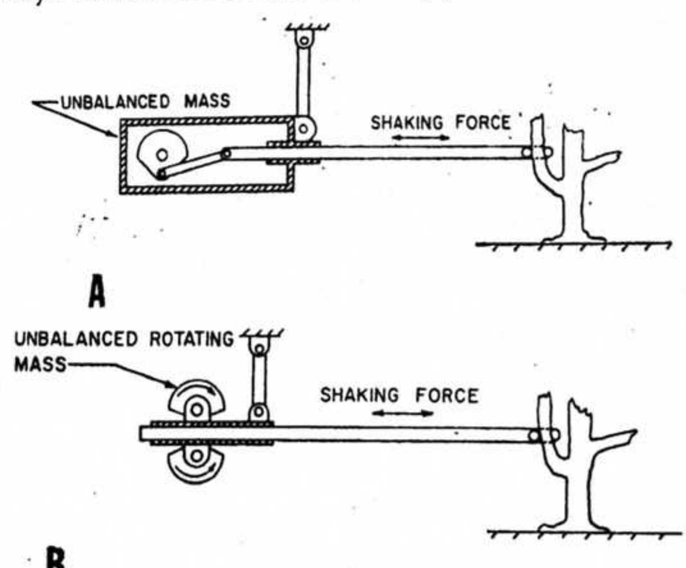

Fig. 2. Principles used in inertia-type limb shaker to develop shaking forces: (A) Slider crank; and (B) Rotating masses.

quire more energy input from the operator, but have somewhat greater positioning flexibility. Remotely positioned shakers, where limbs are visible and accessible, can achieve higher removal rates because positioning is less tiring to the operator. However, remote positioning requires a more highly skilled operator.

One of the greatest problems with citrus limb shakers is that their operational reliability is inherently low. Large oscillating forces delivered through long strokes at varying shaker boom angles result in considerable fatigue, breakage, and wear on the shaker components and supporting mechanisms. Another problem with limb shakers is one of adaptability. Limbs must be visible to the operator and accessible to the physical dimensions of the positioning mechanism. In most groves, these conditions usually require varying amounts of pruning.

Bark damage from limb shaker clamps can be a problem, especially in 'Valencia.' The amount of damage depends on the magnitude of the shaking force, the condition of the shaker clamp pads, angle of attachment on limb, condition of bark, and care exercised by the operator.

The limb shaker is a relatively low-cost fruit removal device with a fair degree of flexibility. It can be used to achieve mature fruit removals up to 90% with or without abscission chemicals, the latter condition usually resulting in lower removal rates and efficiencies, considerably more wear and tear on the shaker, and greater tree damage.

Foliage shakers. A foliage shaker is a fruit removal device which removes fruit by applying oscillating forces near the outer canopy (foliage) of the tree. The forces are transmitted to the tree and/or fruit by contact. Two types of foliage shakers have been tested (Fig. 3). The first is a foliage shaker which utilizes basically horizontal oscillating forces to contact both fruit and foliage and the second type clamps to the foliage and applies vertical oscillating forces to accomplish fruit removal.

The main advantage of the foliage shaker is that the shaking forces are applied near the principal fruit bearing zones of the tree, and thus the fruit removal process can be controlled with greater precision than with other shaker concepts. Precise control of the shaking process is especially important in removing the mature 'Valencia.'

The horizontal foliage shaker has been under development for over a decade. The shaking head that is inserted into the tree consists of horizontal rows of flexible tines approximately 1 m in length. Alternate rows of the tines are oscillated in opposite directions and accomplish fruit removal by contacting both fruit and limbs. Mature fruit removal efficiencies have been 70 to 85% under good operating conditions and have been very dependent on tree size and shape and fruit set. Fruit removal rates have been about 1800 to 2700 kg/hr with a 120 cm x 120 cm picking head. Private developers report reasonably good mature fruit removal in 'Valencia' with little apparent damage to the young fruit. However, published data are not available to substantiate this statement.

The main problems with the horizontal foliage shaker are tine breakage, inability to penetrate sufficient depth into the canopy in the wide variety of tree structures, and the complexity of the positioning mechanism for the picking head. Generally, this concept has shown promise in small trees with small limbs in that the problems associated with the depth and difficulty of canopy penetration, positioning, and tine breakage are greatly reduced.

