MOBILE LIMB SHAKER FOR APPLE HARVESTING

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A limb shaker mounted on the rear of a tractor is described as a mobile shaker for apple harvesting. The main feature included an extendable-retractable boom which can be swung in the vertical and horizontal planes as well as rotated about its longitudinal axis to expedite the attachment of the clamp to selected limbs. Three shaking devices were compared and rates of 20-53 apple trees /h with 90% fruit removal were obtained.

INTRODUCTION

In the mechanical shake-and-catch apple harvesting systems, the shaker to remove the fruit from the tree is a major component. Limb- or trunk-shakers are the main types employed. Limb-shakers have generally been more effective than trunk-shakers in applying the required shaking action to long willowy limbs for apple removal (Fridley and Adrian 1966). Limb-shakers may be mounted on the catch-frame or be independent of the catch-frame. The latter may be tractor-mounted, tractor-trailed or self-propelled (Coppock 1974; Levin et al. 1960).

The boom of a limb-shaker mounted on a catch-frame is generally hung in a free-swinging pivot-type suspension. This isolates the shaking forces from the catch-frame and allows the boom and clamp to oscillate as a unit (Fridlay and Adrian 1966). The suspension point is selected so that the boom is in a balanced condition. The suspension arrangement is such that the boom can be manually pivoted in horizontal and vertical directions, as well as rotated about its longitudinal axis to aid the clamping of various limbs. The support arm carrying the suspension mechanism may have provisions to move in horizontal and vertical directions to add to the maneuverability of the boom for positioning. Even with this latter arrangement, catch-frame mounted shakers have severe limitations in boom positioning to clamp desired limbs. In addition, considerable manual effort is required and there is a problem in depth perception when positioning the clamp.

On independently mounted limb-shakers, the boom is usually pivoted at the vehicle end so it can be raised or lowered by a hydraulic cylinder (Fridley and Adrian 1966). With a fixed boom length and no provisions for horizontal swing of the boom, such units need to be maneuvered into position for each limb to be shaken (Coppock 1974).

In our development of a shake-and-catch apple harvesting system, a shaker mounted on the catch-frame could not be devised to ensure that all limbs could be reached for shaking or could one be found at the time in the literature. Reported limb-shakers that were tractor-mounted, tractor-trailed or self-propelled appeared to lack the boom maneuverability for efficient operation.

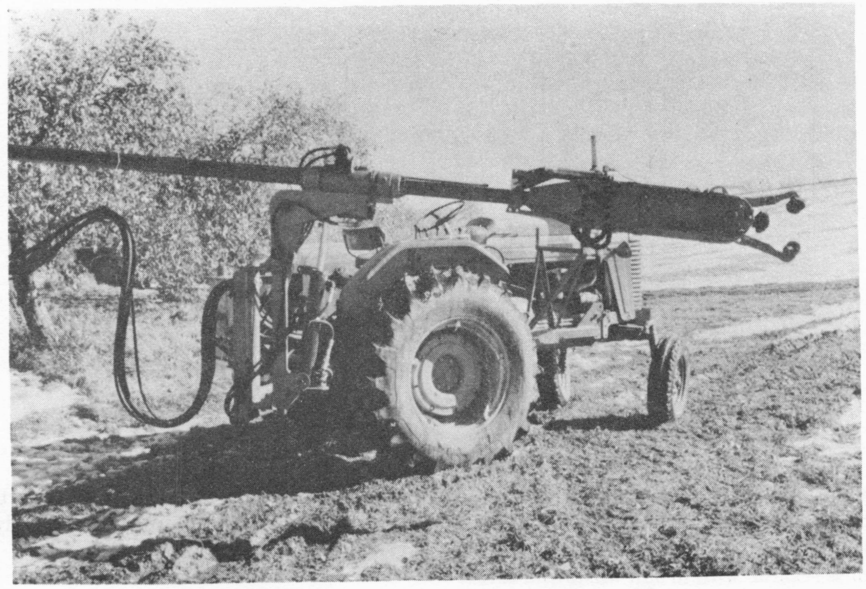

Figure 1. View of the unit with a double-crank shaker.

