Trunk Shakers for Citrus Harvesting—Part I: Measured Trunk Shaker and Tree Trunk Motion

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ABSTRACT

THE motions of shaker and trunk were measured in 'Hamlin' and 'Valencia' oranges for two harvest seasons on linear and mulidirectional shaking patterns. Trunk amplitudes ranged from 20 to 32 mm and shaker amplitudes ranged from 21 to 30 mm. The average difference between the simultaneous position of the tree trunk and shaker ranged from 6 to 11 mm. Trunk amplitude was negatively correlated to trunk circumference. Percent fruit removal was positively correlated to trunk amplitude for the treatments without abscission chemicals.

INTRODUCTION

Trunk shakers have been in use for many years to remove a variety of deciduous fruits and nuts in mechanical harvesting operations (Brown, 1983). They have seen limited use in attempts to mechanically harvest Florida citrus (Whitney, 1974; Whitney and Sumner, 1977). Hedden et al. (1984) and Whitney et al. (1983) have briefly discussed some of the problems with trunk shaker use in Florida citrus and the results of field experiments. Trunk shaking has good potential for mass removal of Florida citrus with the aid of abscission chemicals in future plantings where suitable trunks are established and smaller tree size is maintained.

One of the most serious problems with the trunk shaker in Florida citrus has been bark damage on the trunks of Valencia orange trees, especially when they are young. The Valencia is a late season cultivar and is growing vigorously at harvest time. Its bark is very succulent and susceptible to damage compared to the early and mid season cultivars. Whole areas of bark have torn off during clamping, shaking, or unclamping in the vicinity of shaker pad contact with the tree trunk. Some of the bark tearing during shaking is caused by excessive shearing forces on the bark. The shaker clamping pads develop shearing forces on the bark when the shaker force and shaker motion are not perpendicular to the pad surface.

The objectives of this study were: (a) to measure the motions of two trunk shakers and the tree trunks for four shaking patterns during the harvesting of Hamlin and Valencia cultivars, (b) to measure the corresponding fruit removal percentages, with and without abscission chemicals, and (c) to observe the bark damage associated with each shaking pattern. Part II* of this series discussed a 5-year field study on the effects of the shakers and abscission chemicals on orange tree growth, fruit yield, and removal.

MATERIALS AND METHODS

Hedden et al. (1983) have described two identical experiments designed to collect performance data on trunk shaking early season oranges (Hamlin) and late season oranges (Valencia) at a location in south Florida. The trees were 18 and 11 year-old, respectively, in 1984 when the measurements on trunk and shaker motion were initiated. Tree size was uniform and trunk height was adequate for grasping with the shaker clamps. Each experiment was a randomized, split-plot design which included 60 trees and six replications. One of the two 5-tree main plots in each replication was randomly assigned to be sprayed with abscission chemicals before harvest while the other main plot was not sprayed. Within each main plot, 4 trunk shaker treatments and 1 handpick check treatment were randomly assigned to each tree or subplot. The trunk shaker and check treatments were as follows:

1. Linear shaker with 60.4 kg of unbalanced mass rotating at 6 r/s with 140 mm eccentricity and 458.2 kg of total mass excluding the unbalanced mass.
2. Linear shaker with 90.9 kg of unbalanced mass rotating at 5 r/s with 140 mm eccentricity and 272 kg total mass excluding the unbalanced mass.
3. Multidirectional shaker (FMC† Model 729 shaker head) with two 30.9 kg unbalanced masses rotating in opposite directions at 11 and 13 r/s with 114 mm eccentricity and a 450 kg total mass, excluding the unbalanced masses.
4. Same shaker as 3 except both eccentric masses rotated in the same direction.

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*Hedden, S. L., D. B. Churchill, and J. D. Whitney. Trunk shakers for citrus harvesting—Part II: Tree growth, fruit yield and removal. Applied Engineering in Agriculture (this issue).

†Trade names are included for the benefit of the reader and do not imply endorsement by the University of Florida or the USDA.

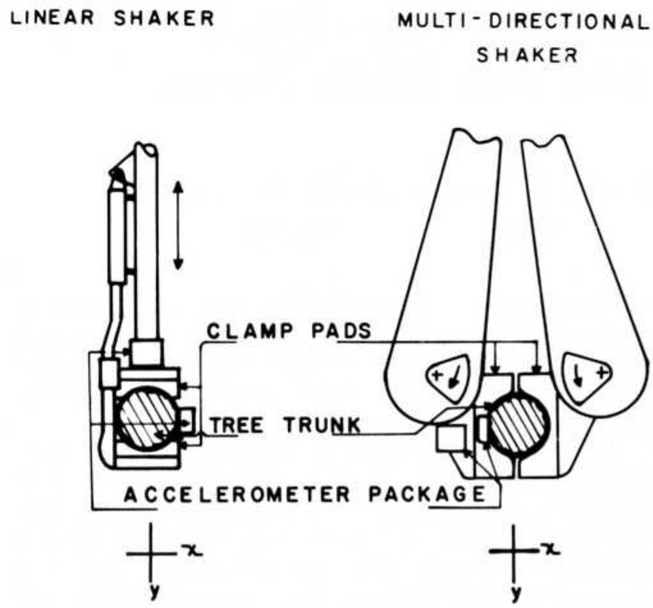


Fig. 1—Schematics of trunk shakers showing location of tree trunk, clamp pads, accelerometer packages, and X and Y axes. Treatments 1 and 2 were conducted with linear shaker on the left; Treatments 3 and 4 were conducted with multidirectional shaker on the right.