Interest in vertical foliage shakers for citrus has developed, in the last decade, mainly because of the difficulty of selectively removing mature 'Valencia' by shaking. Technically, controlled vertical shaking reduces the shaking time for fruit removal (2). It was hoped that vertical shaking could be used to achieve high mature fruit removal efficiencies with insignificant damage to the young fruit.

Vertical foliage shakers evaluated in the field consisted of a vertical bank of metal tines driven by a shaker drive (21, 30). The metal tines clamped the smaller tree limbs at

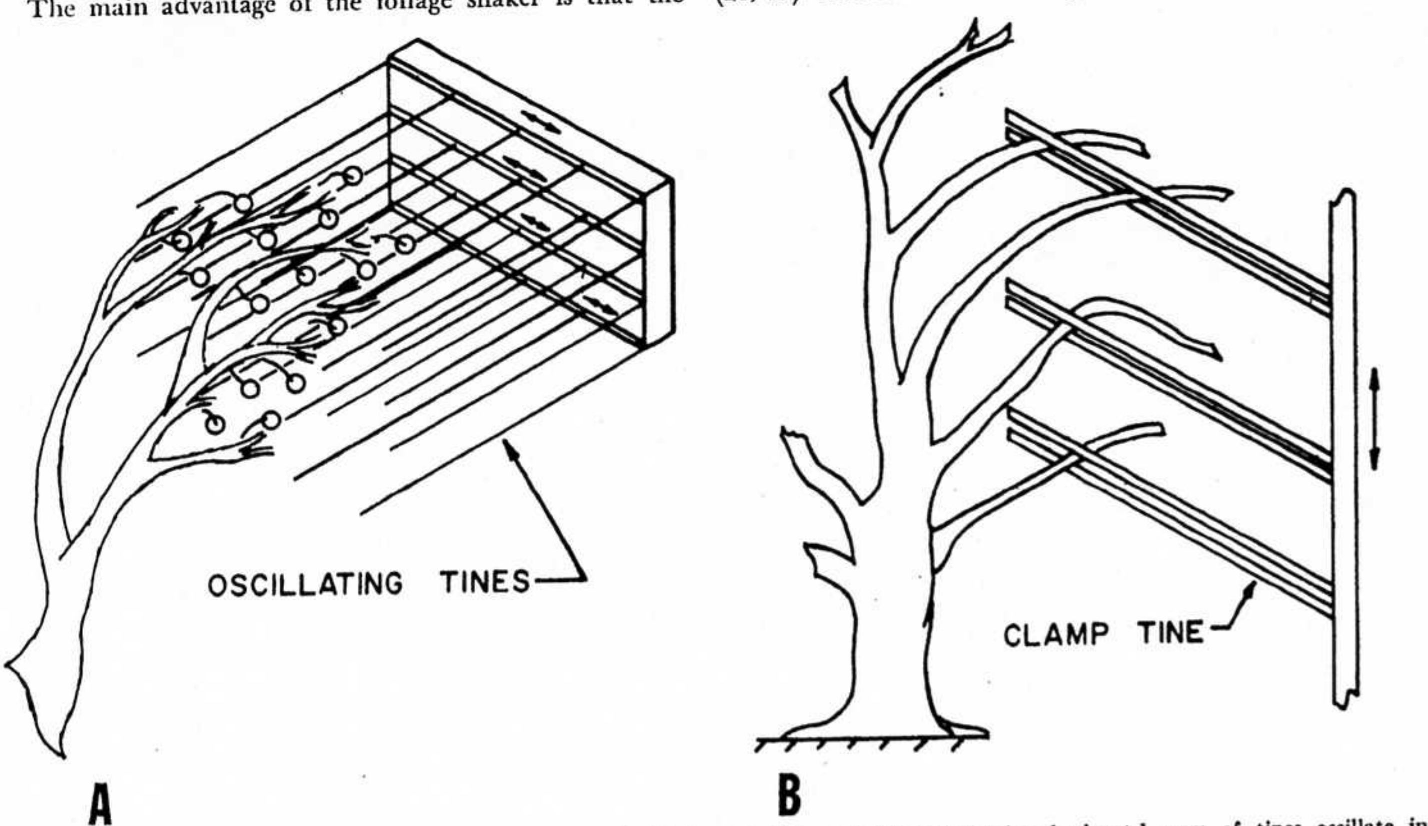

Fig. 3. Foliage shaker principles used to remove citrus: (A) Horizontal foliage shaker; alternating horizontal rows of tines oscillate in opposite directions; (B) Vertical foliage shaker; metal tines clamp outer tree canopy and shake through a vertical motion.