This paper describes the design and operation of a tractor-mounted limb-shaker that has proven to be highly maneuverable and effective in shaking apple trees.

CONSTRUCTION OF THE MOBILE SHAKER

The Design Objectives

The design objectives for a new shaker were as follows:

1. The shaker should be independent of the catch-frame and preferably be farm tractor mounted.
2. The operation of the boom, clamp and shaking mechanism should all be hydraulically operated.
3. The tractor should supply the power to operate the shaker hydraulic system.
4. The clamp design should be such that a limb can be approached head-on to eliminate depth perception problems.
5. The boom should be mounted to give the operator a good view of the clamping operation.
6. A means should be provided to extend or retract the boom.
7. All shaker controls should be positioned for the tractor-operator's convenience.
8. A minimum of time and effort should accomplish the mounting of the shaker on the tractor.
9. The shaker should be mountable on various models of tractors with minimum changes.

Design of the Shaker

The basic concept of the unit was a limb shaker mounted on a frame attached to the underside of a tractor at the rear wheel housing and the tractor front-end loader attachment points (Figs. 1 and 2). A mounting post for the shaker was vertically hinged to a frame post at the rear and to the right of the tractor. A hydraulic cylinder was attached to the main frame and mounting post to provide the means to swing the shaker boom in a horizontal plane. A horizontal pivot pin attached a boom holder to the top of the mounting post. A hydraulic cylinder connected to the base of the mounting post and the base of the boom holder provided the means to vertically swing the boom.

The boom holder consisted of a base and a short length of round mechanical tubing in which a corresponding length of square

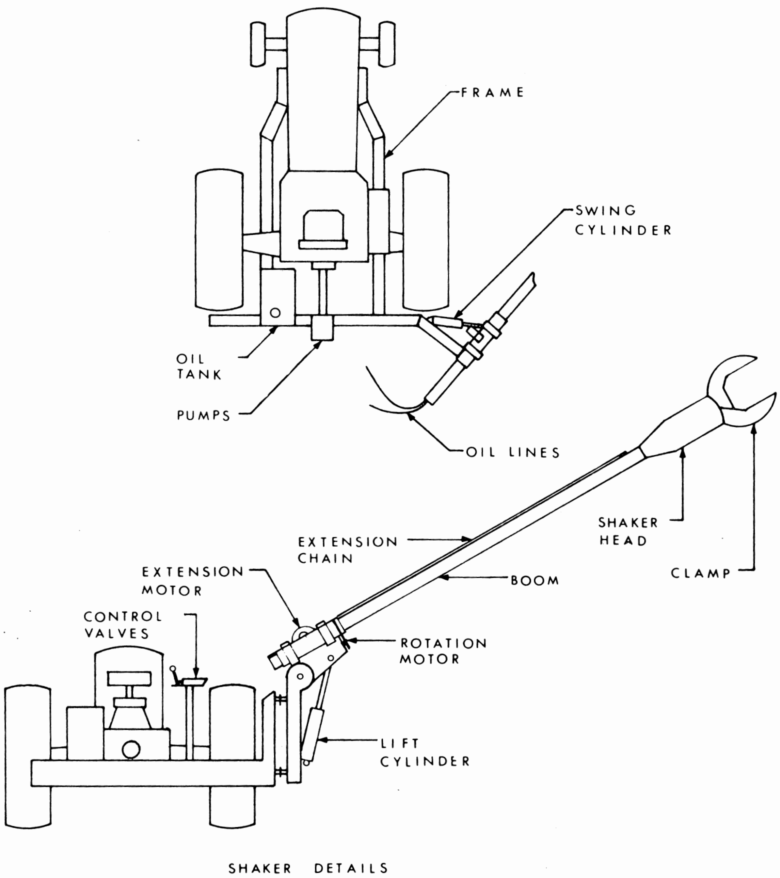

Figure 2. A schematic of the mobile tree shaker.