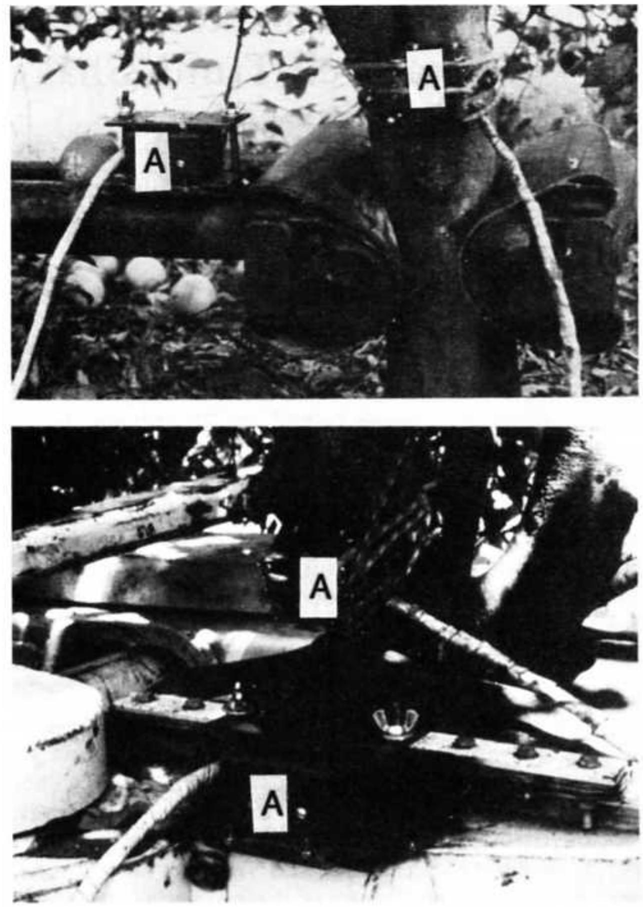


Fig. 2—Photos of the trunk shakers clamped to the citrus trunk; linear shaker, top; multidirectional shaker, bottom. Locations of accelerometer packages on trunks and shakers are designated with "A".

5. Handpicked checks. This treatment will be discussed with the yield data in Part II.

Treatments 1 and 2, conducted with a linear shaker (Figs. 1 and 2), had theoretical shaking amplitudes of 18 mm and 47 mm, respectively, under no-load conditions. Each of the two clamp pads was a 40 durometer rubber cylinder, 280 mm long, with outside and inside diameters of 100 and 25 mm, respectively. During shaking, the two slip-belts between each of the pads and the tree trunk were not lubricated to minimize shear forces on the bark and the clamping force was set at 30 kN.

Treatments 3 and 4, conducted with a commercially available multidirectional shaker (Figs. 1 and 2) had a theoretical shaking amplitude of 16 mm under no-load conditions. Each of the two clamp pads was a 40 durometer rubber cylinder, 508 mm long, with outside and inside diameters of 229 and 89 mm, respectively. The inside diameter of each pad was filled with conventional flat belting wrapped around a 25 mm diameter metal pipe. During shaking, the two slip-belts between each of the pads and the tree trunk were not lubricated to minimize shear forces on the bark and the clamping force was set at 50 kN.

Four to 5 days prior to harvest, abscission chemicals were applied in an amount dependent upon fruit and tree condition and cultivar. In Hamlin oranges, the normal abscission chemical mixture was 75 ppm RELEASE (5-chloro-3-methyl-4-nitro-pyrazole), 1.5 ppm ACTI-AID (cycloheximide), and 0.1% ORTHO X-77 surfactant. The mixture was applied at 15 L/tree. The abscission chemical mixture in Valencia oranges was 250 ppm RELEASE and 0.1% ORTHO X-77 surfactant, and applied at 15 L/tree.

Just prior to fruit removal with the shaker, trunk circumference at 200 mm above ground was measured. The parallel shaker pads were clamped to the tree trunk, and an accelerometer package was fastened onto the shaker near the pads and another accelerometer package was fastened to the tree trunk (Fig. 2). Each accelerometer package contained two accelerometers (X and Y) mounted in the same plane perpendicular to each other. The plane of the accelerometers was oriented parallel with the ground and the X and Y on the trunk coincided with the X and Y on the shaker. The Y axis was parallel to the direction of linear shaking and perpendicular to the shaker clamp pads for Treatments 1 and 2; in contrast, the Y axis for Treatments 3 and 4 was parallel to the shaker clamp pads (Fig. 1). The heights above ground of the shaker pads and the accelerometer package on the trunk were measured.

The shaker treatment trees were then shaken for 7 s, and the fruit removed and the fruit left were weighed for each tree. During shaking, analog voltage signals from the PCB Model 308B accelerometers in the accelerometer packages were conditioned with PCB Model 480A power packs and recorded on a Teac Model R61 tape recorder in the field. Shaker and tree trunk amplitudes were calculated as described by Block (1986) by sampling each of the four tape recorder channels every 4 ms with a Cyborg Model 91A a/d converter, filtering the digital data with a second order band pass filter, and numerically integrating with respect to time with an Apple IIe computer. A 1.0 s period of digital data was used in calculating the X and Y amplitudes of the trunks and shaker versus time.