distances up to 60-90 cm inside the canopy to transmit the vertical shaking motion for fruit removal. Shaking strokes of at least 20 cm at frequencies of 2.5 to 3 hz were generally required for high mature fruit removal efficiencies in 'Valencia.' Mature fruit removal efficiencies from 80 to 90% have been demonstrated, but with varying effects on subsequent yields (13, 21, 30). Fruit removal rates were about 1800 kg/hr.

One of the main problems with the vertical foliage shaker was its inherently low operational reliability (30). Breakage was common in the metal tines when fairly rigid limbs were clamped, and in the shaker drive and prime mover because of the high vibrational forces generated by oscillating the mechanism of clamping tines, which weighed approximately 450 kg, through an 20 cm stroke at 3 hz. Another problem was that shaking the outside canopy of the tree was usually inadequate to remove inside fruit. Bark damage by the metal clamping tines was also of some concern.

Air shakers. An air shaker is a fruit removal device which removes fruit by pulsating air blasts into the tree. Shaking forces in the direction of air movement result from the air drag on all components (fruit, leaves, and wood) in the tree. Movement of the components in the opposite direction of air movement depends on the spring constant of the wood (Fig. 4). A detailed discussion of air shaker principles has been described elsewhere (32).

Work with the air shaker concept of fruit removal began in the early 1960's (16). Initial tests (24, 25) without abscission chemicals indicated that up to 70% of mature oranges and 84% of the mature grapefruit could be removed with subsequent yield reductions from 5 to 12%. In an effort to increase fruit removal efficiencies and rates, the air shaker was developed into a larger machine (31). It was demonstrated that fruit removals in the 90% range could be achieved toward the latter portion of the early and midseason harvest period when the bonding strengths of these fruits were naturally at their lowest levels. These results encouraged development work to continue on air shakers as a removal device that would potentially have high fruit removal efficiencies and rates if the fruit bonding strengths could be considerably reduced.

In the late 1960's, the first field tests were conducted with the air shaker operating in fruit which had been loosened by an abscission chemical (31). These tests indicated the importance of fruit loosening by abscission chemicals for the air shaker to achieve high fruit removal efficiencies and rates. With abscission chemicals, the fruit removal efficiencies and rates were 95% and 18000 kg/hr. Without abscission chemicals, the efficiencies and rates were only 55% and 3600 kg/hr. Other tests (26) indicated similar fruit removal efficiencies and rates for the air shaker with abscission chemicals.

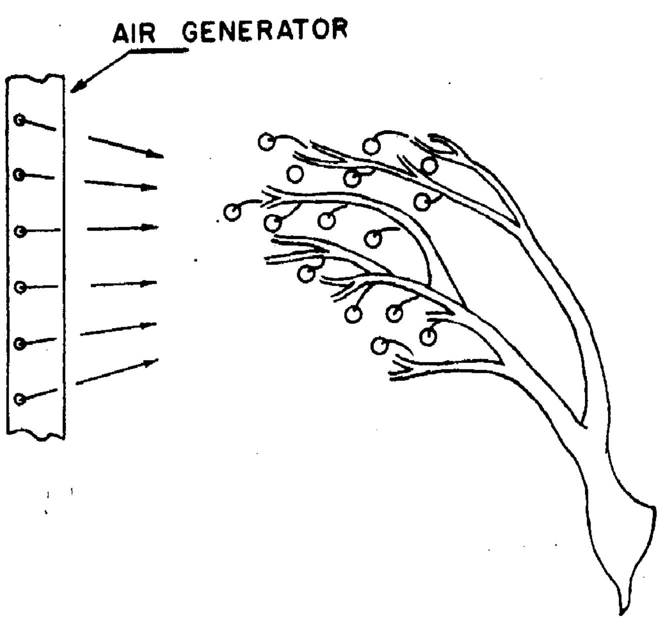

Fig. 4. Air shaker principle used to shake citrus limbs. Similar principle used by water shaker.

