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Effects of Three Limb Shaker Mechanisms on Removal of Oranges

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ABSTRACT

THE motion of three types of limb shakers for orange harvesting was determined while 18 selected limbs were shaken. Continuous measurement of acceleration and displacement showed that the rotating-mass shakers had a lower peak-to-peak acceleration than the slider-crank shaker, but produced a smoother shaking motion. Limb acceleration increased with shaking frequency for all treatments; however, limb displacement was not highly influenced by frequency.

Field comparison of the shakers in harvesting 'Valencia' oranges was evaluated for fruit removal with and without the aid of abscission chemicals. Removal of mature fruit averaged 90 to 93 percent for all shakers, and removal was higher with the use of abscission chemicals than without. Subsequent yields in Valencia oranges were reduced by all shaker treatments, indicating that an excessive amount of green fruit was removed.

Chemically sprayed trees required fewer attachments and less shaking time per limb than the non-sprayed trees.

INTRODUCTION

Research to mechanize the harvesting of Florida's 7.1 million metric tons (t) of oranges (Fla. Agr. Statis. 1975) has been underway for several years. Most of the crop is presently hand harvested, and the labor requirements are seasonal. Mechanical systems have been developed that reduce dependence on seasonal labor for harvesting; however, the success of these systems has been limited due, in part, to their inability to harvest Valencia oranges without causing reduced fruit yields in subsequent years (Coppock, 1972; Whitney et al., 1973; and Coppock and Tucker, 1974). Approximately 45 percent of Florida's processing orange crop consists of Valencias.

Shakers for the removal of early and midseason oranges from the trees have shown considerable merit when they are assisted by an abscission chemical for fruit loosening. Successful removal of late season or Valencia oranges by shaking requires a shaking motion that will selectively remove the mature fruit without removing an excessive number of the young fruit that represent next year's crop. Attempts to produce selective shaking motions in Valencia with air, foliage, trunk, and limb shakers have been only partially successful (Whitney et al., 1973; Coppock, 1971; Whitney, 1975). Coppock (1972) reported that the use of slider-crank limb shaker to harvest Valencias when an abscission chemical had not been applied to loosen the fruit resulted in a 5 to 40 percent yield reduction depending on the date of harvest.

The development of limb shakers for harvesting oranges began in 1961 (Coppock and Jutras, 1962). For several years limb shakers have been used in Florida for the harvesting of early and midseason oranges. The slider-crank and rotating-mass shakers (Coppock and Jutras, 1962 and Sumner, 1976) are two types of inertial-mass limb shakers that have been used for harvesting citrus. The slider-crank was used in the initial investigation of limb shakers for citrus harvesting. It has been the most widely used of the two shakers since it generally produces a larger displacement at low shaking frequencies than a rotating-mass shaker. The rotating-mass shaker is simply designed, less complicated to build, and better suited for use in a full-powered positioning system. Sumner (1976) obtained satisfactory removal of oranges with a large rotating-mass shaker. Harvesting rate and removal were increased when abscission chemicals were used for fruit loosening. Observations of a small rotating-mass shaker indicated that removal efficiency was lower than that of the slider-crank shaker; however, it is expected that when fruit is loosened with abscission chemicals, its performance would be acceptable. The objective of this study was to determine the shaking motion and removal characteristics of three limb shakers designed for the harvesting of oranges with and without the use of abscission chemicals for fruit loosening.

EQUIPMENT AND METHODS

The three limb shakers used in this study were the slider-crank shaker, a 109-kg rotating-mass shaker and 73-kg rotating mass shaker, hereafter referred to as SC, 109-kg RM and 73-kg RM shakers, respectively. Fig. 1 is a schematic drawing of the inertial mass of the slider-crank shaker, the timing arrangement of the rotating masses, and the directions of force for the three shakers at four positions.