TABLE 1. MEAN VALUES OF PERCENTAGE FRUIT REMOVAL AND PARAMETERS RELATED TO SHAKER AND TRUNK MOTION MEASUREMENTS IN 'HAMLIN' AND 'VALENCIA' ORANGES FOR 1983-84 AND 1984-85 SEASONS*

Treatment		Trunk circ., mm	Shaker clamp ht, mm	Shaker ampl., mm	Trunk ampl., mm	% fruit removal	ΔX, mm	ΔY, mm	Δ Resultant, mm
					Hamlin				
1. Linear, 60 kg unbal. mass	NC	691 a	330 ab	24.7 cd	17.7 c	56.2 d	3.9 bcd	8.8 a	10.2 a
	C	641 b	349 a	22.6 de	22.6 ab	88.4 a	4.4 b	6.5 b	8.6 b
2. Linear, 90 kg unbal. mass	NC	687 a	300 ab	29.0 ab	21.8 ab	64.9 c	6.0 a	8.2 a	11.2 a
	C	677 ab	351 a	30.0 a	23.1 a	88.9 a	5.7 a	8.5 a	11.1 a
3. Multidirectional opposite rotation	NC	702 a	282 b	21.2 e	19.6 bc	60.4 cd	4.4 cd	5.0 cd	7.4 bc
	C	672 ab	332 ab	20.5 e	21.0 ab	89.4 a	3.4 bcd	4.4 d	6.1 c
4. Multidirectional same rotation	NC	692 a	305 ab	26.8 bc	21.8 ab	71.9 b	3.1 cd	6.1 bc	7.4 bc
	C	646 b	282 b	26.3 c	22.2 ab	89.7 a	3.0 d	6.1 bc	7.2 bc
					Valencia				
1. Linear, 60 kg unbal. mass	NC	577 a	302 ab	25.6 c	23.0 e	49.8 c	4.9 a	5.0 ab	7.7 ab
	C	509 c	349 a	26.5 bc	27.2 cd	89.0 a	5.4 a	5.0 ab	8.2 ab
2. Linear, 90 kg unbal. mass	NC	551 ab	328 ab	29.3 ab	32.0 a	71.1 b	5.4 a	5.7 a	8.7 ab
	C	539 bc	330 ab	30.2 a	31.3 ab	90.6 a	4.8 a	5.6 a	8.2 ab
3. Multidirectional opposite rotation	NC	555 ab	288 b	25.6 c	26.9 cde	62.8 b	3.5 bc	4.2 b	6.1 cd
	C	566 ab	302 ab	25.1 c	24.9 de	89.3 a	3.0 c	4.1 b	5.7 d
4. Multidirectional same rotation	NC	556 ab	294 ab	28.9 ab	29.6 abc	71.6 b	4.6 ab	4.8 ab	7.2 bc
	C	549 ab	316 ab	29.0 ab	28.3 abcd	89.1 a	4.3 ab	5.0 ab	7.0 bc

*Percentage fruit removals are average with and without abscission chemicals. Trunk circumferences were measured at 200 mm above ground. Means in each column within 'Hamlin' or 'Valencia' followed by same letters are not significantly different at 0.05 by Duncan's multiple range test. NC = non-chemical; C = chemical.

The X and Y amplitudes were printed out and plotted on a printer. To get the difference in the trunk and shaker position at any given time, the simultaneous X's and Y's were subtracted, and were referred to as ΔX and ΔY. A Δ resultant was also calculated. An average value was calculated over the 1.0 s period (250 values) for the ΔX, ΔY, and Δ resultant. High speed movies (1200 frames/s) were utilized to help explain the irregularly shaped pattern of the multidirectional shaker (Treatments 3 and 4).

Data were collected in 1984 and 1985 and statistically analyzed. Significant differences refer to the 0.05 level of significance.

RESULTS

Table 1 lists the means of eight of the parameters measured in this study.

Trunk Circumference

The first column of Table 1 shows the trunk circumferences at 200 mm above ground. The Hamlin trunk circumferences averaged 676 mm. Trunks shaken by Treatments 1 through 4 (NC) were significantly larger than those shaken by Treatment 4 (C).

Valencia trunk circumferences averaged 550 mm. Trunks shaken by Treatment 1 (NC) were significantly larger than those shaken by Treatments 1 and 2 (C).

Shaker Clamp Height

Generally speaking, the shaker clamp pads were positioned as high as possible on the trunk and immediately below the lower branches. Because the clamp pads on the shaker in Treatments 3 and 4 were larger than those in Treatments 1 and 2, clamp heights were generally greater for Treatments 1 and 2. In Hamlin, clamp height averaged 316 mm. The clamp height of Treatments 1 and 2 (C) were significantly greater than Treatments 3 (NC) and 4 (C).

Clamp height averaged 314 mm in Valencia. The clamp height of Treatment 3 (NC) was significantly less than Treatment 1 (C).

Trunk accelerometer heights are not shown in Table 1. On the average, trunk accelerometer heights were 250 mm greater than shaker clamp heights for Treatments 1 and 2, and 350 mm greater than shaker clamp heights for Treatments 3 and 4.