The effects of abscission chemicals and air shakers on subsequent yields have been measured under various conditions (26, 27). In early and midseason oranges, the effect has been minimal when care has been exercised not to apply excessive amounts of chemical. Fruit removal efficiencies with reasonably good fruit loosening have usually been 85 to 95%. In 'Valencia,' however, subsequent yields have been reduced up to 40%. The most recent tests (28) showed that with the best available abscission chemical, subsequent yields in 'Valencia' may be reduced from 10 to 15% at mature fruit removal efficiencies of about 90%.

With the advent of abscission chemicals, the power requirements and size of air shakers have not been reduced much because high removal efficiencies with the aid of existing abscission chemicals still often require considerable horsepower to deliver large airflow rates at fairly high velocities. High air flow rates have been required to (a) maximize the area of air pressure exposure on the tree so that leaf and twig damage will be minimized and (b) develop sufficient air shaking energy for satisfactory fruit removal efficiencies when mature fruit fails to loosen uniformly following the application of an abscission chemical.

Air shakers which have been used most extensively in field development accomplish fruit removal in two passes (one on each side) per tree row (26, 27, 28, 29). Up to 85 m^3/s of air at 65 m/s emanates from a tall, rectangular discharge approximately 7 m high and 70 cm wide. Fan power requirements are 250 to 300 kw. Removal efficiencies of 95% can be achieved at capacities of 18000 to 36000 kg of fruit/hr when the average fruit bonding strength is approximately 20 N. Fuel consumption has been 3 to 5 ml of diesel per kg of removed fruit.

One of the main advantages of the air shakers is that no mechanical attachment is made to the tree. This characteristic makes the air shaker readily adaptable for use on different shapes of trees. The height of tree suitable for an air shaker has been limited to about 6 m. Because no attachments are made, continuous, down-the-row operation is feasible and bark damage is not a concern. Fruit removal capacity is inversely related to fruit bonding strength since no fixed-time operations such as positioning are involved. Operational reliability is very high.

The main disadvantages of air shakers have been that initial investment and power consumption are high, the size and weight of the units are substantial, and high removal efficiencies and capacities are dependent to a great extent on reduced fruit bonding strengths resulting from abscission chemicals.

Water shakers. A water shaker uses generally the same principle to remove citrus as does an air shaker, except that water tends to remove the fruit by impinging on the fruit rather than by shaking the limbs (Fig. 4).

To date, development work on the water shaker has been by a private individual. Fruit removal was initially accomplished with a manually positioned water gun (cannon). The water stream from the gun swept the tree in an oscillatory movement. Force of the water impinging on the various components of the tree caused fruit removal. Initial tests without abscission chemicals required 25 to 30 l/s of water at 700 kg/cm^2 for satisfactory fruit removal. Impinging forces of the water were high and tree damage was sometimes severe, even for short exposure times. Positioning of the water shaker required considerable effort by the operator.

Recent field tests have involved an automated positioner for the water shaker (Fig. 4) used with abscission chemicals. The water delivery rate has been reduced to 15 l/s at a pressure of 400 kg/cm^2. With a fruit bonding strength of about 20 N, fruit removal efficiencies of 90% can be achieved at capacities of 18000 kg/hr. Approximately 4000 l of water are used to remove a tonne of fruit.

The main advantage of the water shaker concept is low initial investment when an adequate water supply exists. The fruit removal efficiencies and capacities can be high when the fruit bonding strength has been substantially reduced by using abscission chemicals. Published data are not available on the field performance to include effects on subsequent yields.

Disadvantages of the concept are that an adequate water supply is essential within the proximity of the grove, and the logistics of water delivery to the shaker can be a substantial problem.

Trunk shakers. A trunk shaker removes fruit by applying oscillating omnidirectional or unidirectional forces to the trunk or major scaffold limbs of a tree. The forces are usually developed by eccentrically mounted masses on a rotating shaft in a shaker head which includes the clamping pads for transmitting the shaking forces to the tree.