The SC shaker had a total mass of 240 kg (16.4 slugs), an inertial mass of 166 kg (11.4 slugs), and an eccentricity of 10.1 cm (4 in.). The total mass of the 109-kg RM shaker was 317 kg (21.7 slugs), and

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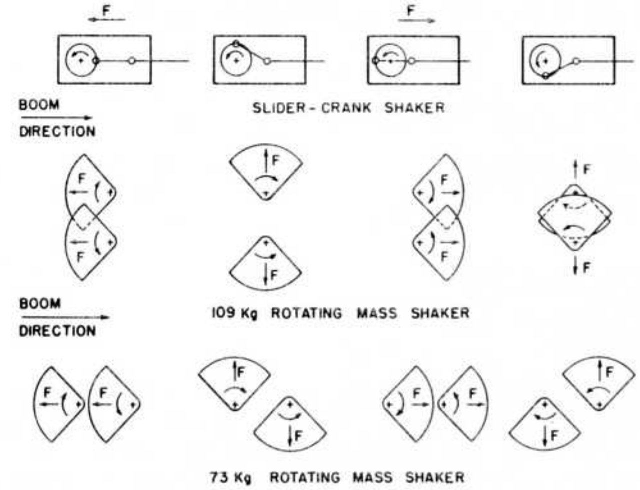

FIG. 1 Schematic drawing of mass arrangement and directions of force for the SC, 109-kg RM and 73-kg RM shakers.

FIG. 2 Force transducer and accelerometer attached to the limb and shaker.

the two 54.5 kg (3.7 slugs) masses with an eccentricity of 16 cm (6.3 in.) were timed such that they would produce a force along the shaker boom, but no force in the vertical plane. The total mass of the 73-kg RM shaker was 281 kg (19.2 slugs), and the two 36.3-kg (2.5 slugs) masses with an eccentricity of 14 cm (5.5 in.) were 25 cm (10 in.) apart along the direction of the boom. The motion of the two masses resulted in a clockwise and counterclockwise moment on the boom as the masses rotated 6.28 radians. The timing arrangement of the masses produced a shaking force along the shaker boom; however, energy was lost to the shaker boom as it was deflected by the resulting moment.

Shaking Motion Tests

To evaluate the shaking motion delivered to the limbs, tests were conducted on 18 selected limbs on 'Hamlin' orange trees. Each shaker was mounted on a full-powered positioning mechanism (Sumner 1976) for testing. The shaking frequencies ranged from 3.34 to 8.34 Hz (200 to 500 rpm). Limb sizes ranged from 8 to 15 cm (3 to 6 in.) in diameter, and the point of shaker attachment was 0.15 to 0.40 of the limb length from the tree trunk. The limb attachment point was marked, and the position of the boom with respect to each limb was referenced from two points on the ground so each shaker could be attached to the same point on each of the 18 limbs.

A piezoelectric accelerometer (0 to 50 g's) was attached to the shaker boom for measurement of the shaking characteristics (acceleration, displacement, and shaking frequency). A force transducer (strain gauge bridge) attached between the shaker and the limb was used to measure the shaking force imparted to the limb and a pressure transducer measured the hydraulic pressure of the shaker drive motor (Fig. 2).

Lenker and Hedden (1968) developed the following equation to determine the displacement of a citrus limb shaken with an inertial limb shaker:

$$S_1 = \frac{S_e M_u \omega^2}{\sqrt{(K \cos \alpha - M_b \omega^2 - M_u \omega^2)^2 + (K \sin \alpha)^2}}$$

where

S_1 = displacement amplitude of the limb, cm (in.)

S_e = displacement amplitude of the unbalanced mass, cm (in.)

M_u = unbalanced mass of shaker, kg (slugs)

ω = shaking frequency, rad/s

K = apparent stiffness of the limb, N/cm (lb/in.)

a = phase angle of force with respect to S_1, rad

M_b = mass of the shaker boom, kg (slugs)

Field Performance Tests

The 'Parson Brown' test (January 10, 1975) consisted of six treatments in which the three limb shakers (SC, 109-kg RM and 73-kg RM), with and without abscission chemical, were used. Three tree plots were replicated four times for each treatment. Only one tree from each plot was used to determine removal efficiency. Chemically treated trees, 4.9 m (16 ft) high, were sprayed with 20 ppm of cycloheximide (ACTI-AID) plus surfactant at the rate of 19.5 L (5.2 gal) per tree. The machine settings for each shaker were the same as those used in the shaking motion tests. The frequency for the SC shaker varied from zero to 5 Hz; and for the 109-kg and 73-kg RM shakers, from zero to 8.3 Hz. The frequency depended on limb size and was reduced when the shaker was overloaded on large limbs that required high shaking forces. The operator shook each limb to obtain a 95 percent fruit removal efficiency. Data collected included: Number of preharvest drops, number of fruit left on tree after harvest, total number of mature fruit removed, number of clamp attachments required per tree, shaking time per tree, and total harvest time per tree.