Shaker Amplitudes

Shaker amplitudes in Hamlin averaged 25.1 mm. The amplitudes of Treatment 2 were significantly greater than those of Treatments 1 and 3. Shaker amplitudes in Valencia averaged 27.5 mm with treatment differences similar to Hamlin.

Trunk Amplitudes

Trunk amplitudes in Hamlin averaged 21.2 mm with no significant treatment differences. For Valencia, trunk amplitudes averaged 27.9 mm, with Treatment 2 having significantly greater amplitudes than Treatments 1 and 3.

Percentage Fruit Removal

Percentage fruit removal in Hamlin averaged 76.2%.

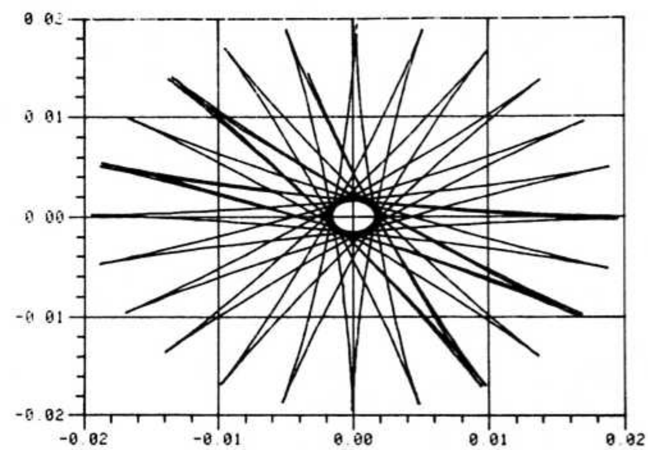


Fig. 3—Theoretical position pattern of shaker in Treatment 3 rigidly attached to trunk with spring constant of 10^6 N/m. One unbalanced mass is rotating CW at 13 r/s, the other CCW at 11 r/s. The scales on the 2 position axes are in m.

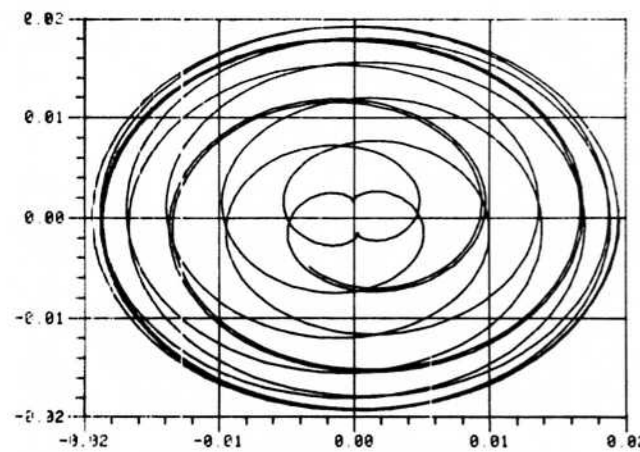


Fig. 4—Theoretical position pattern of shaker in Treatment 4 rigidly attached to trunk with spring constant of 10^6 N/m. Both unbalanced masses are rotating CCW, one 3 r/s, the other at 11 r/s. The scales on the 2 position axes are in m.

Without abscission chemicals (NC), there were differences with Treatment 4 (NC) being significantly higher at 71.9% and Treatment 1 (NC) being the lowest at 56.2%. With abscission chemicals (C), however, there were no significant differences in removal.

In Valencia, percentage fruit removal averaged 76.6%. Treatment 1 (NC) gave significantly lower removals (49.8%) than did the other treatments without abscission chemicals. With abscission chemicals, as in Hamlin, there were no significant differences in removal.

Shaker and Trunk Motion

Before discussing the Δ values in the last three columns of Table 1, consider the theoretical, and measured motions of the shakers and trunks. Theoretical motion of the shaker and trunk (Treatments 1 and 2)