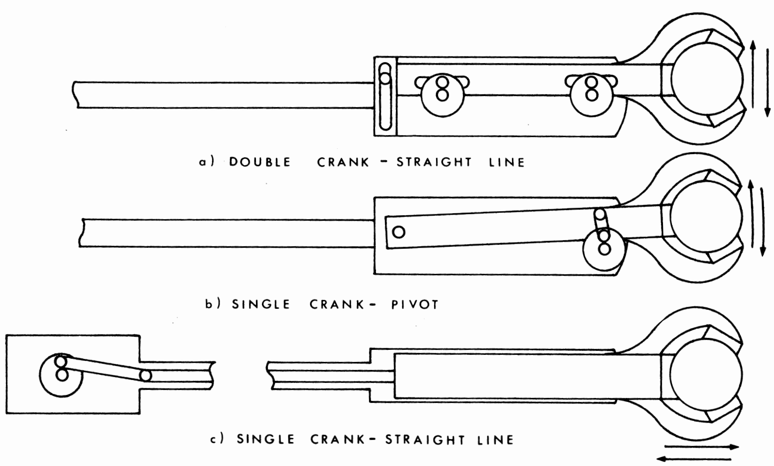

Figure 3. A schematic of various types of shaking mechanisms tested.

tubing had been welded. The round tubing was mounted on the base by two collars in which the tubing could be rotated. A square boom was fitted into the inner square tubing in which an allowance had been made for a sliding fit. A roller chain with its two ends fastened to the ends of the boom was employed to extend or retract the boom relative to the boom holder. A reversible hydraulic motor fitted with a sprocket and attached to the base of the boom holder provided the means to drive the chain. A second reversible hydraulic motor also fastened to the base of the boom holder drove a chain to rotate the cylindrical tubing in its collars. This rotation provided the means to rotate the boom about its longitudinal axis.

Shaking Mechanism

With the shaker completely power-operated, the boom was a fixed member during the shaking action. Therefore, a new concept was required in which the shaking action could be applied only to the clamp. Three new shaking mechanisms were designed and evaluated. These were as follows:

1. A double-crank unit built into the clamp housing and driven by a hydraulic motor (Fig. 3a). The double-crank was arranged to provide a straight-line shaking motion to the clamp at 90° to the longitudinal axis of the boom. The theory of this design was to prevent a rotation action of the clamp on the limb during shaking which could be a source of damage to the bark. A scissor-type clamp was opened and closed by a cam powered by a hydraulic cylinder. The shaking mechanism and the clamp, enclosed in a housing, formed the shaking head attached to the outward end of the boom.
2. A single-crank unit built into the clamp housing was operated by a hydraulic motor (Figs. 3b and 4). The clamp mechanism was pivoted at one end and a crank and connecting rod were employed to reciprocate the clamp in an arc about the pivot point. A hydraulic cylinder opened and closed the clamp. The shaking mechanism and clamp enclosed in a housing formed the shaking head attached to the outer end of the boom.
3. A single-crank unit mounted on the opposite end of the boom to the clamp (Fig. 3c). A crank, powered by a hydraulic motor, drove a connecting rod enclosed within the boom which reciprocated the clamp in a straight-line motion parallel to the longitudinal axis of the boom. A hydraulic cylinder at the clamp end opened and closed the clamp by a cam. The shaker head, in this case, consisted only of the clamp mechanism and its housing attached to the outer end of the boom.