The Valencia test (May 28, 1975) had the same six treatments as the previous test but with five replications. The chemically treated trees, 5.5 m (18 ft) high, were sprayed with 275 ppm of 5-chloro-3-methyl-4-nitro-1H-pyrazole (RELEASE), plus surfactant at the rate of 32 L (8.6 gal) per tree. Machine settings were the same as before, and data were collected as before, except that the total amount of mature fruit was determined by weight. The number of green fruit removed in 1975 were recorded for each tree, and the subsequent yield of mature fruit was determined in 1976. Limbs were shaken to obtain a high percentage of mature fruit removal (90 to 95 percent), but shaking was stopped as soon as mature fruit removal diminished so that the removal of young fruit would be minimized. The green fruit had an average diameter of 3.6 cm (1.42

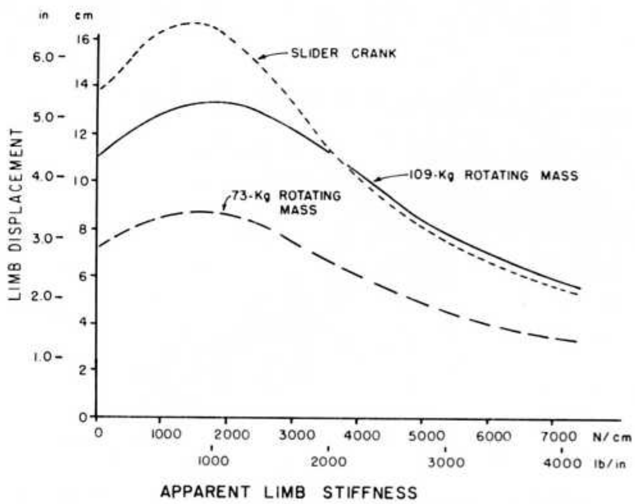

FIG. 3 Calculated maximum limb displacement as influenced by apparent limb stiffness for three shakers at 5 Hz [300 rpm].

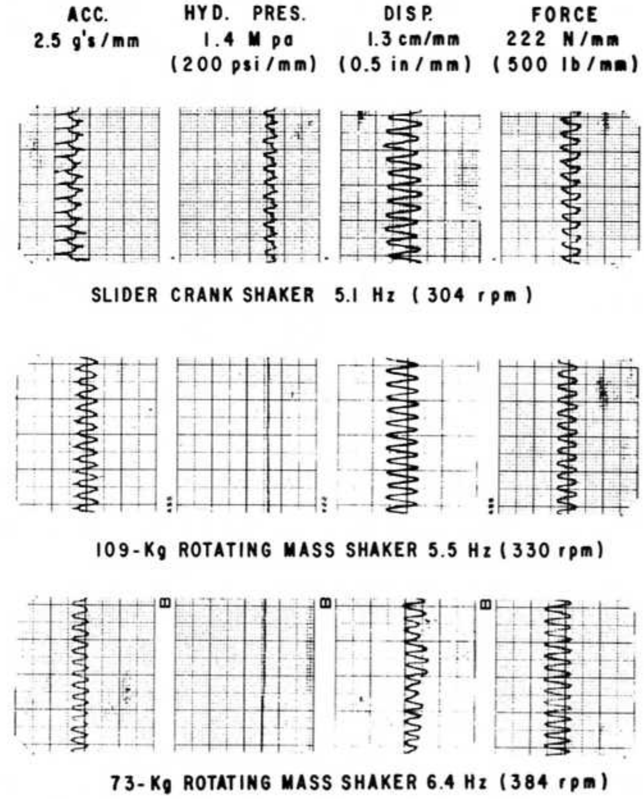

FIG. 4 Limb motion measurements for three limb shakers attached to a Hamlin orange limb of 8.9 cm [3.5 in.] diameter, at a point 0.27 of the tree limb length from the tree trunk. Acceleration [Acc.], displacement [disp.], force, and hydraulic pressure [Hyd. Pres.] measurements were made simultaneously for each shaker.

in.). Test data was subjected to analyses of variance to evaluate recorded and calculated data differences for the shaker treatments. The 5 percent level was considered significantly different.