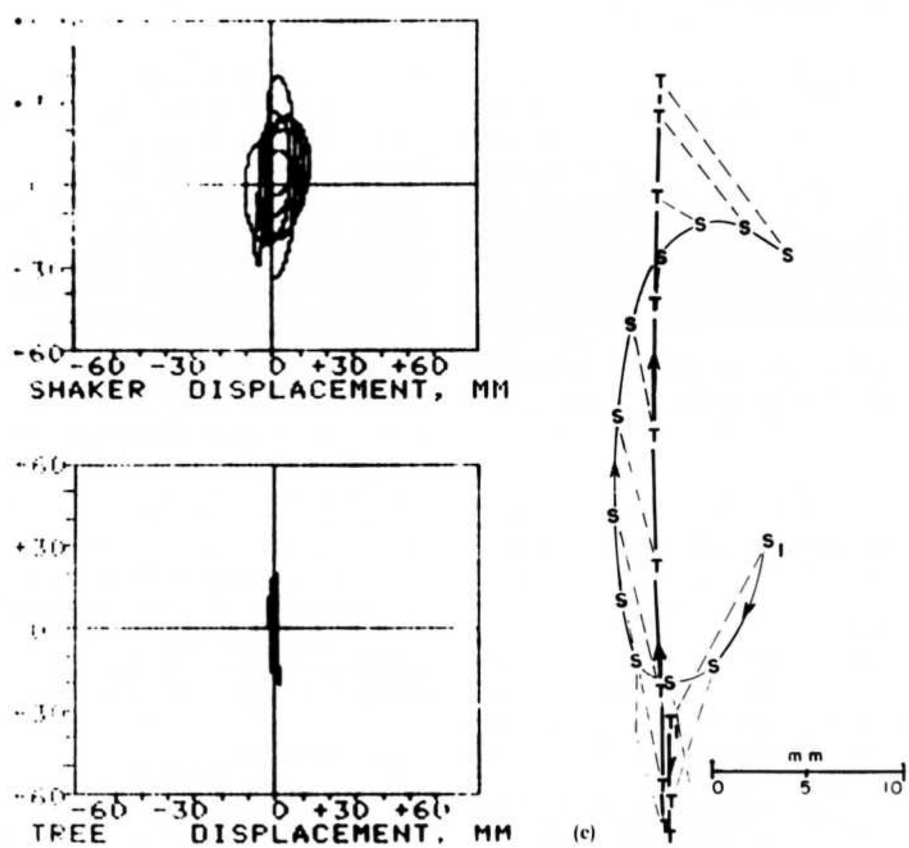
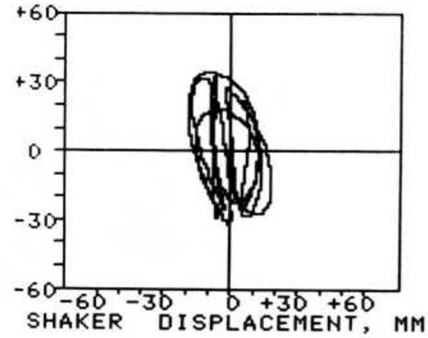
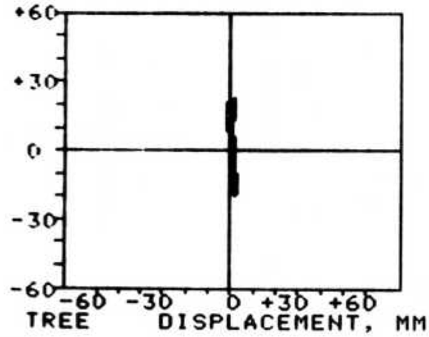


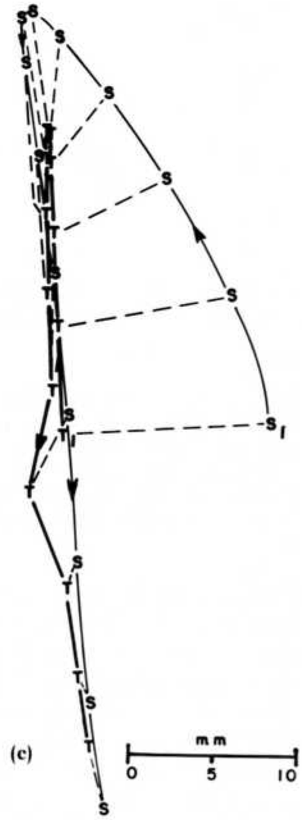
Fig. 5—Position patterns of Treatment 1 on a 'Hamlin' orange tree. Part (a) is the shaker and Part (b) is the trunk for a 1 s time period. Part (c) is the simultaneous positions of the shaker (S) and trunk (T) for approximately 1 cycle. Graph X and Y axes are horizontal and vertical, corresponding to parallel and perpendicular to the clamp pads, respectively. Trunk circumference, 654 mm; clamp height, 368 mm; trunk accelerometer height, 635 mm.



(a)



(b)



(c)

Fig. 6—Position patterns of Treatment 2 on a 'Hamlin' orange tree. Part (a) is the shaker and Part (b) is the trunk for a 1 s time period. Part (c) is the simultaneous positions of the shaker (S) and trunk (T) for approximately 1 cycle. Graph X and Y axes are horizontal and vertical, corresponding to parallel and perpendicular to the clamp pads, respectively. Trunk circumference, 680 mm; clamp height, 406 mm; trunk accelerometer height, 508 mm.

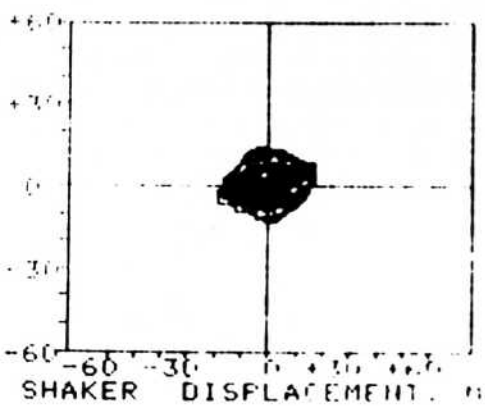
would be linear (parallel to the Y axis in Fig. 1).

Theoretical shaker and trunk position patterns of Treatments 3 and 4 should be multidirectional as shown in Figs. 3 and 4. For each treatment, the shaker was assumed to be rigidly attached to a trunk with spring constant of 10^6 N/m and no damping. The faster rotating mass was rotating at 13 r/s while the other mass was rotating at 11 r/s.