All of the development work on trunk shakers in Florida citrus has been done by commercial companies. Initial tests with trunk shakers in Florida were conducted with machines that were being used in other tree crops. The shaker head utilized two sets of masses, each rotating at slightly different speeds in opposite direction about a common shaft (Fig. 5). This shaker head produced an omnidirectional peak shaking force with the same magnitude at a given driving speed. The shaking frequency was variable up to a maximum of

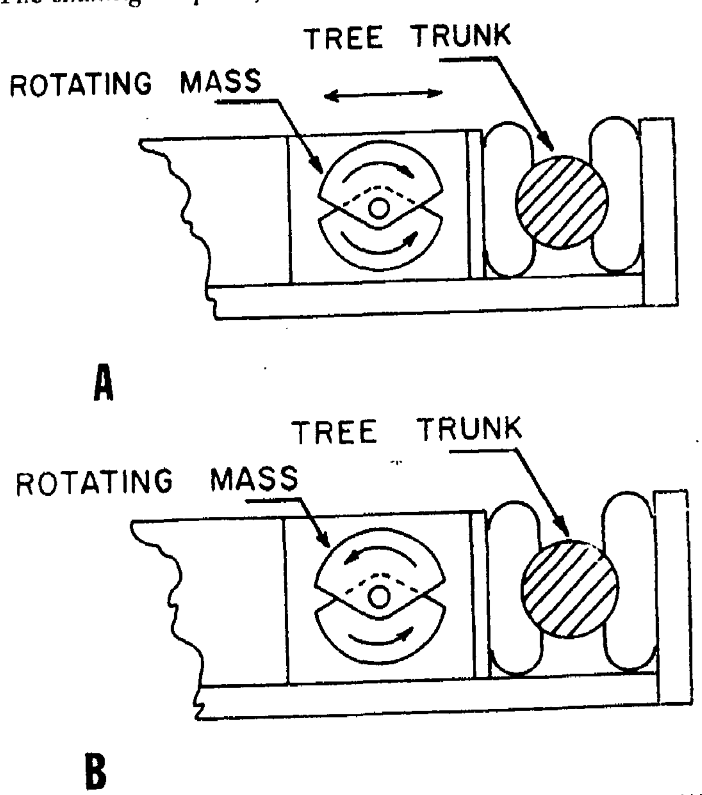

Fig. 5. Trunk shaker principles used to shake citrus trees: (A) Masses rotating in opposite direction; (B) Masses rotating in same direction.

15 hz. The maximum and minimum shaking force was developed approximately twice per shaft revolution. Fruit removal efficiencies of this shaker head appeared to be acceptable only where abscission chemicals had uniformly reduced bonding strengths to the 20 N range.

Another generation of trunk shaker was developed for Florida citrus (a) to reduce its dependence on abscission chemicals for high fruit removal efficiencies and (b) to increase its maneuverability for use in a greater variety of grove conditions. The shaker head was mounted on a three-wheel prime mover (27). The masses rotated about a common shaft as described above except that they rotated in the *same* direction at slightly different speeds (Fig. 5). At a given driving speed, this shaker head produced an omnidirectional shake which gradually changed in magnitude from minimum to maximum and vice-versa. This type of shaking pattern seemed to be slightly superior to the first one. However, the relative fruit removal effectiveness of the 2 patterns was not ascertained by valid field tests.

Fruit removal efficiencies with trunk shakers and abscission chemicals are comparable to those of the air shaker (27). Fruit removal capacities of the trunk shaker range from 9000 to 13000 kg/hr. Limited data in early or mid-season indicate that the trunk shaker with abscission chemicals has little effect on subsequent yields. However, in 'Valencia' subsequent yield reductions averaged 13% at mature fruit removal efficiencies of 86%.

Several problems have been encountered in shaking Florida citrus trees with the trunk shaker. The trunks of many bearing trees are short, making them inaccessible to trunk shakers. The root systems grow in sandy soils which can absorb a substantial amount of the trunk shaking energy. 'Valencia' tree bark is succulent during much of the harvest season and is very susceptible to damage by the high trunk shaker clamping forces. These problems, coupled with high fruit bonding strengths of citrus, even with abscission chemicals, inhibit high fruit removal efficiencies and have limited the acceptance of trunk shakers as fruit removal devices. Trunk shakers have been used to shake main scaffold limbs to increase fruit removal efficiencies, when the tree trunks are short and if the limbs are accessible to the clamping mechanism.

The advantages of the trunk shaker are that their operational reliability is inherently high and fruit removal capacity is high commensurate with cost.

Discussion and Summary

Mechanical removal of citrus has been researched for the past two decades. A considerable number of contact devices have been proposed and tested. Field acceptance of these devices thus far has been *very* limited.