RESULTS AND DISCUSSION

Shaking Motion Tests

In Fig. 3 the calculated maximum limb displacement of the three limb shakers used in these tests, based on the equation of Lenker and Hedden (1968), are compared. The phase angle in the calculation was 0.96 rad (55°) and the shaking frequency was 5 Hz (300 rpm). The calculated displacements of the SC and the 109-kg RM shakers were approximately the same on limbs with a stiffness of more than 3750 N/cm (2000 lb/in.). The displacement of the 73-kg RM shaker was about 0.6 those of the displacement of the SC and 109-kg RM shakers.

Fig. 4 illustrates a continuous measurement of the acceleration, hydraulic pressure, limb displacement, and shaking force of the three shakers, attached to a Hamlin orange limb of 8.9 cm (3-1/2 in.) diameter, at a point 0.27 of the limb length from the trunk. The acceleration curve for the SC shaker had sharp peak values that were of short duration and that resulted in a nonsmooth curve. The hydraulic pressure of the drive motor produced a similar curve with peaks that corresponded to the peak values of acceleration. The force curve, also, was nonsmooth.

Both rotating-mass shakers gave smooth curves for acceleration and force. The constant hydraulic pressure shown indicated that the rotating-masses gave some fly wheel effect. The limb displacement with the 109-kg RM shaker gave a smooth curve, however, the 73-kg RM shaker produced an erratic curve of limb displacement. That type of displacement can be accounted for by the moment produced by the timing and arrangement of the masses on the 73-kg RM shaker (Fig. 1).

The measured limb displacement with the SC shaker was less than the 109-kg RM shaker on large limbs but greater on small limbs. This general trend can be observed in the theoretical curve in Fig. 3. The average measured limb displacements for the 18 limbs (peak to peak) with the SC, 109-kg RM, and 73-kg RM shakers were 10.4, 10.2, and 5.5 cm (4.1, 4.0, and 2.2 in.), respectively. These measured values of displacement were of the same general trend and order of magnitude as the calculated values shown in Fig. 3.

Analysis of the recorded acceleration, hydraulic pressure, limb displacement, shaking force, and frequency measurements of the 18 limbs provided other conclusive information as follows:

1 Limb diameter and apparent stiffness had more influence on limb displacement than did the shaking frequency.

2 Limb acceleration increased with shaking frequency for all treatments.

3 An increase in the shaking frequency of the 109-kg and 73-kg RM shakers increased their shaking force more than did a similar increase with the SC shaker.

4 The 109-kg RM shaker had a smoother shaking motion and produced higher shaking forces than did the 73-kg RM and SC shakers; therefore, it produced a larger displacement of the large-diameter limbs.

5 The shaking frequency required with the 73-kg RM shaker to give a limb shaking motion that would remove oranges was higher than that with either the 109-kg RM or SC shaker.

Field Performance Tests

The average results of the six treatments for the field tests with the Parson Brown and Valencia oranges are summarized in Table 1. The average percentage of fruit drop before harvest was an indication of the effectiveness of the abscission chemicals in loosening the fruit. Fruit predrop averaged above 10 percent for all spray treatments.