Hydraulic System

The tractor power take-off (pto) drives a jack-shaft on the shaker frame which, in turn, drives high and low volume pumps. The high volume flow was delivered through control valves to the shaker and extension motors. The low volume flow fed the control valves for the boom lift, swing and rotation and the movement of the clamp. The control valves were mounted on the shaker frame to the right of the operator for easy accessibility. The hydraulic oil reservoir and filter were located on the left rear corner of the shaker frame. The four hydraulic lines for the shaker motor and clamp cylinder were run inside the shaker boom. For the shaker mechanism mounted on the opposite end of the boom to the clamp, only two lines for the clamp were run inside the boom leaving sufficient room for the long connecting rod. The circuit diagram for the hydraulics is shown in Fig. 5.

FIELD RESULTS

The tractor used for initial tests was a Massey-Ferguson 165. A smaller tractor had been used but the rear wheels were fully extended and wheel weights were added to the left rear wheel to counterbalance the weight of the extended boom.

To mount the unit, the tractor was backed over the frame. The front end of the frame was lifted and held temporarily by a chain or bolts, depending upon the attachment arrangement at the front. Then the back was lifted into place by the use of suitable jacks and the mounting completed front and back. All tractors used with the shaker had a live pto. Some tractors had independent clutches for pto as opposed to the two-stage clutch found on the Massey-Ferguson 165. A decided advantage is a foot-operated gas pedal. This enables the operator to control the speed of response of the hydraulic system without removing his hands from the control valves. This is also a valuable asset for changing the shaking frequency for fruit removal.

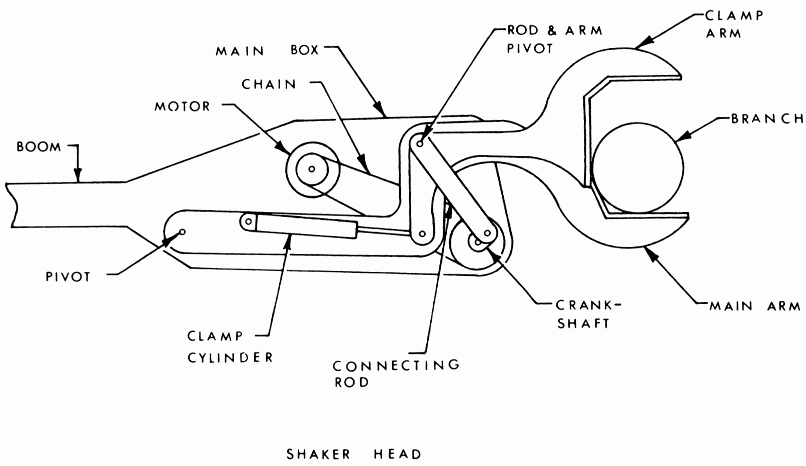

Figure 4. A schematic of the single-crank pivot shaker mechanism.