Shakers of various types have been developed and have gained some acceptance in the field for removing early and midseason oranges for processing. Abscission chemicals are used in conjunction with most shaker equipment. The magnitude and rate of fruit loosening by abscission chemicals are not always predictable. As a result, scheduling of fruit removal and harvesting can be difficult and frustrating.

Based on performance, shakers can generally be placed in two categories—limb and foliage shakers in one; and trunk, air, and water shakers in the other. Limb and foliage shakers can generally achieve high fruit removal efficiencies with less dependence on fruit loosening by abscission chemicals and have inherently low operational reliabilities and fruit removal capacities. They have been used to shake fruit onto both catchframes and the ground. Trunk, air, and water shakers generally depend on fruit loosening by abscission chemicals to achieve high fruit removal efficiencies and capacities, and their operational reliabilities are inherently high. Because of their dependence on abscission chemicals and the resulting fruit drop, these shakers have been used mainly to remove fruit to the ground. The risk of detrimental tree damage from abscission chemicals has been generally less with foliage and limb shakers because lower rates of chemical are usually applied. Sufficient field data are not available to correlate defoliation from abscission chemicals with subsequent yield losses. However, until data are available, defoliation from abscission chemicals will probably be considered an undesirable side effect.

Since there are a number of problems with abscission chemicals, could shakers be made feasible in citrus without the use of chemicals? It does not appear likely except toward the end of the early and midseason, when fruit loosens naturally. Although limb shakers and foliage shakers have demonstrated 90% mature fruit removal in field studies, it is questionable whether these shakers can be designed with enough operational reliability and capacity at a reasonable cost to be satisfactory to the average user. Whether the tree can remain an economic producer and withstand the energy input required from the shaker, except perhaps by a highly skilled operator, is questionable. In the area of fresh fruit harvesting, removal of citrus with acceptable levels of damage will be extremely difficult because of the long shaking strokes required.

The 'Valencia' orange provides the greatest challenge to shaker removal without abscission chemicals. The best results indicate that when 85 to 90% of the mature fruit are removed, the subsequent crop is reduced 15 to 20%. These losses would be difficult to justify when considered along with the cost of the high shaking energy inputs which would be required. It appears that the only promising solution in 'Valencia' is an effective abscission chemical coupled with lower shaking energy inputs.

What is the future for mechanical removal devices? Acceptance of contact devices will probably be determined by the demand for mechanical removal of fresh fruit and by the development of more compatible fruit zones such as narrow tree walls with small, flexible limbs. However, in the area of mechanized fresh fruit removal, a high frequency, short stroke shake harvest system combined with a suitable abscission chemical may be a competitive approach.

Shakers will continue to be the removal device for processed fruit. Abscission chemicals will continue to be used as an aid for removing processed fruit. Limb shakers will continue to be attractive to the small grower whose bearing trees are large and have good limb visibility and accessibility. Trunk shakers will gain greater acceptance with further developments and as growers train their small trees to have smooth, high trunks and as they maintain the maximum canopy height to 5 m. If fuel costs do not become prohibitive, air shakers will be suitable for large organizations when further developments have been made in abscission chemicals.