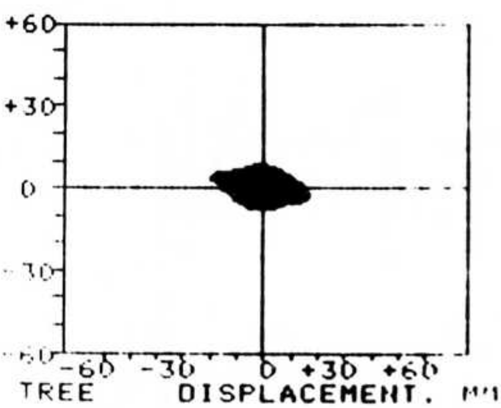
The position patterns as measured in the field are shown in Figs. 5 to 8 (Hamlin) and 9 to 12 (Valencia). Parts (a) and (b) of each figure are the composite shaker and tree trunk patterns, respectively, for 1.0 s. Part (c) shows approximately one cycle of the shaker (S) and trunk (T) motion. The simultaneous location of the shaker (S) and trunk (T) are connected with a dotted line.

For Treatments 1 and 2 (Figs. 5, 6, 9, and 10), trunk motion was very linear along the Y axis. Measured shaker motion along the X axis was considerably more than that of the trunk, although that may have been due to high noise to signal ratios recorded on the shaker in the X direction. In the Y direction, the trunk position lagged behind the shaker position in most instances.

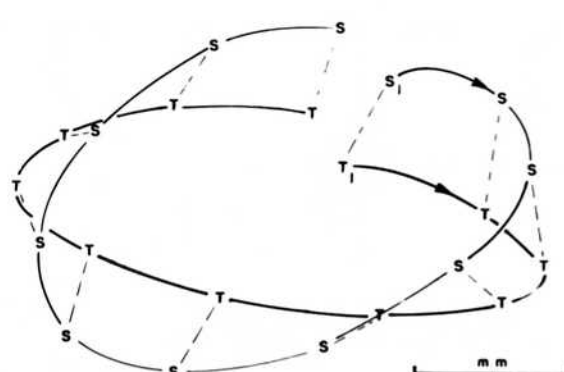
The average △X, △Y, and △ resultant are shown in Table 1. For Treatments 1 and 2, △X was nearly as large as △Y in some cases.



(a)

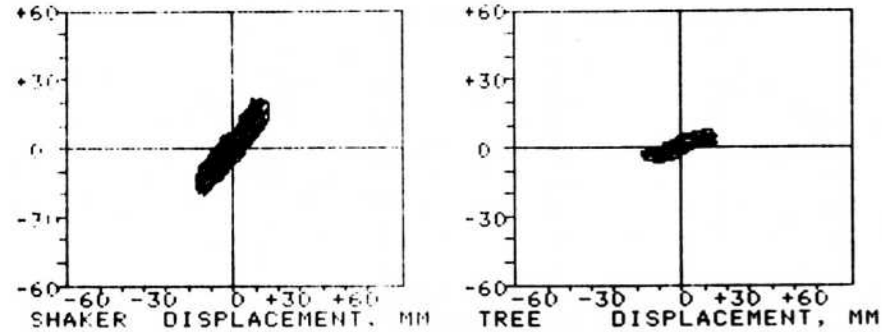


(b)

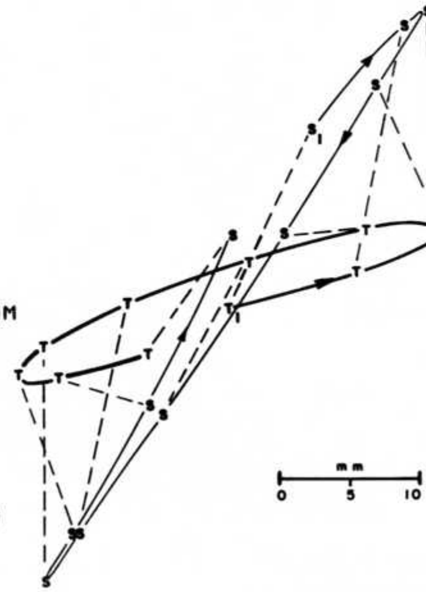


(c)

Fig. 7—Position patterns of Treatment 3 on a 'Hamlin' orange tree. Part (a) is the shaker and Part (b) is the trunk for a 1 s time period. Part (c) is the simultaneous positions of the shaker (S) and trunk (T) for approximately 1 cycle. Graph X and Y axes are horizontal and vertical, corresponding to parallel and perpendicular to the clamp pads, respectively. Trunk circumference, 699 mm; clamp height, 305 mm; trunk accelerometer height, 597 mm.