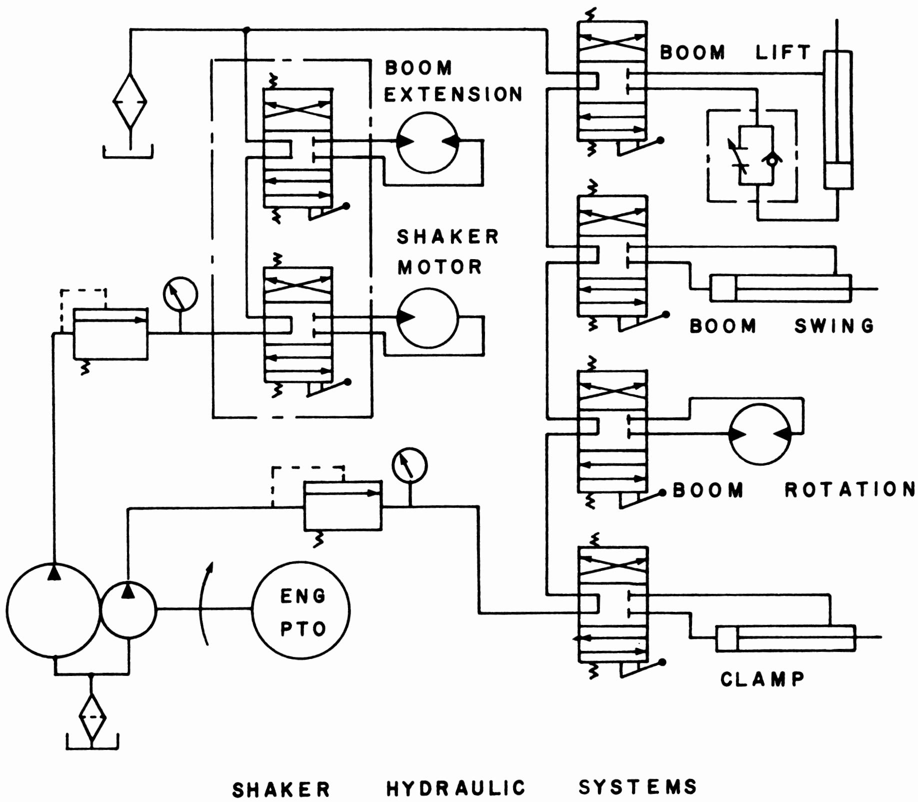

Figure 5. The layout of the hydraulic system.

Tests on Shaking Mechanism

A marked difference in operation between the single-crank straight-line shaker mechanism and two other units was observed.

The former unit results in positive displacement of the limb during the shaking action. At times, the torque of the hydraulic motor was not sufficient to initiate movement of large limbs and so the motor would stall. Either repeated operation of the control valve or a new hold further out on the limb was required to accomplish shaking. On the other two units, there was a positive displacement between the boom and clamp at 90° to the boom axis. During shaking, the boom itself flexes until limb movement initiates, thus preventing motor stall on large limbs.

Another difference in the shaking operation is in the plane that shaking occurs. The single-crank straight-line unit produced shaking forces in line with the boom axis. Thus, limbs were always shaken in horizontal or near horizontal plane, depending upon the angle of the boom to the horizontal. In the other two units, the shaking forces were at 90° to the boom axis. The angle of the limb therefore determines in what plane it was shaken. On a vertical limb, shaking was in a horizontal plane. When the boom and clamp were rotated 90° to clamp a horizontal limb, shaking was in a vertical plane.

It was observed that vertical limbs were easier to shake. For vertical limbs, a force was required to work against the stiffness of the limb as well as the force for acceleration of the combined mass of limb and fruit. On the horizontal limbs, an extra force was required to offset the force of gravity acting on the combined mass of the limb and fruit.

The design of the double-crank mechanism did, to a large extent, prevent clamp rotation on the limb during shaking. Slight rotation did occur when there was a pronounced flexing of the boom. There was no problem of clamp rotation on the limb during shaking with the single-crank, straight-line shaker, which would be expected. There was noticeable clamp rotation with the single-crank pivot unit. To protect the bark on the limbs, several types of clamp pads were evaluated. The final selection was two-stage molded rubber Devcon Flexane pads on plates which bolted to the clamp jaws. The center of the pads had a Shore hardness of 30 and the outer shell a hardness of 80. The softer inner cores allowed the rubber pads to flex and absorb the rotation movement of the clamp and thus prevented bark damage.

The three shaking mechanisms were evaluated in field operations. The results in Table 1 were obtained by timing individual operations and collecting and measuring the apples removed and retained for each tree. As the type of shaker mechanism did not affect the time required to move from tree to tree, an average time of all tests was used for moving time in the table. The double-crank unit resulted in the best time, the least number of shakes per tree and the highest percentage of apples removed. The poorest

TABLE I SHAKER MECHANISM COMPARISONS, NORTHERN SPY ORCHARD

Shaker mechanism	Time (minutes) Position and clamp†	Shake†	Move‡	Total§	No. of attachments per tree†	Fruit removal† (%)
Single-crank pivot	1.63	0.31	0.21	2.15	3.4	91.3
Single-crank straight-line	2.09	0.52	0.21	2.82	4.8	90.9
Double-crank	1.19	0.20	0.21	1.60	3.0	94.4

†Average of 8 trees.
‡Average of 24 trees.
§Using average move time for 24 trees.