TABLE 1. EFFECTS OF SHAKER TREATMENTS ON RESULTS OF FIELD PERFORMANCE.*

Treatment and variety†	Fruit pre-drop, percent	Limb attachment/tree (No.)	Shake time/tree, (min)	Harvest rate (trees/h)	Fruit removal, percent	1976 yield kg/tree	Harvest efficiency, percent
Parson Brown							
SC-S	10.6	2.6d	0.15c	28.8d	94.9a	-	-
SC-NS	0	4.3bc	0.50b	16.7b	91.6ab	-	-
109-S	15.3	2.9d	0.16c	27.5d	96.4a	-	-
109-NS	0	4.4ab	0.48b	18.1bc	93.2a	-	-
73-S	10.7	3.4cd	0.22c	23.5cd	92.1ab	-	-
73-NS	0	5.2a	0.73a	11.6a	87.8b	-	-
Valencia							
SC-S	10.9	3.8bc	0.33bc	24.8ab	96.7a	116bc	61.1bc
SC-NS	0	6.0a	0.65a	15.0cd	87.0b	83c	43.8cd
109-S	16.0	3.2c	0.28c	28.0a	95.5a	87bc	47.9cd
109-NS	0	4.6abc	0.43bc	18.3bc	88.6b	92bc	43.5cd
73-S	27.3	3.2c	0.26c	22.9ab	95.8a	124b	74.2b
73-NS	0	5.4ab	0.47b	13.8d	82.1c	86bc	41.1d
HP-S	-	-	-	-	-	170a	95.0a
HP-NS	-	-	-	-	-	199a	98.0a

*Values within a column followed by unlike letters are significantly different at the 0.05 level of probability according to Duncan's Range Test.

†SC - Slider crank shaker S - Sprayed
109 - 109-kg RM shaker NS - Nonsprayed
73 - 73-kg RM shaker HP - Handpicked

Most of the major significant differences between results of field performance tests were between chemical levels (sprayed or nonsprayed) and not between shakers. Significantly more limb attachments per tree were required for the nonsprayed trees (4.6 and 5.3 for Parson Brown and Valencia, respectively) than for the sprayed trees (3.0 and 3.4 for Parson Brown and Valencia, respectively). Significantly more time was usually spent in shaking each of the nonsprayed trees (an average of 0.57 and 0.52 min/tree for Parson Brown and Valencia, respectively) than in shaking each of the sprayed trees (an average of 0.18 and 0.29 min/tree for Parson Brown and Valencia, respectively). The resulting harvesting rate was significantly higher for the sprayed trees (26.6 and 25.2 trees/h average for Parson Brown and Valencia, respectively), than for the nonsprayed trees (15.5 and 15.7 trees/h average for Parson Brown and Valencia, respectively). Fruit removal was also significantly lower for the Valencia nonsprayed trees (an average of 85.9 percent) than for the Valencia sprayed trees (an average of 96.0 percent). The number of green fruit removed from the nonsprayed Valencia trees was significantly higher (289) than from the sprayed Valencia trees (213). The removal of green fruit resulted in a significantly greater yield from the sprayed trees (109 kg/tree) than the nonsprayed (87 kg/tree) in 1976. The analysis of the 1975 yield showed no significant difference in yield of the trees.

Within chemical treatment levels (sprayed or nonsprayed) the only difference between results with the shakers was in the percentage of mature fruit removal and in harvesting rate. In the nonsprayed trees for Parson Brown and Valencia the 73-kg RM shaker generally had a significantly lower harvesting rate than in the sprayed trees. The 73-kg RM shaker generally removed significantly less mature fruit than did the 109-kg RM and SC shakers from the nonsprayed trees.

Harvesting efficiency (1976 ÷ 1975 yield x percentage removal) is one of the most important factors to consider in the evaluation of a harvesting treatment for Valencia oranges since removal efficiency and yield reduction of the subsequent crop are taken into consideration. The average harvesting efficiency in the sprayed trees (0.61 percent) was significantly higher than in the nonsprayed trees (0.43 percent).

The 73-kg RM shaker which removed a high percentage of mature Valencias from sprayed trees and provided a high subsequent yield, had the highest harvesting efficiency (74.2 percent). The same shaker had the lowest harvesting efficiency in nonsprayed trees (41.1 percent) because of a low removal of mature fruit (82.1 percent).

For sprayed trees, the higher harvesting efficiency with the 73-kg RM shaker, which was the less aggressive of the three shakers, indicated that better harvesting efficiency can be obtained by a reduction in the fruit pull force (apply abscission chemicals) and in the amount of energy imparted to the limbs.

The results of the shaker motion test indicated that a difference existed between shakers in the type and magnitude of shaking action at the shaker clamp. However, the input energy and motion that reached the small branches and fruit did not reflect a significant difference that was measured in field performance.

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