(a) (b)



(c)

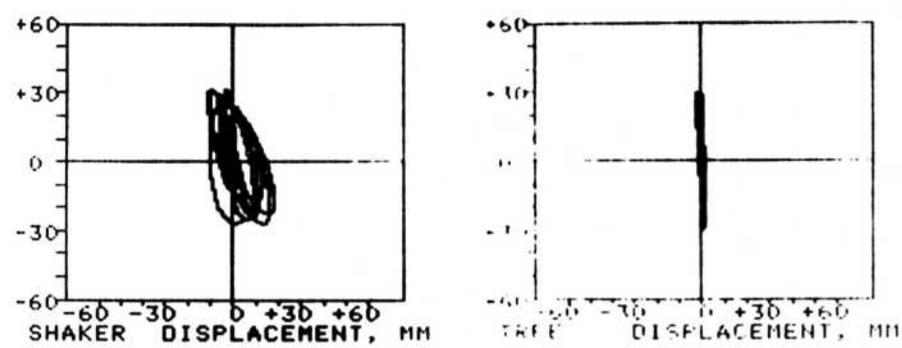
Fig. 8—Position patterns of Treatment 4 on a 'Hamlin' orange tree. Part (a) is the shaker and Part (b) is the trunk for a 1 s time period. Part (c) is the simultaneous positions of the shaker (S) and trunk (T) for approximately 1 cycle. Graph X and Y axes are horizontal and vertical, corresponding to parallel and perpendicular to the clamp pads, respectively. Trunk circumference, 724 mm; clamp height, 305 mm; trunk accelerometer height, 546 mm.

Figs. 7 and 11 show the measured position patterns for Treatment 3. The measured shaker position patterns (Figs. 7(a) and 11(a) were considerably different than the theoretical pattern Fig. 3. The measured pattern was not symmetrial and the successive amplitudes rotated alternately in the CW and CCW directions with time, whereas the theoretical pattern developed equal successive amplitudes which rotated continuously in the same direction. Relative to the shaker, measured trunk motion was considerably less in the Y direction than the X direction (Figs. 7(b) and 11(b). The result was greater values of ΔY than ΔX (Table 1). The shaker position led the trunk position.

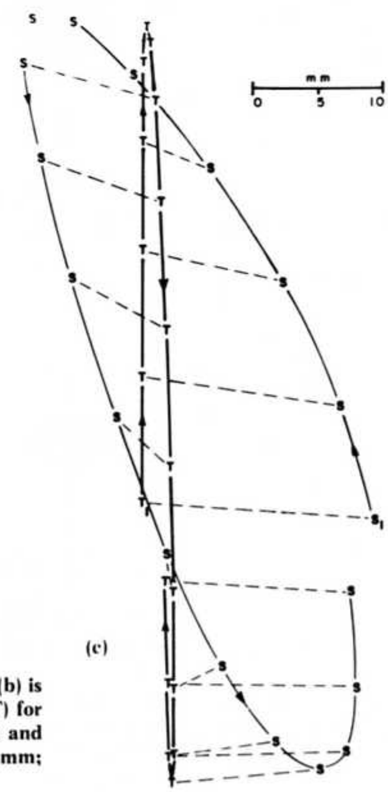
The measured shaker position patterns of Treatment 4 (Figs. 8(a) and 12(a) were diagonally oriented elliptical shapes and dissimilar to the theoretical patterns in Fig. 4. The direction of position rotation in the measured pattern changed from CW to CCW and vice versa with time within the elipse. The theoretical pattern was symmetrical in all 4 quadrants and rotated in the same direction continuously. As with Treatment 3, measured trunk motion relative to the shaker was considerably less in the Y direction than the X direction (Figs. 8(b) and 12(b). Again, greater values resulted for ΔY (parallel to clamp pads) than for ΔX (perpendicular to clamp pads). Trunk positions lagged shaker positions. Noise to signal ratios for both X and Y accelerometers were low for Treatments 3 and 4.

Parameter Correlations

Table 2 shows the Pearson correlation coefficients between the eight parameters in Table 1 over all shaker treatments. Correlation coefficients were compared separately with abscission chemicals (C) and without abscission chemicals (NC). Coefficient values numerically less than 0.20 were considered insignificant.

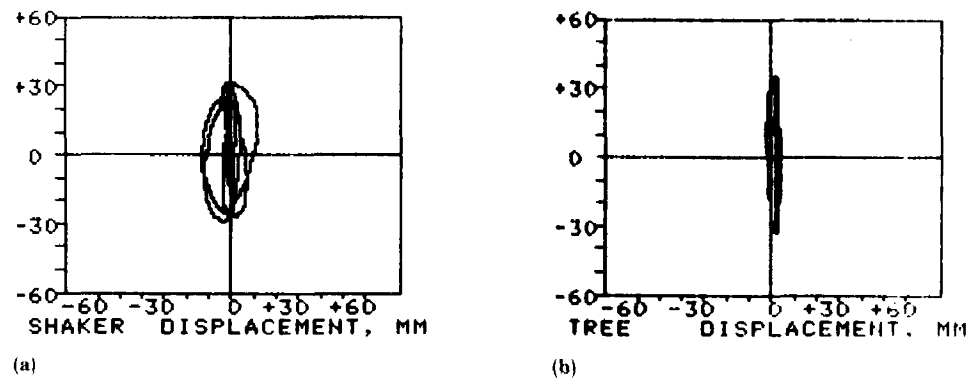


(a) (b)



(c)

Fig. 9—Position patterns of Treatment 1 on a 'Valencia' orange tree. Part (a) is the shaker and Part (b) is the trunk for a 1 s time period. Part (c) is the simultaneous positions of the shaker (S) and trunk (T) for approximately 1 cycle. Graph X and Y axes are horizontal and vertical, corresponding to parallel and perpendicular to the clamp pads, respectively. Trunk circumference, 432 mm; clamp height, 330 mm; trunk accelerometer height, 559 mm.