TABLE II SELECTED SHAKER MECHANISMS OPERATIONS

Shaker mechanism	Average total time per tree (min)	Orchard conditions	Fruit removal
Double-crank	1.16†	Northern Spy, 7.0-m diam trees at 7.3 X 6.0 spacing	Very good
Double-crank	1.03‡	Rome, 7.0-m diam trees at 7.3 X 6.0 spacing	Very good
Single-crank pivot	1.13§	Pruned for 1.2 to 1.5-m ground clearance	Good to very good

†Average for 22 trees.
‡Average for 30 trees.
§Average for 16 trees.

results were obtained from the single-crank straight-line shaker.

Work by Garman et al. (1972) indicated that shaking in a vertical plane should result in the most efficient fruit removal. As the single-crank straight-line unit shakes only in horizontal planes, this may explain its lower percentage of fruit removal. Stalling on the larger limbs would account for greater time required.

The results in Table II were obtained by taking the total time to shake all the trees in each test. The fruit removed was not collected. Much better times were obtained for the two units used in these tests which was due largely to the tree spacing and the condition of the trees. In the Rome orchard, there was enough room in the row so the operator could shake two rows in a single pass through the orchard.

The maximum rate was 58 trees shaken per hour with double-crank and 53 for the single-crank pivot. Further tests in other orchards indicate that rates of 30-40 trees/h are practical in most orchards. The unit successfully operated in orchards with cultivars such as Rome, McIntosh, Red Delicious, Cortland, Wagner, Northern Spy, Ben Davis and Golden Russet.

Although the double-crank mechanism gave superior performance, the single-crank pivot mechanism was selected for the final design. The double-crank mechanism was considerably more complex and there was continued mechanical breakdown. The single-crank pivot unit was much simpler in design and, after initial problems were corrected, gave little trouble.

SUMMARY

A tree shaker designed for attachment to a farm tractor overcame problems associated with other limb shakers. The ease of positioning the tractor and the ability to extend or retract the boom while swinging it into position greatly aided in reaching limbs and minimized the time required to shake a tree. Of three shaking mechanisms designed and tested, a single-crank unit was selected as the most suitable when effectiveness of fruit removal and mechanical design were taken into account. Shaking rates varied from 20 to 53 trees/h, 30-40 being considered the norm for most orchards. Removal of over 90% of fruit could be expected. The design of the carrying frame was such that it could be readily customized to various tractors. The unit could be moved from orchard to orchard at the normal road speed of the tractor and with no need to prepare the unit for travel.

SHAKER SPECIFICATIONS

Tractor	— Low profile, approximate 40 kW
Boom	— 7.6 cm X 7.6 cm X 0.64 cm hollow square steel tubing — Extended, 5.25 m — Retracted, 2 m — Extension rate, 1.1 ms^{-1} — Rotation rate, 1.6 rad s^{-1} — Horizontal swing, 2.8 rad — Vertical swing, 1.5 rad
Clamp	— Jaw opening, maximum, 30 cm — Shake frequency, 7.0 Hz max — Shake displacement, 15 cm at jaw centers
Hydraulics	— Tandem pump-pto driven 90 and 25 l min^{-1} at 7,000 kPa
Storage tank	— 70-liter capacity
Hydraulic valves	— Shaker and extension — two metering spools tandem four-way, 90 l min^{-1} at 7,000 kPa, spring centering — Lift, clamp and swing — three metering spools tandem four-way, 25 l min^{-1} at 7,000 kPa, spring centering
Shaker motor	— 105 rad s^{-1}, 40 N.m at 67 l min^{-1} and 7,000 kPa
Extension motor	— 14 rad s^{-1}, 226 N.m at 67 l min^{-1} and 7,000 kPa
Rotation motor	— 4.7 rad s^{-1}, 226 N.m at 22 l min^{-1} and 7,000 kPa

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