Literature Cited

1. Alper, Y. and A. Foux. 1976. Strength properties of orange fruit-stem joints. *Trans. of the ASAE* 19(3):412-416.
2. ————, ————, and J. Linor. 1976. Detachment analysis for oranges in shaker harvesting. *Trans. of the ASAE* 19(6):1029-1033.
3. Chen, Pictiaw. 1973. Selective Harvesting of Valencia oranges with a flexible hook device. *Trans. of the ASAE* 16(4):645-647.
4. Coppock, G. E. 1961. Picking citrus fruit by mechanical means. *Proc. Fla. State Hort. Soc.* 74:247-251.
5. ————. 1971. Harvest Valencia oranges with a limb shaker. *Proc. Fla. State Hort. Soc.* 84:84-88.
6. ————. 1972. Properties of young and mature Valencia oranges related to selective harvest by mechanical means. *Trans. of the ASAE.* Vol. 15(2):235-238.
7. ————. 1974. Developments of a limb shaker for harvesting Florida citrus. *Trans. of the ASAE.* 17:262-265.
8. ————, S. L. Hedden and D. H. Lenker. 1969. Biophysical properties of citrus fruit related to mechanical harvesting. *Trans. of the ASAE.* 12:561-563.
9. ————, and P. J. Jutras. 1960. An investigation of the mobile picker's platform approach to partial mechanization of citrus fruit picking. *Proc. Fla. State Hort. Soc.* 73:258-263.
10. ————, and ————. 1962. Harvesting citrus fruit with an inertia shaker. *Proc. Fla. State Hort. Soc.* 75:297-301.
11. Hedden, S. L. and G. E. Coppock. 1965. A tree shaker harvest system for citrus. *Proc. Fla. State Hort. Soc.* 78:302-306.
12. ————, and ————. 1968. Effects of the tree shaker harvest system on subsequent citrus yields. *Proc. Fla. State Hort. Soc.* 81:48-52.
13. ————, and ————. 1971. Comparative harvest trials of foliage and limb shakers in Valencia oranges. *Proc. Fla. State Hort. Soc.* 84:88-92.
14. Hendershott, C. H. 1964. The effect of various chemicals on the induction of fruit abscission in Pineapple oranges. *Proc. Amer. Soc. Hort. Science.* 85:201-209.
15. Jutras, P. J. and G. E. Coppock. 1958. Mechanization of citrus fruit picking. *Proc. Fla. State Hort. Soc.* 71:201-204.
16. ————, and ————. 1963. Harvesting citrus fruit with an oscillating air blast. *Trans. of the ASAE.* 6:192-194.
17. Lenker, D. H. 1970. Development of an auger picking head for selectively harvesting fresh market oranges. *Trans. of the ASAE.* Vol. 13:500-504-507.
18. ————, and S. L. Hedden. 1968. Optimum shaking action for citrus fruit harvesting. *Trans. of the ASAE.* Vol. 11:347-349.
19. Schertz, C. E. and G. K. Brown. 1968. Basic considerations in mechanizing citrus harvest. *Trans. of the ASAE.* Vol. 11:343-346.
20. Seamount, D. T. 1971. Consistency of picker picking rates in oranges as a factor in influencing performance on man positioning devices. *Trans. of the ASAE.* Vol. 14:911-913.
21. Sumner, H. R. 1973. Selective harvesting of Valencia oranges with a vertical canopy shaker. *Trans. of the ASAE.* Vol. 16, 6:1024-1026.
22. ————, and S. L. Hedden. 1969. Performance of an auger picking head for fresh market oranges. *Proc. Fla. State Hort. Soc.* 82:89-93.
23. ————, and ————. 1975. Harvesting oranges with a full-powered positioning limb shaker. *Proc. Fla. State Hort. Soc.* 88:117-120.
24. Whitney, J. D. 1968. Citrus fruit removal with an air harvester concept. *Proc. Fla. State Hort. Soc.* 81:43-48.
25. ————. 1970. Performance of an oscillating, forced-air concept for removing citrus fruits. *Trans. of the ASAE.* 13:653-655, 660.
26. ————. 1972. Citrus harvest results with the air shaker concept. *Proc. Fla. State Hort. Soc.* 85:250-254.
27. ————. 1975. Orange yield and removal studies with air and trunk shakers using two abscission chemicals. *Proc. Fla. State Hort. Soc.* 88:120-124.
28. ————. 1976. Air shaker harvest trials in Valencia oranges with two rates of abscission chemical. *Proc. Fla. State Hort. Soc.* 89:41-43.
29. ————. 1977. Design and performance of an air shaker for citrus fruit removal. *Trans. of the ASAE.* 20(1):52-56.
30. ————, S. L. Hedden and H. R. Sumner. 1973. Harvesting Valencia oranges with a vertical foliage shaker. *Proc. Fla. State Hort. Soc.* 86:41-48.
31. ————, and J. M. Patterson. 1972. Development of a citrus removal device using oscillating forced air. *Trans of the ASAE.* 15, 5:849-855, 860.
32. ————, and D. R. Schultz. 1975. Analysis of air shaker principles to remove citrus fruit. *Trans. of the ASAE.* 18(6):1061-1064. 1069.
33. Wilson, W. C., R. E. Holm and R. K. Clark. 1977. Current availability of abscission chemicals as an aid to citrus fruit removal *Proc. Int. Soc. Citriculture.* Paper No. E-5.