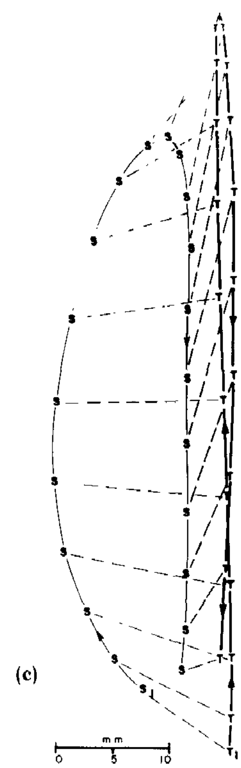


Fig. 10—Position patterns of Treatment 2 on a 'Valencia' orange tree. Part (a) is the shaker and Part (b) is the trunk for a 1 s time period. Part (c) is the simultaneous positions of the shaker (S) and trunk (T) for approximately 1 cycle. Graph X and Y axes are horizontal and vertical, corresponding to parallel and perpendicular to the clamp pads, respectively. Trunk circumference, 451 mm; clamp height, 406 mm; trunk accelerometer height, 635 mm.

Trunk circumference was negatively correlated with shaker amplitude (NC) in Valencia, trunk amplitude (NC and C) in both Hamlin and Valencia, percent fruit removal (NC) in both Hamlin and Valencia, ΔX (NC) in Hamlin and ΔY (C) in Valencia.

Shaker clamp height was positively correlated with shaker amplitude (NC) in Valencia, and Hamlin, trunk amplitude (NC) in Valencia and (C) in Hamlin, percent fruit removal (NC and C) in Valencia and (C) in Hamlin, ΔX (NC) in Valencia, ΔY (C) in Valencia, and (NC) in Hamlin.

Shaker amplitude was positively correlated with trunk amplitude (NC and C) in Hamlin and Valencia, percent fruit removal (NC) in Hamlin and (NC and C) in Valencia, ΔY (NC and C) and Δ resultant in Hamlin, ΔY (C) in Valencia, and Δ resultant (C) in Valencia.

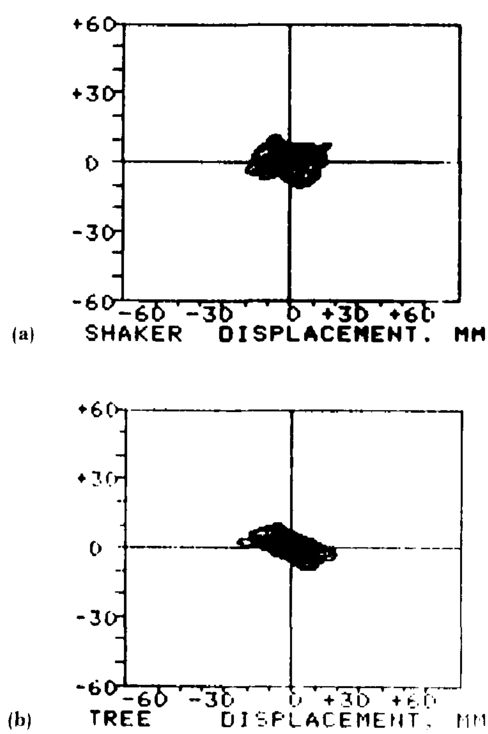
Trunk amplitude was positively correlated with percent fruit removal (NC) in Hamlin and Valencia, ΔX (NC and C) in Hamlin, ΔX (C) in Valencia, and Δ resultant (NC and C) in Valencia.

Percent fruit removal was negatively correlated with ΔX (C) in Hamlin and Valencia, ΔY (C) in Hamlin, and Δ resultant (C) in Hamlin.

For the most part, ΔX, ΔY, and Δ resultant were positively correlated.

DISCUSSION

Percent fruit removal for the treatments without abscission chemicals had high positive correlations with shaker and trunk amplitude, but high negative correlations with trunk circumference. Treatments with abscission chemicals did not reveal such high



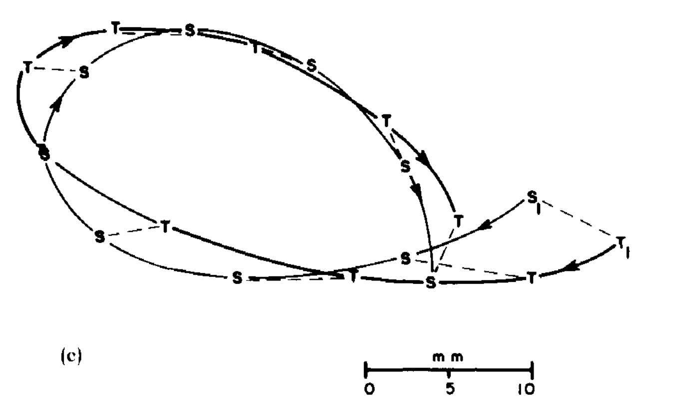


Fig. 11—Position patterns of Treatment 3 on a 'Valencia' orange tree. Part (a) is the shaker and Part (b) is the trunk for a 1 s time period. Part (c) is the simultaneous positions of the shaker (S) and trunk (T) for approximately 1 cycle. Graph X and Y axes are horizontal and vertical, corresponding to parallel and perpendicular to the clamp pads, respectively. Trunk circumference, 489 mm; clamp height, 279 mm; trunk accelerometer height, 508 mm.